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TURFGRASS RESPONSE TO BIO-ORGANIC AMENDMENTS

By

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ABSTRACT

TURFGRASS RESPONSE TO BIO-ORGANIC AMENDMENTS

By

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Several newly marketed turfgrass bio-organic amendments were submitted to Michigan State University for evaluation of turfgrass thatch and nitrogen response to repeated product application. Field plot evaluations and several laboratory oriented evaluations were performed to examine the nitrogen related variables tissue chlorophyll content, tissue nitrogen content, clipping yield weights and visual quality. Thatch variables thickness, organic matter content, lignin content, density, water retention, microbial activity and earthworm activity were measured. Also, ^{14}C-labelled plant tissue decomposition as influenced by product application was evaluated.

Kentucky bluegrass responded favorably when the amendments *in situ* were compared to N carriers such as sulfur-coated urea, but did not compare as well with industry standards such as soluble urea on all test variables including visual ratings. When applied to thatched Kentucky bluegrass turf *in situ* the amendments produced increases in earthworm activity while significantly decreasing thatch thickness as rates of

application increased. The decreases in thatch thickness led to an accumulation of thatch lignin and increases in water holding capacity. When applied to thatched Kentucky bluegrass turf in vitro a contrast in results occured. Thatch treated at the higher rates, regardless of N carrier evolved significantly more carbon dioxide but thatch thickness was retained. As rates became lower, thatch thickness decreased. When no N carrier was applied, thatch was reduced the most. When the amendment Lawn Restore was applied to differing soils with ^{14}-C labelled wheat straw incorporated, decomposition was not enhanced over non treated (i.e., no applied N) units. Decomposition was enhanced over Milorganite treated labelled tissue regardless of soil type.

DEDICATION

To Mom, Dad and Dave

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I would like to thank Dr. Paul Rieke for his help and for giving me a chance. I would also like to thank Dr. Joe Vargas, Dr. Bruce Branham, Dr. Jim Tiedje and Dr. Eldor Paul for their inspiration and motivation and to Judd Ringer and Ringer Corporation for financial support. Special thanks to John Genuise for his help in the summer of 1985 and to the graduate staff for their support. Lastly, special thanks to Keith, Mary, Dave, Sherri and Jeff for sticking by me the last few years.

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INTRODUCTION

As economic and time related investments in turfgrass management increase, the need for maintenance products of increasing diversity emerges. Ideally, some such products might provide turfgrass macro and micro environments with nutritional benefit while enhancing certain soil related properties.

Ringer Corporation of Eden Prarrie, Mn., has submitted to the Department of Crop and Soil Sciences at Michigan State University several products for evaluation of turfgrass and thatch response to repeated applications. These products, termed bio-organics, are called Lawn Restore, Lawn Rx and C-50, and are registered trademarks of the Ringer Corporation. The products are biologically enriched organic turfgrass amendments, which contain microbial inoculum, mainly soil fungi, bacteria and actinomycetes. The products are postulated by Ringers to provide adequate turf nitrogen response, using yeast as an N carrier, while enhancing turf thatch control through the degradative activities of the inoculum. The objective of the evaluations was to document the biological, chemical and physical attributes of nitrogen release from the products as related to plant uptake, and to characterize the turfgrass thatch decomposition potential associated with use of the products. Methods of investigation used in the research employed field plots, greenhouse and growth chamber studies as well as basic laboratory oriented measurements.

LITERATURE REVIEW

The Concept of Field Nitrogen Response

Of the elements essential for turf plant growth, nitrogen is regarded as having a predominant influence. Turfgrass needs nitrogen for enzyme, protein, nucleic acid and chlorophyll synthesis and for other metabolic activities. Continued whole plant production of these compounds is mandatory for high quality turf. Thus, nitrogen is the nutrient applied in the largest amounts in turfgrass fertility programs (5, 16, 65).

Turf nitrogen fertilizers come from different sources. Most are derivatives of ammonia reactions with carbon dioxide or inorganic acids and are so classified. The categories are synthetic inorganic, synthetic organic, natural organic or coated type carriers (5). Each differs in molecular formula and method and rate of nitrogen release. The class of carrier affects such variables as nitrogen loss potential, chemical and biological reactions with soil, rates of nitrification and plant uptake (21).

Quick release carriers, such as the synthetic inorganics and certain synthetic organics, typically have high water solubility, rapid release of nitrate or ammonia nitrogen, low cost, high foliar burn potential and high nitrogen loss potential. Brown et al. (11) report that fertilizer nitrogen losses in turf are carrier dependent. They cite quick release

carriers as being implicated with accelerated nitrate and ammonium leaching and runoff in bermudagrass (Cynodon dactylon (L.) Pers.) greens.

Alternatively, there are several types of slow release carriers. Included are coated carriers, carriers of limited water solubility dependent on microbial decomposition, materials of limited plant available forms of nitrogen and partially soluble salts (21). As a group, they may possess distinct advantages over quick release carriers. Reductions in foliar burn, less salt accumulation and decreases in nitrogen losses from volatilization, denitrification, leaching and runoff are but a few examples (21). Brown et al. (11) state that the best means of minimizing nitrogen losses in turf is use of slow release nitrogen carriers. One particular slow release nitrogen carrier receiving much attention is protein-organic waste (28). This type of carrier (i.e., sewage sludge or soybean meal) contains organic and inorganic forms of nitrogen not readily soluble in water. Because nitrogen release is dependent on microbial mineralization, it is dependent on temperature, moisture, pH, and time.

The conversion of slow release fertilizer nitrogen (and certain forms of quick release carriers) to plant usable nitrogen (i.e., mineralization) is dependent on a restricted number of autotrophic bacteria (4). It is a two step process whereby ammonia (or ammonium ion) is oxidized first to nitrite then to nitrate. Currently, the Gram negative autotrophic nitrifying bacteria of the family Nitrobacteriaceae are the only micro-organisms directly linked to nitrification in natural environments (55). Heterotrophic nitrification does not appear to make a major contribution in the natural system (4).

Proper carrier selection is influenced by turf type, turf soil condition, level of management, cost per unit of nutrient and other considerations. The plant response effect is a major decision influencing factor.

Nitrogen source and rate directly affect plant shoot growth, root growth, shoot density and color (5). Nitrogen affects cell wall construction, protein content, transpirational processes and metabolic temperature (35). Nitrogen also interacts with carbohydrates and mineral constituents such as potassium (35). Potassium exerts a regulatory influence on nitrogen use in protein synthesis (5, 35). Increases in added nitrogen stimulate shoot growth which generally increases density and degree of greenness. High nitrogen levels increase stem length, leaf length, internodal length and number but decrease seedhead production (35). However, in turfed situations, high nitrogen levels also cause distinct supression in root growth relative to shoot growth (5, 35, 53). Theories are that nitrogen influenced photosynthate partitioning stimulates aerial growth but does not increase photosynthate production, draining carbohydrate reserves in nodes, rhizomes, stolons and roots (35). Aerial tissue accumulates while root growth remains static (35). Type and rate of carrier application will also influence incidence and severity of disease and tolerance to environmental stresses, soil pH, macro and micro organism activity and thatch accumulation. Milorganite enhanced microbial activity and reduced thatch accumulation when compared to ammonium sulfate on bermudagrass putting greens (40). Increasing rates of ammonium nitrate nitrogen from 5 to 25 g M^{-2} anually resulted in significant decreases in soil and thatch pH and in earthworm biomass

(49).

Nitrogen response evaluations involve various qualitative and quantitative methods. Turf quality scoring and physical and physiological constituents are common variables (9, 23, 27, 36). Quantititative evaluations are more precise but consume more resources. Qualitative evaluations require less time and money but are more dependent on operator bias (23).

Visual quality ratings are largely subjective and are influenced by sward density, texture and uniformity (5, 27, 37). Subjective visual evaluations are limited in validity to within experiment interpretation and have limited year to year or station to station value (27, 36). Even though Horst and Engelke (23) believe that researcher reliability in assigning quality ratings may increase with experience, they generally regard quality scores as inadequate. Still, visual ratings are the most widely used evaluations in turfgrass research. Ledeboer and Skogley used visual ratings as a basis for evaluation of nitrogen response in Kentucky bluegrass (Poa pratensis L.) (34). Rieke (52) reports visual ratings as the basis for nitrogen response evaluations on creeping bentgrass (Agrostis paulustris Huds.) fertility trials at Michigan State University.

Attempts to measure turf color objectively with a spectrophotometer or amassing a chlorophyll index have been successful (9, 27, 36). Birth and McVey, using reflectance spectrophotometry developed an objective turf color index. Madison and Andersen (36), Mantell and Stanhill (37) and subsequently Johnson (27) reported the use of a methanol extraction technique to quantify chlorophyll concentrations in dried turf clippings, indicative of degree of turf color. Johnson reports that

resulting values are not confounded by turf density, texture or thatch. Turf color quantification thru mechanical means may provide objective color comparisons irrespective of time, location or personal preference (9), but has not been widely adapted.

To provide a reliable index of turfgrass color it is necessary to examine the color components in relation to some established color influencing factor (27, 36). Cool season turfgrasses growing at higher nitrogen levels have a higher nitrogen content (5). Johnson reports finding excellent relationships between chlorophyll concentration and nitrogen content (27). Percent nitrogen values are directly related to yield, color and chlorophyll content but may be of marginal value as performance evaluators alone (27, 36).

The Concept of Turfgrass Thatch

Historically, thatch was considered an accumulation of dead but undecayed turfgrass stem and leaf tissue lying at the soil surface (3). Later, it was characterized as the accumulation of a tightly intermingled mass of living root and stem tissue appearing between the verdure and the soil surface (63). More recently, the definition of thatch which is widely accepted is a tightly intermingled layer of living and dead root, stem and crown tissue developing between the zone of green vegetation and the soil surface in turfed situations (5, 13, 17, 24, 33, 39, 49, 61, 68).

Physical components which comprise the majority of the thatch mass are sclerified vascular strands of grass stem and leaf sheaths, intact fibrous roots, nodes and crown tissue (25, 33). It is generally accepted that leaf blade tissue *per se* does not contribute to thatch

accumulation (38, 69). Principal plant cell constituents which make up the components are water soluble and insoluble fractions: sugars, proteins, hemicellulose, cellulose, lignin and silica (32, 33, 54, 61, 62). Cellulose is the primary constituent, followed by lignin and hemicellulose respectively (4, 29, 38, 41).

Cellulose is a non-reducing carbohydrate consisting of beta 1-4 linked D(+)-glucose units. It is insoluble in water and has a high molecular weight (4, 41). Hemicellulose is not structurally related to cellulose; rather, it is a polysaccharide composed of various pentoses and hexoses.

Lignin is a collective term for a group of very high weight aromatic polymers which help to provide rigid cell wall structure (38, 41). Lignin polymers are structurally very complex. Lignin is formed by the oxidative polymerization of p-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol. Coniferyl alcohol dominates in graminaceous tissue (29). Kentucky bluegrass was shown to be intermediate in overall plant lignin when compared to creeping bentgrass and creeping red fescue (Festuca rubra spp. rubra L.), with the fescue having the largest lignin percentage (38). Root tissue possessed the highest lignin content when compared to stem and leaf tissue, independent of turf type (38). Thatch consisted of a greater proportion of lignin than shoot tissue (33, 38). Contrary to previous research, it was also demonstrated that lower layers of thatch contained more highly lignified tissue than upper layers in a composite turf sample (38).

Characterization of thatch has proved difficult due to high degree of experimental error. Danneberger measured thatch from several sources for CEC, bulk density, pH and organic matter content (13). Results

indicate a high degree of variability across measurements regardless of thatch type. Total organic matter content ranged from 46% to 90%, bulk density from 0.17 to 0.53 g cm^{-3} and pH varied from 7.13 to 5.36. Hurto et al. (25) measured total porosity, bulk density, organic matter and moisture retention on thatch and surface soils from thatched and thatch-free Kentucky bluegrass sites. It was reported that thatch porosity was greater than that of silt loam soils. It was also reported that water retention of thatch at low water potentials was less than that of similar surface soils from thatch free sites. This suggests that pore size distribution in thatch is much more limited than in soil.

Thatch overaccumulation has been considered detrimental. Increases in disease activity, localized dry spot, insect activity, decreased environmental tolerance, scalping potential and pesticide inactivation have been associated with it (5, 6, 33). An accelerated rate of diazinon (0,0-diethyl-0-(2-isopropyl-6-methly-4-primidinyl) phosphorothioate) breakdown in thatched Kentucky bluegrass turf has been reported (10). This finding suggested that reduced insect control in thatch may be a function of thatch induced diazinon degradation. Increased scalping in 'Tifgreen' bermudagrass was positively related to increases in thatch accumulation, which directly affected visual quality (40). Vargas (69) believes that thatch per se does not cause an increase in pathogen activity. He maintains that turf in thatched situations seems to be more susceptible to environmental stresses associated with increased disease activity.

Excessive thatch may also affect the selection of turf cultural practices. Fertilization, pest management, cultivation, mowing and irrigation practices may have to be altered to compensate for thatch.

Applications of urea resulted in significantly greater nitrogen leaching when compared to slow release carriers in thatched Kentucky bluegrass situations (45). Leaching was also greater in thatch than in soil regardless of carrier type.

Many turf problems implicating thatch obviously exist. The point is that in certain management situations, thatch may accumulate, and where it does, problems may develop.

The Nature of Thatch Accumulation

Thatch accumulates when there is an imbalance between turfgrass plant production and tissue decomposition rate (5). Many factors influence thatch equilibrium. Any cultural or environmental factor which either encourages excessive plant shoot growth or depresses tissue decomposition rate contributes to thatch accumulation.

Source and rate of nitrogen affect thatch equilibrium. Evaluation of several cultural practices and nitrogen sources on thatch accumulation revealed that bermudagrass putting greens fertilized with activated sewage sludge produced more thatch than when ammonium nitrate was the nitrogen carrier (73). Turfgrass growth rates were not determined, but visual quality ratings suggest that sludge treated plots were darker green and more dense, indicative of accelerated plant growth. In contrast, Meinhold et al. found that bermudagrass putting greens treated with Milorganite had significantly less thatch and thatch lignin content than ammonium sulfate treated greens (40). The higher level of nitrogen, independent of carrier, increased thatch accumulation in a 6 month growing period by 30% and reduced microbial activity by 6% compared to the low level. Plant growth measurements were not taken but

scalp injury ratings suggest ammonium sulfate plots to be more "lush." The explanation that differences may have been attributable to nitrogen effects on plant growth is consistent with the conclusion of White and Dickens (73). Independent studies by Shearman (56) and Turgeon (67) involving cultivar evaluations of Kentucky bluegrass found no increases in thatch accumulation when turf was subjected to increases in rates of nitrogen fertilization. They suggest that environmental conditions may have to be favorable within a given turf type for nitrogen induced thatch accumulation to occur.

Indirectly, nitrogen carriers may influence thatch accumulation by increasing or decreasing soil pH. Increasing annual rates of ammonium nitrate nitrogen from 5 to 15 to 25 g M^{-2} on Kentucky bluegrass resulted in a linear decrease in soil and thatch pH (49). And, as nitrogen rates increased, so did thatch accumulation. A highly significant decrease in earthworm density was also observed with increasing nitrogen rate which may have been a significant contributing effect to thatch accumulation. Changes in thatch/soil pH probably influenced earthworm populations.

Pesticides may also influence thatch accumulation (6). Applications of chlordane (1,2,4,5,6,7,8,8-octochloro-2,3,3a,4,7,7a-hexahydro-4,7-methanoindene) resulted in significant thatch accumulation in Kentucky bluegrass during a 1 year period (50). Randell et al. (50) found that with insecticide application numbers of earthworm burrows decreased and thatch thickness increased. Where insecticide had not been applied, thatch did not accumulate. Smiley et al. (58) found that repeated fungicide applications over 4 seasons led to significant increases in Kentucky bluegrass thatch depth and sod tensile strength. He believes that

fungicides do not significantly alter the microflora of the soil/thatch system but allow thatch equilibrium to shift toward root and stem tissue production. Control of root born pathogens may be causative.

Contribution to thatch accumulation from clipping tissue is considered minimal (38). However, Meinhold et al. (40) found clipping return to directly affect plant growth and indirectly affect thatch accumulation in bermudagrass. Clipping residue treatments increased thatch lignin content and decreased microbial activity as compared to the no treatment check. Apparently the contribution of mineralized nitrogen from clipping tissue may have substantially affected thatch accumulation. Turf clippings contain between 3 and 6 percent nitrogen by weight (5, 8).

Biological Control of Field Thatch

Once turf management practices are such that thatch accumulates to excess, measures must be taken to control it. Greater than 1.25 cm of thatch in Kentucky bluegrass is considered excessive (5). A basic principle of thatch control is based on natural decomposition.

Decomposition of plant residue is microbially mediated, though environmental conditions must be favorable. Specific organisms, mainly fungi and bacteria, mineralize, immobilize or otherwise transform complex organic plant polymers (i.e., cellulose, hemicellulose and lignin) into various organic and inorganic compounds, including microbial biomass.

About one half of the normal soil community microorganisms have the ability to degrade cellulose (20). Basidiomycetes and celluloytic bacteria are the principal cellulose degraders on the soil surface,

though specific populations are moisture and pH dependent (20). End products are carbon dioxide, water, cell biomass and simple dimers and monomers.

Basidiomycetes, white rot fungi, brown rot fungi, soft rot fungi and a few certain bacteria are the major organisms associated with lignin decay (4, 20, 29, 39, 54). Due to the complexity of its structure, lignin is very resistant to microbial degradation. Lignified material decomposes more slowly than other plant constituents and is a major factor in the rate of organic matter turnover (38). Paul (47) cites lignin as having an uncorrected first order rate constant of 0.001 day^{-1} based on 365 days as compared to 0.003 day^{-1} for cellulose and hemicellulose. Thus, the overall proportion of lignin in decomposing plant material should increase as decomposition increases (14). Microbial degradation of lignin utilizes various enzymes and is accelerated in the presence of hydrogen peroxide (20) and inhibited in the presence of nitrogen (30). Lignin decomposition yields carbon dioxide, water and small molecular weight aromatic acids and alcohols and is considered to contribute substantially to soil humus formation (4, 20, 29).

Documenting rates of carbon turnover by measuring total carbon dioxide production or following radioactively labeled carbon decay have proven effective in plant residue decomposition studies (12, 20, 46, 47, 51). Methods involving titrimetric or infra-red carbon dioxide analysis or liquid scintillation counting of carbon isotopes are most often used. Carbon dioxide evolution is a useful index of microbial activity but may be confounded by plant root respiration. Radioactive carbon permitts monitoring of labeled tissue decomposition independently of plant

respiration, but microbial assimilation and subsequent turnover of the label are problems (72). Following organism oxygen uptake is also a popular method of estimating microbial activity.

Several methods of enhancing thatch decomposition exist. Conventional methods include topdressing and core cultivation (5). Beard reports that topdressing with soil has been the most effective method of biological control to date (6). Hypotheses are that regular topdressing initiates intimate contact between residual thatch matter and topdressing soil, thereby providing more favorable conditions for microbial decay in terms of moisture retention and pH (6, 73). Frequent topdressing was shown to be more effective than annual topdressing for reducing rate of thatch accumulation in bermudagrass putting greens (73). Eggens (15) found topdressing to be an effective thatch control treatment alone or in combination with core cultivation and vertical mowing on creeping bentgrass. But coring and vertical mowing were not as effective by themselves as when used in combination with topdressing. The literature concludes that topdressing is a good antidote for thatch problems but is inappropriate for many turf situations (17).

Core cultivation may enhance the decomposition processes by contributing to soil aeration status. Thompson and Ward (64) and Engle and Alderfer (18) found core cultivation to be only somewhat effective in reducing thatch on bermudagrass and creeping bentgrass putting greens. White and Dickens (73) found no influence on thatch or thatch plus mat depth with different core aerification treatments after 2 years of treatments on bermudagrass.

Another facet of biological control involves the application of enzymes, sugars or bio-organic soil amendments to thatch. Martin (38)

found that adding pectinase, sucrose or ferulic acid to creeping red fescue thatch *in vitro* increased microbial activity as measured by carbon dioxide production and ultimately increased decomposition. However, Ledeboer and Skogley (33) found applications of sucrose, glucose and cellulase yielded no dectetible influence on thatch from Kentucky bluegrass, creeping red fescue, velvet bentgrass (*Agrostis canina* L.) or creeping bentgrass. Koths (31) reported that additions of sucrose or glucose resulted in changes of the thatch ecological balance but decay was not enhanced. No means of increasing thatch breakdown by chemical additives has been demonstrated to be of practical value to date (1).

Direct application of microbial inoculum has effected plant tissue decay. Controlled environment studies report significant reductions in plant material in association with several white rot fungi (39, 54). Inoculation of zoysiagrass (*Zoysia japonica* Steud.) stolon tissue with several strains of white rot fungi resulted in cortical cell wall decomposition as revealed by electron microscopy. Epidermal cell walls and bundle sheath fibers were reported much more resistant to decay (39). The authors also report that atmospheric vapor pressure affected fungal activity on the stolon tissue independent of temperature. This disputes Sommers *et al.* (59) and Nyhan (46) who independently found rate of microbial activity in blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) tissue decomposition a linear function of water potential and temperature. Koths (31) found no significant reduction in thatch through isolate (fungal) introduction. His recommendations were to direct efforts toward increasing the activity of indigenous microflora rather than replacing them.

Application of the bio-organic amendments Bio-de-Thatch and Thatch Away failed to degrade common bermudagrass thatch over a five month period (42). The published data shows a trend toward increased thatch accumulation with increased product application.

MATERIALS AND METHODS

Field Nitrogen Response

Nitrogen carrier Study 1

The objective of study 1 was to document potential turf response differences to applications of differing nitrogen carriers.

The study was conducted on a seeded blend of Kentucky bluegrass (Poa pratensis L.) established in 1980 at the Hancock Turfgrass Research Center at Michigan State University in East Lansing, Mi. Specific turf cultivars were unknown. Plot size was 4.46 M^2. The soil type was a mixed Owosso-Marlette sandy loam. The Owosso was classified taxonomically as a fine, loamy, mixed mesic Typic Hapludalf and the Marlette a fine, loamy mixed mesic Glossoboric Hapludalf, having 95 kg phosphorus and 113 kg potassium ha^{-1}. Testing determined soil reaction to be pH 7.7 with a CEC. of 8 me/100 grams soil.

Height of cut was maintained at 6.5 cm with clippings removed. Alleyways 53 cm wide between the treatment blocks were maintained at 4 cm height. The alleyways were necessary for protection against cross plot contamination in harvesting of clippings for analysis. In addition, surrounding plot borders were also maintained at 4 cm.

Irrigation was supplied as needed to prevent wilting. Herbicides (2,4-dichlorophenoxyacetic acid) were applied spring and fall but no other chemical or cultural pratices were implemented during the experimental period. No supplemental phosphate or potash was applied.

Carrier treatments applied during the 1984-85 seasons consisted of Ringer's Lawn Restore (10-3-3), Ringer's Lawn Rx (3.5-1-1), Canadian Industries Limited urea (46-0-0) and Miller's sulfur coated urea (32-0-0), each applied at rates of 97.6, 195.3 and 292.9 kg nitrogen ha^{-1} yr^{-1}. Due to non-uniformity in product nitrogen content, Lawn Rx treatments were dropped out of the study in 1985. Carrier nitrogen content was verified by conventional micro-Kjeldahl nitrogen determination. Treatments were arranged as a two factor factorial in a randomized complete block design with three replications, with carrier type and rate of nitrogen application as main factors. Treatments were mechanically applied in 1984 with a Gandy 122 cm drop type spreader calibrated by a fertilizer weight to application area ratio (except for the S.C.U.). The sulfur coated urea was hand applied to prevent coating breakage. In 1985, mechanical application was discarded due to uneven product (Lawn Restore) distribution. Subsequent materials were pre-weighed and hand applied. Supplemental irrigation ensued each treatment application to prevent foliar burn. Applications were made near day 15 in May, June, July and September during both years. No late fall nitrogen applications were made.

Plot clippings for analysis were harvested with a 53 cm rotary mower with clipping catcher attachment. Paper sacks (25# plain brown paper) were used in place of the cloth sack. One pass with the mower longitudinally through the middle of each plot yielded the clipping

harvest. The height of cut during clipping collection was arbitrary and dependent on relative growth but consistent among all plots for collection days and greater than 6.5 cm. After collection, clippings were oven dried for 24 hours at 60 C., weighed, ground to pass 40 mesh and stored in the dark. Clippings were harvested seven times in 1984 and eight times in 1985 at approximately two week intervals beginning in June.

Several quantititative variables in clipping tissue from each treatment combination were measured during both seasons. Dried clipping weights and tissue nitrogen contents, excluding nitrates, for each treatment plot per replication per collection were determined on duplicate samples by the micro-Kjeldahl method for plant tissue for both years. Concentrations of chlorophyll A and B as mg. chlorophyll g^{-1} dried shoot tissue for each treatment sample were determined colorimetrically (Spectronic 20, Bauch and Lomb, N.Y.) using Johnson's (27) modified methanol extraction procedure on duplicate samples. Treatment samples were again duplicated for both years.

In addition to the quantititative measurements, qualitative visual score ratings were taken on a weekly basis. Rating scale ranged from nine to one with higher scores indicative of a greater degree of greeness.

Treatment mean separation was provided by least significant difference (LSD) P=0.05 and P=0.01. No collapsing of analysis of variance over time was done. All test variable treatment means within dates were collapsed across all dates and equivalent conditions correlated to determine degree of variable association.

Nitrogen carrier Study 2

The objective of study 2 was to document the short term turf response effect produced by increasing rates of applications of different nitrogen carriers.

Study #2 was conducted on a seeded block of Kentucky bluegrass var. 'Adelphi' established at the Hancock Turfgrass Research Center in 1981. Soil, environment and cultural conditions were similar to those previously described in study #1. Plot size was 2.23 M^2. Treatments were Ringer's Lawn Restore (10-3-3), Ringer's Lawn Rx (3.5-1-1) and C.I.L. urea (46-0-0) applied at rates of 24.4, 48.8 and 97.6 kg nitrogen ha^{-1}, one time on August 8, 1984. Treatments were arranged as a two factor factorial in completely randomized design with three replications having rate of carrier application and carrier type as main factors.

Percent nitrogen and total chlorophyll concentration as previously described were evaluated. Clippings for analysis were collected as previously described on September 17 and 30. Visual quality ratings were taken weekly through September 30.

Treatment mean separation was provided by LSD P=0.05 and 0.01. Again, all variable treatment means were collapsed over dates and equivalent conditions correlated for strength of association. Study #2 was discontinued in 1985.

Nitrogen carrier Study 3

The objective of study 3 was to document possible visual differences produced by increasing rates of applications of differing nitrogen carriers.

Study #3 was conducted on a seeded block of Kentucky bluegrass

similar to that described in study #1. Again soil, environmental and cultural conditions were similar to those previously described in study #1. Plot size was 2.23 M^2.

Carrier treatments consisted of Ringer's Lawn Restore (10-3-3), Ringer's C-50 (10-3-3) and Miller's sulfur coated urea (32-0-0) applied at rates identical to those in study #1. Application dates were the same as in study #1. Treatments were factorially arranged with carrier type and application rate as the factors. Design was a randomized complete block with three replications.

Visual quality (as previously described) was the only variable measured. Treatment mean separation was accomplished with LSD P=0.05 and 0.01. Study #3 was conducted only in 1985.

Field Thatch Decomposition Response

Field Thatch Decomposition Study 4

The objective of study 4 was to obtain a preliminary indication as to the relative thatch decomposition potential associated with repeated application of the Ringer Corporation products Lawn Restore, Lawn Rx and C-50.

Study #4 was conducted on a sodded Kentucky bluegrass (varieties unknown) blend previously established on a Carslile muck (euic, Typic Medisaprist) soil. Subsoil was classified as a sandy clay loam with soil reaction pH 8.0 and CEC. at 9 me/100g soil. Fertility testing showed 92 kg phosphorus, 47 kg potassium and 3587 kg calcium ha^{-1}. Existing muck thatch was shown to be approximately 25 to 28 mm in depth and considered uniform. Thatch had a C:N of 26:1 when unwashed and 35:1

when washed free of soil. Thatch reaction was variable between pH 6.0 and pH 7.0 and bulk density averaged 0.22 g cm^{-3} when unwashed.

Sward height of cut was maintained at 7 cm with clippings removed. Spring and fall applications of 2,4-D (2,4-dichlorophenoxyacetic acid) controlled broadleaf weeds. Irrigation was supplied so that moisture would not be limiting to the thatch environment. No other cultural practices or supplemental nutrients were applied during the experimental period. Plot size was 2.23 M^2.

Product treatments consisted of Ringer's Lawn Restore (10-3-3) with a C:N of 4.7:1, Ringer's C-50 (10-3-3) with a C:N of 4.5:1 and Ringer's Lawn Rx (3.3-1-1) having a C:N of 4.8:1. Application rates were 0, 97, 195 and 390 kg nitrogen ha^{-1} $app.^{-1}$. Applications were made initially in October, 1984 and four times during the 1985 season, in May, June, July and August. Treatments were arranged as a two factor factorial with product and rate of product application as factors. Statistical design was a randomized complete block with three replications.

In October, 1985, six subsamples per treatment plot per replication were collected with a 10.8 cm diameter cup cutter (Par Aid Inc.), dried at 60 C for 24 hours and stored in the dark for future analysis.

In the beginning of the analytical procedures, it was necessary to define standard thatch boundaries. Aerial vegetative tissue was removed to the pseudothatch (5) dorsally, and root tissue and muck were removed from the ventral to the first visibly distinct rhizome layer. Remaining mass was considered thatch for all purposes.

Several thatch variables were examined to document any possible treatment related differences. Uncompressed thatch thickness measurements were taken with a Glogau's #12 vernier caliper and reported

as millimeters. Five thickness measurements on random sections of each of the six subsamples per plot were taken. 20 square centimeter thatch sections were oxidized techniques to determine total unwashed thatch organic matter carbon as a percentage by weight. Determinations were done in triplicate. Duplicate density values in grams thatch cm^{-3} were calculated by weighing four of the six subsamples and calculating the volume for each. Volumetric moisture holding characteristics at moisture tensions of 0 through 60 cm (in increments of 10 cm) were made on one subsample per plot with the use of a conventional tension table. Plugs were saturated initially and then allowed to equilibrate for 24 hours at each moisture potential and weighed. Values were reported as volumetric water content. Also, percentages by weight of cellulose and lignin were determined on duplicate samples using the conventional acid detergent fiber/Klason lignin determination (3). For the ADF procedure, it was necessary to grind the thatch to pass 20 mesh and then flush the muck and soil particles from the plant tissue. After grinding, the thatch was placed, for one full minute, in a Waring blender containing 500 ml warm water (40 C). The thatch suspension was then wet sieved to pass 150 mesh. Material retained on the sieve was dried at 55 C for 48 hours and stored in a dessicator for future use.

In November, 1985, three additional subsamples per treatment plot were collected. Each subsample was 10.8 cm wide by 20 cm deep and contained turf, thatch, muck and the subsoil. Samples were taken again with a conventional cup changer. Aerial vegetative tissue was removed and discarded. The subsoil section was separated from the thatch/muck portion at the soil-muck interface. Subsoil was dry sieved to 2 mm and earthworm (Lumbricus spp. Hoff.) numbers tabulated and reported as

number of earthworms per square meter of turf. Thatch/muck sections were soaked in a mild formalin solution (i.e., 0.5%), acting as an irritant, to force earthworms from habitation. After a period of several minutes, the sections were picked apart by hand to assure complete collection of all worms.

Treatment mean separation was provided by LSD P=0.05 and 0.01.

Laboratory Thatch Decomposition Response

Greenhouse Thatch Decomposition Study 5

The objective of study 5 was to document the thatch decomposition potential associated with several of the Ringer products and two quick release nitrogen carriers.

Thatch for experimental use was obtained from the site previously described in study #4. Several strips of the sodded field site were cut with a Ryan sod cutter set to a depth 5 cm below the thatch dorsal surface and left in place. This depth setting was chosen so that experimental units would contain turf, thatch, muck and minimal subsoil. From these strips, circular plugs 182 square cm in area were collected and placed into 3000 cm-3 plastic containers (Sweetheart Plastics, Willmington, MA) and transported the greenhouse.

Prior to placing the plugs in the containers, several 3 mm holes were drilled in each container bottom for drainage. Inner container bottoms were lined with cheesecloth and filled with washed silica sand to a depth of 2.5 cm. Sand contained 0.025% carbon. With this arrangement, the experimental plugs rested with the thatch dorsal surface 5 cm beneath the uppermost level of the container. This enabled an easily

maintained 5 cm height of turf cut while assuring complete containment of the thatch.

General greenhouse cultural practices were followed to maintain the turf plugs. Frequent mist syringing, depending on weather, was administered to ensure that water would not be limiting in the thatch environment. Deep irrigation was used infrequently to prevent wilting. Several applications of diazinon (0,0-diethyl-0-(2-isopropyl-6-methyl-4-primidinyl)-phosphorothioate) were used to eradicate soil and plant born macro-organisms (worms, mites etc.). Temperature and humidity were not controlled but supplemental flourescent lighting was used. Daylength was set at 16 hours. No supplemental potash or potassium was applied. Also, no fungicides or herbicides were used.

Study #5 was actually sub-divided into two smaller experiments each slightly different. Both were preliminary in nature. They should be recognized as studies 5a and 5b respectively. Study 5a was executed prior to study 5b.

Study 5a was a two factor factorial arrangement of six treatments with four replications in a completely randomized design. Treatments consisted of Ringer's Lawn Restore and Ringer's C-50 (previously described) and ammonium sulfate (21-0-0) applied at rates of 24.4 and 122 kg nitrogen ha^{-1} totaling 15 applications. Factors were product type and rate of product application. Study length was 15 weeks.

Six weeks into the study, the plastic dishes containing the experimental thatch units were fitted with snap on/off plastic lids enabling the creation of a closed atmosphere within the containment dish. Each lid posessed a serum stopper which allowed withdrawal of

atmospheric gas samples from each experimental unit when the lid was snapped onto place. With this arrangement it was possible to sample carbon dioxide from microbial respiration in each unit. It was assumed that if carbon dioxide levels increased in certain treatment conditions relative to others, then carbon substrate (ie thatch) mineralization must have been enhanced, presumably due to product application. Root respiration was not corrected for.

Gas samples from each experimental unit were withdrawn using a 3 cc Becton-Dickinson Plastipack syringe with a 25 G Yale hypodermic needle. Samples were taken at dusk at 1, 2 and 3 hours after container closure for six consecutive days. Supplemental lighting was removed 1 hour prior to sampling. Sample injections were then made into a Beckman model 865 infra-red gas analyzer (Beckman Instruments, Fullerton, CA) equipped with a Hewlett-Packard model 3390A (Hewlett-Packard, Corvalis, OR) integrator. Due to high levels off carbon dioxide, sample injection size was varied. Sample variates were reported as the log of integrator peak area, relative only within days, and analyzed as such. Log values for each sampling date were averaged over replications. Mean separation was provided by LSD P=0.05 and 0.01.

Study 5b was essentially a replication of study 5a. The study was created as a two factor factorial arrangement of 12 treatments in a completely randomized design with three replications. Treatments consisted of Ringer's Lawn Restore, Ringer's Lawn Rx, Ringer's C-50 (previously described) and urea (46-0-0) applied at rates identical to study A. However, untreated controls were employed in this study. Factors were again product and rate of product application. Cultural conditions and experimental procedures were the same as previously

described.

After ten weekly applications, experimental units were monitored for carbon dioxide evolution over a 31 day period during which no treatments were applied. Seven days after the nine week treatment application, the first carbon dioxide samples were withdrawn and injected as described in study A. After the initial sampling, tenth week treatments were applied. Twenty four hours was allowed to elapse, then the second sampling commenced. Sampling was continued on days 3, 5, 7, 11, 17 and 31. After day 31 the eleventh treatment application was applied and continued weekly until 15 applications had elapsed. Sample peak areas from 0.62 cc injections were converted to mg carbon per liter container atmosphere using the ideal gas law (22), a carbon dioxide concentration curve and linear regression. Since sample injection size and accumulation times were known, rates of carbon evolution from treatments were calculated. Further, total carbon additions thru product application to experimental units were determined (by LOI carbon content x number of applications). When total carbon evolution over the life of the study (4150 hours) was calculated (based on the average carbon dioxide evolution rate of the weekly treatment application cycle x the study length), estimations of percentages of carbon turnover due to thatch and product (hence carbon turnover efficiencies) were estimated.

For both studies, at the end of the 15 treatments, aerial vegetative tissue was removed and thatch defined as previously described in study #4. Thatch was then oven dried at 55 C.

Thatch thicknesses were measured for both studies as previously described. A portion of each experimental unit for study B was prepared as previously described in study #4 for cellulose and lignin

determinations.

Treatment mean separation was provided by LSD P=0.05 and 0.01.

Isotope Decay Study 6

The objective of study 6 was to scrutinize patterns of mature grass tissue decomposition in differing soils as influenced by applications of differing nitrogen carriers.

Mature wheat straw (Triticum sativum L.), uniformly labeled (previously reported by Reyes et al., 49) and possessing an activity of 186 uCi ^{14}-C per gram carbon (40% carbon) was used as a model since it was assumed to be high in lignin content and uniformly labelled. Straw was ground to pass 20 mesh with a Wiley mill and divided into 10 mg treatment lots. Combustion of duplicate lots yielded an average of 27,063 bq of ^{14}-C carbon dioxide.

Separate tissue lots were then incorporated into previously sterilized (by autoclaving for 15 minutes at 15 psi) 20 ml glass vials containing either 22 grams sterile sand (>96% passing 500 microns and > 92% retained by 250 microns and .025% carbon) or 20 g sterile sand plus 2 g non-sterile soil (52% sand 26% silt and 22% clay with 1.23% carbon). An identical number of units having no added radioactivity were prepared to estimate background radiation. Nitrogen carriers added to the soil conditions were Ringer's Lawn Restore (10% nitrogen and C:N 4.7:1) and Milorganite (6% nitrogen and C:N 7.2:1). Treatment combinations were factorially arranged in completely randomized design with four replications so that one third of each soil condition recieved 48.8 kg nitrogen ha^{-1} from Lawn Restore and one third received a similar application of Milorganite on day 0 and day 28 of the study. The

remaining third received no added nitrogen. Factors were nitrogen carrier and soil type.

Experimental units were then permanently suspended within 0.95 liter (1 quart) Ball canning jars using cotton twine and rubberbands. Three milliliters sterile water was added to each vial to facilitate decomposition. Twenty milliliter low activity glass scintillation vials containing 2 mls de-aired 1 N sodium hydroxide solution were temporarily suspended within each jar, also using twine and rubberbands. Jars were then sealed with air tight lids to assure a static atmosphere for each experimental unit. The study was incubated in the dark at 24 C for the duration of the study. Jars were opened and aerated for one hour and carbon traps removed every 24 on days 1, 2, 3, 4, 5, 6, 7, 11, 14, 20, 27, 29, 30, 31, 32 and 55. To assure complete trapping of the gas, jar atmospheric samples were withdrawn at the onset of the study through a septum in the jar lid using a hypodermic syringe and subjected to infra red gas analysis (using the technique previously described in study 5). Labelled carbon dioxide exhaust was trapped in hydroxide and discarded. No free carbon dioxide was detected at any time. After the first 7 days jars were opened and aerated periodically (in a fume hood). Water was added as needed. Soils were remixed after the day 28 nitrogen application prior to water addition so that soil aeration status would be enhanced.

Resulting radioactive sodium carbonate solutions, produced by diffusion of the labelled carbon dioxide from mineralization of labelled plant tissue into the NaOH, were diluted with 15 ml of liquid scintillation counting fluid for aqueous media (Saftey-Solve, Research Products International). The primary cocktail solute was butyl PBO

(2,4'-tetraphenyl-5,4''-biphenyl-1,3,4-oxidiazole) and secondary wavelength shifter was dimethyl popop (1,4-bis(2-(4-methyl-5-phenyloxazoyl))-benzene) dissolved in a high flashpoint naptha. Sample solutions were counted in a Beckman 8100 liquid scintillation counter and corrected for quenching by the external standard H number method. Sample values for each treatment per replication in counts per minute (cpm) had background radiation values subtracted and were transformed to disintegrations per second. In addition, percent labelled carbon remaining, across sampling dates (calculated by subtracting accumulated dps from 27,063), for each treatment, was plotted exponentially against time using non-linear regression, so that labeled tissue decay rate constants and subsequent half lives of the decomposition curves could be calculated. Since plant tissue decay follows first order kinetics, the rate of change of plant tissue (A) = $-dA/dt = kA$. After integration, the equation simplifies to $A = Ao\ e^{-kt}$ where A = the concentration of plant tissue remaining at any time and k = the rate constant (time $^{-1}$). It follows that when log A/Ao is plotted vs. time (t), a straight line with slope = $-k/2.303$ is obtained (since log $A/Ao = -kt/2.303$). Rearranging, $t = 2.303/k \log (2) = 0.693/k$.

Also, curve peeling (as described by Paul, 47) was used to estimate plant component decay rates. Plant tissue is comprised of 4 components (i.e., lignin, etc.) with differing rate constants. Curve peeling allowed estimation of each component's rate constant (for each treatment curve). More specifically, each treatment curve was described by the additive equation $C(t) = A1e^{-kt} + A2e^{-kt} + A3e^{-kt} + A4e^{-kt}$ (where C(t) = the amount of carbon at any time (t) and A1 through A4 represent

each component in order of increasing ease of decay).

RESULTS AND DISCUSSION

Field Nitrogen Response

Nitrogen Carrier Study 1

Summarization of the data suggest that more total differences were seen when Lawn Restore or Lawn Rx-treated turf was compared to urea-treated turf than when compared to sulfur-coated urea-treated turf. This should be expected since the nitrogen release rates between fast and slow release carriers, by theory, follow different trends. All test variables, were highly significantly correlated showing a high degree of association. The greatest percentage of carrier type induced differences occurred in percent tissue nitrogen, followed by visual quality ratings, clipping harvest and chlorophyll concentration analyses.

The majority of collection or rating analyses detected significant main effect differences. The greatest number of differences were detected in rates of application which was expected. The total number of differences increased as rates of application increased. This did not imply that higher rate treatments provided "better" turf. The detrimental effects of excess applied nitrogen are well documented (5,

65, 69).The only variable not depicting rate differences 100% of the time was chlorophyll content in 1984. Still, in greater than 70% of this variable analyses significant differences were detected.

Carrier type induced differences were observed in a majority of analyses across both years for all variables. When differences were detected, in comparison to sulfur-coated urea-treated turf, Lawn Restore- treated turf ranked better or was found not different in 57%, 83%, 89% and 61% of nitrogen percentage, chlorophyll concentration, clipping harvest and visual quality rating analyses, respectively. Compared to urea-treated turf, Lawn Restore-treated turf rated better or not different in 36%, 50%, 55% and 0% of variable analyses, respectively. Lawn Rx-treated turf, compared to sulfur- coated urea-treated turf rated better or not different in 29%, 100%, 60% and 0%. When in comparison to urea-treated turf, Lawn Rx-treated turf rated better or not different in 0%, 0%, 0% and 73% of the variables, respectively.

Lawn Rx treatments were dropped out of the study in 1985, therefore, results of the analysis of variance for each variable for each rating date or collection strictly within each season will be reported. Treatment means by collection or rating date for separate years are presented in Tables 1 through 8.

Aerial turf tissue nitrogen content values for 1984 (N=8, see Table 1) ranged from 3.0% to 5.6% total nitrogen (excluding nitrates) in agreement with Waddington et al. (71), Johnson (27) and Beard (5).

Study design replication differences were detected in 71% of the nitrogen content analyses. Sixty percent of these differences were highly significant. All detected differences occurred prior to and

Table 1. Mean treatment values for Kentucky bluegrass aerial tissue nitrogen content response to repeated nitrogen carrier applications for N carrier study 1 in 1984.

Carrier treatment	Nitrogen rate	Collection dates[a]						
		6/12	6/23	7/12	7/31	8/19	8/31	9/17
	kg $ha^{-1}yr^{-1}$	% [b]						
Lawn Rx[tm]	97.6	3.7	3.6	3.0	3.2	3.9	3.2	3.0
	195.3	3.7	3.8	3.2	3.4	3.9	3.4	3.0
	292.9	4.0	4.4	3.6	3.8	4.3	3.5	3.2
Lawn Restore[tm]	97.6	3.8	3.8	3.3	3.4	3.9	3.4	3.0
	195.3	4.0	3.8	3.7	3.8	4.0	3.5	3.2
	292.9	4.2	5.0	4.0	4.3	4.3	3.7	3.3
Urea	97.6	3.7	4.3	3.5	3.6	3.9	3.4	3.1
	195.3	4.3	5.1	3.9	4.0	4.2	3.6	3.2
	292.9	4.2	5.6	4.3	4.6	4.6	3.9	3.4
Sulfur Coated Urea	97.6	3.7	3.8	3.2	3.4	4.0	3.2	3.0
	195.3	3.7	3.9	3.4	3.6	4.2	3.6	3.2
	292.9	4.1	4.4	3.8	4.2	4.6	3.6	3.4
LSD*		0.3	0.3	0.2	0.3	0.3	0.1	0.2
LSD**		0.4	0.4	0.3	0.4	0.4	0.2	0.2

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = date of clipping collection in 1984
b = denotes percent nitrogen excluding nitrates

including 12 July and after and including 31 August. Thus, statistical blocking may have increased experimental precision in detecting true nitrogen content differences in 1984. Prior to 12 July, replication differences probably occurred due to malfunctions of the automatic irrigation system at the research center. The irrigation head covering replication 2 was not functional until 4 July in 1984. Replication differences after 31 August may be attributable to failure of carrier induced or rate of carrier application induced differences to be similar among replications.

Carrier induced differences in tissue nitrogen content, when averaged over rates of application, were detected in 100% of analyses; 86% of the differences were considered highly significant. When compared to sulfur- coated urea-treated turf, Lawn Restore-treated turf ranked significantly higher in tissue nitrogen content in 29% of analyses, significantly lower in 14% and not different in 57%; Lawn Rx-treated turf never ranked higher, ranked significantly lower in 71% of analyses and was not different in 29%. In comparison to urea-treated turf, Lawn Restore-treated turf never ranked higher, but ranked significantly lower in 71% of analyses and was not different in 29%. Lawn Rx treated turf always ranked lower than urea treated turf. Difficulty in applying the Ringer products at the desired rate considering wind drift and product inconsistency may have confounded true differences to some extent.

Highly significant differences in tissue nitrogen content, due to increasing rates of nitrogen carrier application, averaged over carrier types, were detected in 100% of sample analyses. Higher treatment rates (i.e., 292.9 kg N ha^{-1} yr^{-1}) consistently ranked better than middle treatment rates (i.e., 195.3 kg N ha^{-1} yr^{-1}) which consistently ranked

better than low treatment rates (i.e., 97.6 kg N ha^{-1} yr^{-1}) in all sample collections, which is not surprising since cool season turfgrasses growing at higher nitrogen rates have higher tissue nitrogen contents (5).

Considering 1985 sample collections (N=8, see Table 2), treatment mean values ranged from 2.4% to 4.1% nitrogen which is somewhat lower than the previous year but still in agreement with Waddington et al. (71) and Johnson (27).

Differences in tissue nitrogen content due to carrier types, averaged over rates of application, were detected in 88% of analyses; 43% of which were highly significant. When differences occurred, in comparison to sulfur-coated urea-treated turf, Lawn Restore-treated turf never ranked higher in total nitrogen content, ranked lower in 71% of analyses and was not different in 29% of analyses. When compared to urea-treated turf Lawn Restore-treated turf again never ranked significantly higher, but ranked significantly lower in 57% of analyses and was not different on 43%. Since carriers were applied with more accuracy in 1985, detected differences were more indicative of true carrier type induced differences.

Highly significant differences in total tissue nitrogen content, due to increasing rates of application averaged over carriers were detected in 100% of analyses. High nitrogen treated plots were significantly higher than medium rate treated plots in 88% of analyses. Medium rate treated-turf was consistently higher than low rate treated-turf in all analyses.

Considering total mg chlorophyll A and B g^{-1} dried turf tissue (see Table 3), treatment mean values ranged from 5.0 mg to 13.0 mg which is

Table 2. Mean treatment values for Kentucky bluegrass aerial tissue nitrogen content response to repeated nitrogen carrier applications for N carrier study 1 in 1985.

Carrier treatment	Nitrogen rate	Collection dates[a]							
		5/13	5/25	6/16	7/18	8/4	8/19	8/30	9/14
	kg $ha^{-1}yr^{-1}$	% [b]							
Lawn Restore[tm]	97.6	2.9	2.8	2.4	2.6	3.0	3.0	3.3	3.0
	195.3	3.0	3.0	3.1	3.0	3.3	3.3	3.6	3.1
	292.9	3.1	3.2	3.4	3.2	3.4	3.5	3.6	3.2
Urea	97.6	2.9	2.9	2.8	2.8	2.9	3.0	3.4	3.0
	195.3	3.2	3.3	3.5	3.0	3.5	3.4	3.6	3.1
	292.9	3.3	3.7	4.1	3.3	3.7	3.7	3.9	3.3
Sulfur Coated Urea	97.6	2.9	2.7	2.8	2.8	3.0	3.1	3.4	3.1
	195.3	3.0	2.9	3.1	3.1	3.3	3.3	3.7	3.2
	292.9	3.1	3.2	3.6	3.3	3.6	3.8	4.0	3.4
LSD*		0.2	0.2	0.3	0.2	0.4	0.2	0.1	0.1
LSD**		0.2	0.3	0.4	0.3	0.6	0.3	0.2	0.2

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of clipping collection in 1985
b = denotes percent nitrogen excluding nitrates

Table 3. Mean treatment values for Kentucky bluegrass aerial tissue chlorophyll content response to repeated nitrogen carrier applications for N carrier study 1 in 1984.

Carrier treatment	Nitrogen rate	Collection dates[a]						
		6/12	6/23	7/12	7/31	8/19	8/31	9/17
	kg $ha^{-1}yr^{-1}$	mg g^{-1}[b]						
Lawn Rx[tm]	97.6	7.3	10.1	6.4	6.7	5.0	6.9	7.2
	195.3	8.2	10.8	6.2	7.0	5.5	7.9	7.9
	292.9	8.3	11.7	7.1	7.3	6.6	7.4	7.8
Lawn Restore[tm]	97.6	8.1	11.0	7.2	7.7	5.5	7.8	7.4
	195.3	7.7	11.6	8.0	7.4	5.9	7.9	7.2
	292.9	8.4	12.6	9.2	9.1	6.4	8.9	8.8
Urea	97.6	7.0	11.1	6.6	7.6	6.0	7.2	7.1
	195.3	9.9	13.0	7.6	7.1	5.6	9.0	8.0
	292.9	9.0	12.6	8.7	8.6	5.6	8.4	8.7
Sulfur Coated Urea	97.6	7.0	10.9	7.2	6.3	5.2	8.6	7.9
	195.3	7.8	10.2	7.2	6.7	5.2	8.4	8.6
	292.9	8.9	11.5	8.4	8.1	5.6	7.3	8.6
LSD*		1.4	1.3	1.3	1.5	1.5	1.6	1.6
LSD**		1.9	1.8	1.8	2.1	2.0	2.1	2.2

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = date of clipping collection in 1984
b = denotes milligrams chlorophyll A and B per gram dried turf tissue

in agreement with values reported by Johnson (27) and Madison et al. (36).

Carrier induced differences in tissue chlorophyll content, averaged over rates of carrier application, occurred in 29% of sample analyses; with all differences highly significant. When differences in chlorophyll concentrations were detected, Lawn Restore-treated turf, compared to sulfur-coated urea- treated turf, ranked higher in 50% of analyses and never ranked lower. Lawn Rx and sulfur coated urea treatments never differed. In comparison to urea- treated turf, Lawn Restore-treated turf never differed while Lawn Rx-treated turf always ranked significantly lower.

Rate induced differences in chlorophyll content, averaged across carriers, were detected on 71% of collection analyses. Of the detected differences, 80% were considered highly significant. When differences were detected, the high rate treatments ranked significantly higher than the medium rate treatments 60% of the time. The medium rate treatments ranked better that the low rate treatments 20% of the time while the high rate ranked better that the low rate on all occasions.

For 1985 chlorophyll analyses (N=8, see Table 4), significant carrier by rate of application interactions were detected in 38% of sample analyses with 67% of interactions considered highly significant. It was apparent that a substantial portion of the factor simple effects by date were heterogeneous. There was a failure of the carrier effect to be the same within each rate of application and vice versa. However, the majority of analyses detected no significant interactions Treatment mean values ranged from 5.4 mg to 11.8 mg, which was slightly lower than 1984 values.

Table 4. Mean treatment values for Kentucky bluegrass aerial tissue chlorophyll content response to repeated nitrogen carrier applications for N carrier study 1 in 1985.

Carrier treatment	Nitrogen rate	Collection dates[a]							
		5/13	5/25	6/16	7/18	8/4	8/19	8/30	9/14
	kg $ha^{-1}yr^{-1}$	mg g^{-1}[b]							
Lawn Restore™	97.6	6.6	5.9	5.4	7.5	9.5	9.7	9.6	9.1
	195.3	6.6	6.8	6.4	8.5	10.3	10.3	10.4	9.4
	292.9	7.0	7.4	6.7	9.1	11.4	11.2	11.1	9.7
Urea	97.6	6.5	6.5	6.0	7.9	8.9	9.5	9.8	9.2
	195.3	7.1	7.5	7.4	8.4	11.0	10.8	10.9	9.6
	292.9	7.2	8.7	8.5	9.1	11.8	10.9	11.5	9.8
Sulfur Coated Urea	97.6	6.3	6.3	5.7	8.1	9.1	9.6	10.0	9.3
	195.3	6.6	6.8	6.1	8.7	9.7	10.2	10.7	9.6
	292.9	7.2	7.3	7.2	9.3	10.4	11.8	11.6	10.0
LSD*		0.5	0.3	0.4	0.8	0.7	0.7	0.4	0.3
LSD**		0.7	0.4	0.6	1.1	1.0	1.0	0.5	0.4

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of clipping collection in 1985
b = denotes milligrams chlorophyll A and B per gram dried turf tissue

Carrier type induced differences in tissue chlorophyll concentration, when averaged over rates of carrier application, occurred in 50% of sample analyses, with all differences significant at the 1% level. When differences were found, in comparison to sulfur-coated urea-treated turf, Lawn Restore-treated turf ranked higher in 25% of sample analyses, lower on 25% and not different in 50%. Compared to urea-treated turf, Lawn Restore-treated turf never ranked higher, ranked lower in 75% of analyses and was not different in 25%.

Rate induced differences in tissue chlorophyll content, when averaged over carrier type, were detected in 100% of sample analyses. High nitrogen rate treatments consistently ranked higher than medium rate treatments which consistently ranked higher than low rate treatments.

Regarding 1984 clipping harvest collections (see Table 5), treatment mean values in g M^2 ranged from 5.9 to 31.5.

Differences in total harvest induced by carrier types, averaged over rates of application, were detected in 71% of sample analyses, with 80% of the differences considered highly significant. In comparison to sulfur-coated urea-treated turf, when differences occurred, Lawn Restore-treated turf ranked significantly higher in 40% of sample analyses, Lawn Rx treated turf never ranked better and ranked significantly lower in 40% of analyses. In comparison to urea-treated turf, Lawn Restore-treated turf never differed while Lawn Rx- treated turf always ranked significantly lower.

Application rate induced differences in tissue harvest, when averaged over carrier type occurred in 100% of sample analyses, with 86% of the differences considered highly significant. When differences occurred, high rate treatments rated significantly higher than medium rate

Table 5. Mean treatment values for Kentucky bluegrass aerial tissue clipping yield response to repeated nitrogen carrier applications for N carrier study 1 in 1984.

Carrier treatment	Nitrogen rate	Collection dates[a] 6/12	6/23	7/12	7/31	8/19	8/31	9/17
	kg $ha^{-1}yr^{-1}$	g M^{-2}[b]						
Lawn Rx™	97.6	12.0	12.1	8.3	6.4	14.1	8.5	5.9
	195.3	11.9	14.7	12.4	9.9	19.6	10.8	8.7
	292.9	19.8	23.6	19.1	13.8	19.4	13.2	8.6
Lawn Restore™	97.6	15.0	15.7	11.3	9.2	16.9	9.9	7.0
	195.3	17.6	18.2	21.5	16.0	21.4	13.2	10.6
	292.9	25.2	26.4	30.7	20.7	21.2	17.5	12.0
Urea	97.6	14.2	9.9	11.6	13.0	16.5	11.2	8.8
	195.3	19.8	23.4	25.6	16.1	23.3	14.8	10.4
	292.9	28.7	19.9	31.5	21.8	22.9	19.2	13.4
Sulfur Coated Urea	97.6	15.4	11.7	8.3	7.7	17.4	10.1	7.7
	195.3	11.2	12.0	10.9	12.7	21.9	12.8	9.7
	292.9	21.8	22.5	23.0	14.9	19.7	17.7	13.1
LSD*		8.3	14.4	6.0	3.4	4.9	3.2	2.5
LSD**		11.4	19.6	8.1	4.7	6.6	4.4	3.4

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of clipping collection in 1984
b = denotes grams dried turf per square meter

treatments 86% of the time while medium rate treatments ranked better than low rate treatments 71% of the time. High rate treatments always ranked better than the low rate treatments.

For 1985 clipping harvest collections (N=8, see Table 6), tretment mean values ranged from 1.1 to 31.5 grams, comparable to 1984 results.

Carrier type induced differences in tissue harvest, when averaged over rates of carrier application, were detected in 50% of sample analyses. All differences were considered highly significant. When differences were detected, in comparison to sulfur-coated urea-treated turf, Lawn Restore- treated turf never ranked higher, ranked lower 25% of the time and was not different 75% of the time. In comparison to urea-treated turf, Lawn Restore- treated turf always ranked significantly lower.

Rate of application induced differences in tissue harvest, when averaged over carrier types, were detected in 100% of sample analyses. All differences were considered highly significant. High rate treatments ranked significantly higher than medium rate treatments 75% of the time while medium rates ranked higher than low rates 100% of the time.

For visual quality ratings in 1984 (N=12, see Table 7), the range was from 6.6 to 9.0 on a subjective rating scale.

Carrier induced differences in visual quality, when averaged across rates of application, occurred on 92% of the ratings. 91% of the differences were considered highly significant. When differences were found, in comparison to sulfur-coated urea-treated turf, Lawn Restore-treated turf rated significantly higher on 27% of ratings and significantly lower on 9%. Lawn Rx-treated turf never rated higher and

Table 6. Mean treatment values for Kentucky bluegrass aerial tissue clipping yield response to repeated nitrogen carrier applications for N carrier study 1 in 1985.

Carrier treatment	Nitrogen rate	Collection dates[a]							
		5/13	5/26	6/16	7/18	8/4	8/19	8/30	9/14
	kg $ha^{-1}yr^{-1}$	g M^{-2}[b]							
Lawn Restore[tm]	97.6	8.3	12.7	13.7	1.1	2.0	8.2	6.8	3.0
	195.3	10.1	16.5	21.1	3.4	7.4	17.7	12.6	4.6
	292.9	11.4	17.6	21.9	7.9	13.8	24.8	17.4	4.8
Urea	97.6	8.7	15.8	17.8	1.2	3.1	8.2	7.3	3.1
	195.3	12.6	21.7	20.8	4.0	10.9	18.9	14.5	4.6
	292.9	13.2	22.7	25.3	8.7	15.3	24.5	20.8	6.2
Sulfur Coated Urea	97.6	7.0	13.2	16.5	1.1	1.7	9.2	8.7	3.7
	195.3	9.6	16.4	18.9	2.8	5.7	18.6	15.8	5.2
	292.9	12.0	17.1	20.1	8.2	11.6	29.9	20.7	7.3
LSD*		1.7	4.4	5.1	2.2	2.3	4.1	2.7	2.1
LSD**		2.4	6.1	7.1	3.0	3.2	5.6	3.8	2.9

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of clipping collection in 1985
b = denotes grams dried turf per square meter

Table 7. Mean treatment values for Kentucky bluegrass aerial tissue visual quality response to repeated nitrogen carrier applications for study #1 in 1984.

Carrier treatment	Nitrogen rate	Rating dates[a]					
		6/7	6/20	6/28	7/7	7/12	7/27
	kg $ha^{-1}yr^{-1}$	VQ[b]					
Lawn Rx[tm]	97.6	7.0	6.8	6.8	7.0	6.8	6.8
	195.3	7.6	6.8	7.3	7.2	7.3	7.5
	292.9	7.6	7.8	7.6	8.0	8.0	8.0
Lawn Restore[tm]	97.6	7.5	6.8	7.2	7.2	7.5	7.3
	195.3	7.2	7.3	7.5	7.6	8.0	8.0
	292.9	7.8	7.8	7.8	8.5	8.5	8.5
Urea	97.6	7.6	7.3	7.3	7.5	7.5	7.6
	195.3	7.6	8.2	8.2	8.2	8.5	8.5
	292.9	8.8	8.6	8.3	9.0	9.0	9.0
Sulfur Coated Urea	97.6	7.2	6.8	7.0	6.8	6.8	7.2
	195.3	6.8	7.0	7.5	7.3	7.3	7.5
	292.9	7.2	7.8	7.6	8.0	7.8	8.0
LSD*		1.0	0.7	0.6	0.4	0.5	0.4
LSD**		1.3	1.0	0.8	0.6	0.7	0.5

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of visual ratings in 1984
b = denotes subjective visual quality rating ranging from 9 to 1 with high scores better

Table 7 (cont'd.).

Carrier treatment	Nitrogen rate	Rating dates[a] 8/8	8/19	8/28	9/8	9/17	9/24
	kg $ha^{-1}yr^{-1}$	VQ[b]					
Lawn Rx[tm]	97.6	6.8	7.3	6.6	7.0	7.2	6.6
	195.3	7.5	7.6	7.0	7.6	7.5	6.8
	292.9	7.8	7.8	7.5	7.8	7.6	7.5
Lawn Restore[tm]	97.6	7.2	7.5	6.8	7.3	7.3	7.2
	195.3	7.6	7.6	7.3	8.0	7.6	7.5
	292.9	8.2	8.3	7.8	8.3	7.8	7.8
Urea	97.6	7.8	7.6	7.5	7.5	7.3	8.2
	195.3	8.5	8.2	8.2	8.5	8.0	8.6
	292.9	9.0	8.8	8.8	9.0	8.0	9.0
Sulfur Coated Urea	97.6	7.0	7.5	7.0	7.5	7.3	7.5
	195.3	8.0	8.3	7.8	7.5	7.6	7.8
	292.9	8.2	8.2	8.3	8.5	8.0	7.6
LSD*		0.5	0.6	0.8	0.5	0.6	0.5
LSD**		0.6	0.9	1.0	0.7	0.8	0.7

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of visual ratings in 1984
b = denotes subjective visual quality rating ranging from 9 to 1 with higher scores better

rated lower on 27%.

Rate of application induced differences in visual quality, when averaged over carrier types, were detected on 100% of ratings, with 92% of the differences highly significant. High rate treatments were significantly better than medium rate treatments 83% of the time. Medium rates rated higher than low rates 83% of the time.

Regarding 1985 ratings (N=17, see Table 8)), Mean treatment rating values ranged from 5.5 to 9.0.

Carrier type induced differences in visual quality, when averaged over rates of application, occurred on 75% of the ratings, with 75% of the differences highly significant. When differences occurred, compared to sulfur-coated urea- treated turf, Lawn Restore-treated turf never rated better and rated lower 66% of the time. In comparison to urea-treated turf, Lawn Restore treated turf always rated lower.

Differences in visual quality due to increasing rates of application, averaged over carrier types, occurred on 100% of the ratings, with 94% highly significant. High rate treatments consistently rated better than medium rate treatments which rated significantly better than the low rate treatments of application.

Treatment means for each collection or rating date were collapsed across dates within years and equivalent conditions correlated for degree of variable association (see Table 9). All correlation

Table 8. Mean treatment values for Kentucky bluegrass aerial tissue visual quality response to repeated nitrogen carrier applications for N carrier study 1 in 1985.

Carrier treatment	Nitrogen rate	Rating dates[a] 4/30	5/26	6/6	6/12	6/21	6/29	7/9	7/28	8/4
	$kg^{-1}ha^{-1}yr$	VQ[b]								
Lawn Restore™	97.6	7.5	6.8	7.3	7.2	6.3	6.3	6.8	7.2	7.0
	195.3	7.7	6.8	7.5	6.8	6.8	7.5	7.5	8.3	8.0
	292.9	8.0	7.3	8.0	8.2	7.8	8.0	8.2	8.8	8.3
Urea	97.6	7.0	7.5	7.7	7.2	7.0	6.7	6.8	7.8	7.3
	195.3	8.5	8.0	8.3	8.5	8.3	8.3	7.8	8.7	8.5
	292.9	8.5	9.0	9.0	8.7	9.0	9.0	9.0	9.0	9.0
Sulfur Coated Urea	97.6	7.2	6.8	7.3	7.2	6.5	6.5	7.0	7.5	7.5
	195.3	7.7	7.3	7.3	7.2	7.5	7.7	7.5	8.3	8.0
	292.9	8.2	7.7	8.0	8.5	8.0	8.5	8.3	8.7	8.5
LSD*		0.5	0.4	0.7	0.5	0.3	0.7	0.7	0.5	0.5
LSD**		0.7	0.5	0.9	0.7	0.4	1.0	1.0	0.6	0.7

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of visual ratings in 1985
b = denotes subjective visual quality rating scores ranging from 9 to 1 with high score better

Table 8 (cont'd.).

Carrier treatment	Nitrogen rate	Rating dates[a] 8/11	8/19	8/25	9/8	9/19	9/28	10/5	11/3
	kg $ha^{-1}yr^{-1}$	VQ[b]							
Lawn Restore[tm]	97.6	7.5	7.2	6.7	7.8	7.3	7.2	7.2	7.5
	195.3	8.0	8.0	7.3	8.2	7.5	7.8	7.8	8.0
	292.9	8.3	8.5	7.7	8.0	8.2	8.2	8.7	8.3
Urea	97.6	7.5	7.3	6.7	7.8	7.7	7.5	7.2	7.7
	195.3	8.2	8.2	7.8	8.5	8.5	8.5	8.3	8.5
	292.9	8.7	8.8	8.8	9.0	8.7	9.0	9.0	9.0
Sulfur Coated Urea	97.6	7.7	7.7	7.2	8.2	7.8	7.2	7.3	8.0
	195.3	8.0	8.2	8.0	8.5	8.5	8.3	8.3	8.8
	292.9	8.7	8.7	8.8	8.8	8.5	8.7	8.7	8.8
LSD*		0.4	0.6	0.5	0.6	1.0	0.8	0.5	0.4
LSD**		0.5	0.8	0.7	0.8	1.3	1.1	0.7	0.6

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = dates of visual ratings in 1985
b = denotes subjective visual quality rating scores ranging from 9 to 1 with high scores better

Table 9. Correlation coefficients between test variable combinations for N carrier study 1 in 1984 and 1985.

Variable combination*	Years[a]	
	1984	1985
	r[b]	
Visual Rating vs. clipping yield	0.92**	0.97**
Visual Rating vs. tissue nitrogen content	0.98**	0.98**
Visual Rating vs. tissue chlorophyll content	0.89**	0.98**
Clipping yield vs. tissue nitrogen content	0.96**	0.99**
Clipping yield vs. tissue chlorophyll content	0.96**	0.99**
Tissue nitrogen content vs. tissue chlorophyll content	0.93**	0.99**

* = refers to correlation coefficient determinations between test variables percentage tissue nitrogen content, milligrams chlorophyll A and B per gram dried turf tissue, clipping harvest yield in grams clippings per square meter and visual quality scores collapsed across rating or collection dates for each year.
** = denotes significance at the 1% level
a = refers to experimental period
b = denotes correlation coefficients

coeffecients for all possible variable comparisons were significant at the 1% level indicating a high degree of variable association, which is in agreement with correlations done by Johnson (27).

Peak nitrogen content values occurred in later June for high carrier rates and urea at all rates and in late August for lower rates of the less soluble carriers. Clipping harvest peaks were 12 July for higher rates and more soluble carriers and 19 August for low rates of less soluble carriers. Chlorophyll values peaked on 23 June in 1984 and on 30 August for 1985, averaged across carriers. The majority of treatment combinations rated higher in early July, except for the low and medium rates of sulfur coated urea, which looked best in late August (for 1984). In 1985, visual values were very similar except that peaks occurred approximately 1 week later. Also, 1985 treatment means were slightly lower and a definite mid-season decline in all variables for both years was noted. This trend was consistent with the spring/fall growth pattern of cool season grasses.

The overall conclusion was that turf treated with the Ringer products compared favorably to sulfur-coated urea-treated turf, while definite differences from urea-treated turf existed, on all test variables, including visual quality.

Nitrogen Carrier Study 2

Data summarization suggests that an appreciable amount of variability existed on test variables comparing Lawn Restore and Lawn Rx-treated turf to urea-treated turf. More rate of application induced differences than carrier type induced differences were detected.

Treatment means by collection or rating date are presented in Tables

10 and 11. Correlation coefficients between all variable treatment means averaged across sampling or rating dates are also presented in Table 12.

Nitrogen means (see Table 10) ranged from 3.4% to 4.5% N, comparable to values obtained in study 1 and consistent with values described by Beard (5), Johnson (27) and Waddington et al. (71).

Carrier type induced differences in tissue nitrogen content, when averaged over rates of application, were highly significant in all analyses. When compared to urea-treated turf, Lawn Restore-treated turf and Lawn Rx-treated turf both ranked significantly lower in all analyses.

Rate of application induced differences in nitrogen content, when averaged over carrier type, were detected in all analyses, with 50% considered highly significant. The high rate treatments (i.e., 97.6 kg N ha^{-1}) consistently ranked significantly higher than the medium rate treatments (i.e., 48.8 kg N ha^{-1}) which ranked significantly higher than the low rate treatments (i.e., 24.4 kg N ha^{-1}) across all analyses.

Chlorophyll concentration mean values (see Table 10) ranged from 7.5 to 10.2 mg comparable to values reported by others (57, 60).

No carrier type induced differences in chlorophyll concentration were detected in any analysis.

Rate of application induced differences in chlorophyll content were detected in 50% of the analyses, but were significant at the 5% level only. Specifically, no differences between the high and medium rate of application treatments were detected. The only detected differences were between the high and low rates.

Visual quality treatment mean values (see Table 11) ranged from 6.3 to

Table 10. Mean treatment values for Kentucky bluegrass aerial tissue nitrogen and chlorophyll content response to nitrogen carrier application for N carrier study 2.

Carrier treatment	Nitrogen rate	Collection dates			
		9/17		9/30	
	kg ha^{-1}	% N[a]	mg g^{-1}[b]	% N	mg g^{-1}
Lawn Rx[tm]	24.4	3.5	7.9	3.4	7.9
	48.8	3.6	7.6	3.6	8.4
	97.6	3.8	8.9	3.8	9.3
Lawn Restore[tm]	24.4	3.6	7.5	3.7	8.9
	48.8	3.6	8.0	3.7	9.1
	97.6	3.7	8.6	3.8	9.4
Urea	24.4	3.7	9.1	3.8	8.6
	48.8	4.0	9.4	3.8	9.2
	97.6	4.5	10.2	4.2	9.9
LSD*		0.3	2.4	0.3	1.2
LSD**		0.5	3.3	0.4	1.7

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes percent nitrogen content by weight
b = denotes milligrams chlorophyll A and B per gram dried turf tissue

Table 11. Mean treatment values for Kentucky bluegrass aerial tissue visual quality response to nitrogen carrier application for N carrier study 2.

Carrier treatment	Nitrogen rate	Rating dates[a]				
		8/20	8/28	9/8	9/17	9/25
	kg ha^{-1}	VQ[b]				
Lawn Rx[tm]	24.4	7.0	7.2	6.5	7.0	6.5
	48.8	8.2	7.8	7.0	7.3	6.8
	97.6	8.3	8.3	7.2	8.2	7.6
Lawn Restore[tm]	24.4	7.3	7.2	6.5	6.8	6.3
	48.8	7.8	7.3	6.4	7.3	6.8
	97.6	7.8	7.8	7.5	7.8	8.0
Urea	24.4	8.8	8.2	8.2	8.2	7.8
	48.8	9.0	8.8	8.3	8.6	8.5
	97.6	9.0	9.0	8.9	9.0	8.8
LSD*		0.9	0.5	1.0	0.6	0.9
LSD**		1.3	0.7	1.3	0.8	1.2

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes dates of plot ratings
b = denotes subjective visual quality rating ranging from 9 to 1 with high scores better

9.0. Highly significant differences in visual quality induced by carrier types, averaged across rates of application, were detected in 100% of analyses. Both Lawn Restore and Lawn Rx treated turf ranked significantly lower in visual quality than urea treated turf in all analyses.

Rate of application induced differences in visual quality, when averaged over carrier types, were detected in 100% of analyses, with 80% considered highly significant. High rate treatments ranked better than medium rate treatments 60% of the time; medium rate treatments consistently ranked better than low rate treatments.

Variable treatment means were collapsed across dates and equivalent conditions correlated for degree of variable association (see Table 12). All correlation coeffecients were significant at the 1% level, indicating a high degree of variable association.

The greatest number of differences occurred in visual quality ratings and nitrogen percentages followed by chlorophyll concentrations. The Ringer product treated turf fared best in chlorophyll analyses followed by visual quality and nitrogen. Specifically, tissue nitrogen content increased substantially, even after the visual quality peak (i.e., 6 weeks) in Lawn Restore-treated turf, while a definite decline for urea-treated turf was detected. However, urea-treated turf still contained significantly more tissue nitrogen than either Lawn Restore or Lawn Rx-treated turf. Urea-treated turf was rated significantly higher in visual quality than equivalent rates of the Ringer product-treated plots.

The overall conclusion was that definite differences between Ringer product-treated turf and urea-treated turf existed on a short term

Table 12. Correlation coefficients between test variable combinations for N carrier study 2.

Variable combination*	Correlation coefficients
Tissue chlorophyll content vs. tissue nitrogen content	0.92**
Tissue chlorophyll content vs. visual quality rating	0.86**
Tissue nitrogen content vs. visual quality rating	0.84**

* = refers to correlation coefficient determinations between test variables percentage tissue nitrogen content, milligrams chlorophyll A and B per gram dried turf tissue and visual quality rating scores
** = denotes significance at the 1% level

basis.

Nitrogen Carrier Study 3

Summarization of the data suggest that Lawn Restore and C-50-treated turf rated very favorably in visual quality when compared to sulfur-coated urea- treated turf on a short term basis.

Visual quality ratings for each date are presented in Table 13. Rating values ranged from 6.0 to 9.0 which was in agreement with studies 1 and 2.

Design replication differences were detected in 75% of the analyses with 83% considered highly significant. No relationship between replication differences and rating date was established.

Carrier type induced differences in visual quality, when averaged over rates of application, were detected in only 25% of analyses, with 50% of the differences highly significant. When differences occurred, in comparison to sulfur-coated urea-treated turf, Lawn Restore and C-50-treated turf rated significantly lower.

Rate of carrier application induced differences in visual quality, when averaged across carrier types, were detected in 100% of analyses. All differences were considered highly significant. High rate treatments (i.e., 292.6 kg N ha^{-1} yr^{-1}) rated significantly higher than medium rate treatments (i.e., 195.3 kg N ha^{-1} yr^{-1}) which ranked significantly higher than the low rate treatments (i.e. 97.7 kg N ha^{-1} yr^{-1}) which rated significantly higher than the check plots (i.e., no applied nitrogen).

Table 13. Mean treatment values for Kentucky bluegrass aerial tissue visual quality response to repeated nitrogen carrier applications for N carrier study 3.

Carrier treatment	Nitrogen rate	Rating dates							
		7/30	8/4	8/11	8/19	8/25	9/8	9/19	9/28
	kg $ha^{-1}yr^{-1}$	VQ[a]							
C-50	0	7.0	6.5	6.2	6.2	6.0	6.3	6.7	6.0
	97.6	7.5	7.5	7.0	7.2	7.2	7.3	6.8	7.2
	195.3	7.6	8.0	8.0	7.8	7.8	7.8	7.3	8.0
	292.9	8.0	8.1	8.0	8.2	8.5	7.8	8.0	8.7
Lawn Restore[tm]	0	7.0	6.7	6.2	6.3	6.0	6.7	6.0	6.2
	97.6	7.3	7.5	7.0	6.8	7.0	7.3	7.0	7.5
	195.3	8.0	8.0	7.6	8.0	8.0	7.8	8.0	8.0
	292.9	8.0	8.5	8.0	8.8	8.8	8.2	8.0	8.8
Sulfur Coated Urea	0	6.8	6.7	6.3	6.0	6.0	6.7	6.2	6.3
	97.6	7.5	7.7	7.0	7.5	7.5	7.3	7.8	7.7
	195.3	7.8	8.5	7.5	7.8	8.3	8.0	8.2	8.3
	292.9	8.0	8.6	7.8	8.7	9.0	8.5	9.0	8.7
LSD*		0.5	0.7	0.5	0.6	0.5	0.5	0.8	0.5
LSD**		0.7	0.9	0.7	0.8	0.7	0.7	1.1	0.7

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes subjective visual quality ratings ranging from 9 to 1 with high scores better

Field Thatch Response

Field Thatch Decomposition Study #4

The data suggest that application of the Ringer products at the experimental rates effected a change in Kentucky bluegrass thatch. Decreased thickness and organic matter, increased density, increased water retention, increased lignin accumulation and increased earthworm activity (except for the higher rates of C-50) were documented in association with increasing rates of product application regardless of carrier type. The primary causal factors implicated in changing the thatch profile were the activities of micro and macro decomposers (i.e., fungi, bacteria and earthworms), enhanced by application of the products. It would seem logical that increased worm activity would enhance plant tissue decay, directly and indirectly. Also, changes produced by physical additions of the carriers should change the thatch micro environment, possibly encouraging decomposition to proceed.

The reduction of excess thatch should be of benefit to turf quality. Increased moisture retention, rooting into more desirable medium (i.e., soil), less scalping, increased tolerance to environmental stresses and enhanced aesthetic value are but a few of the potential benefits. Results suggest that use of the Ringer products may enhance the reduction process. However, general turf quality at the rates used in the study was low (except at the low rate). As rates of application increased, turf quality declined. Although quality ratings were not taken, heavily treated turf growth was rapid (as would be expected).

Plants became spindly and crown tissue became exposed. A chlorosis developed during late summer at the higher rates. Turf in check plots and at the low rates regardless of carrier type remained upright, vigorous and considerably more attractive. Low rate treated plots, regardless of carrier type maintained adequate color through the season while enhancing thatch control.

Treatment means for thatch variables thickness, organic matter, density, lignin and cellulose content, water retention and earthworm populations are presented in tables 14 through 16. Each measurement will be discussed independently; differences were detected by analysis of variance. Mean separation was provided by LSD P= 0.05 and 0.01.

For thatch thickness measurements (in meters, see Table 14), treatment mean values ranged from 0.0241 M to 0.0149 M, considerably thicker than values reported by Shearman et al. (56) but consistent with depth values reported by Hurto et al. (25), Randell et al. (50) and Smiley et al. (58).

Carrier type induced differences in thatch thickness, when averaged over rates of application, were significant at the 5% level. Lawn Restore-treated thatch (i.e., mean thickness 0.0199 M) was significantly thicker than Lawn Rx- treated thatch (i.e., 0.0185 M) but neither differed significantly from C-50- treated thatch (i.e., 0.0189 M), after five applications.

Rate of application induced differences, averaged across carrier types, were highly significant. Non treated check plot thatch remained significantly thicker (i.e., mean thickness 0.0232 M) than thatch treated at the low rate of application (i.e., 97.6 kg N ha^{-1} per application, 0.0204 M), which was significantly thicker than thatch

treated at the medium rate (i.e., 195.3 kg N ha^{-1} per application, 0.0175 M), which measured significantly thicker than thatch treated at the high rate (i.e., 390.3 kg N ha^{-1} per application, 0.01541 M).

In contrast to Murdoch and Barr's data (42), thickness of the Ringer product treated thatch was negatively correlated with rate of nitrogen carrier application (i.e., r= -0.9067). Highest rates of nitrogen averaged across carriers decreased thatch thickness by 33% over check plots (i.e., 100 - 0.01541/0.02316 * 100) in one year. Applications of Bio-de-thatch and Thatch-away (42) increased thatch depth by approximately 5% in 5 months time. The addition of nitrogen to the thatch should have, in theory, enhanced thatch decay since the thatch was nitrogen limited (C:N = 30:1). Alternatively, addition of excess nitrogen has been theorized to be a major causal factor in thatch accumulation (40, 49, 73) by effecting an increase in plant production. Plant production estimates were not taken in this study. Still, high rate treated plots regardless of carrier possesed more vegetative tissue (as estimated visually). It is possible that the additions of large quantities of inorganic and organic matter, through product application, acted much like a topdressing, enhancing thatch decay.

Thatch organic matter determination analyses (unwashed thatch, see Table 14) values ranged from 37.4 to 64.5% organic matter which was consistent with organic matter values from Kentucky bluegrass thatch treated by core cultivation and vertical mowing (13), but lower than values of untreated Kentucky bluegrass thatch (i.e., 82%). Organic matter content was also similar to that reported by Ledeboer and Skogley (33).

Carrier type induced differences in organic matter content, when

averaged over rates of application, were detected at the 5% level. Lawn Rx-treated thatch was significantly lower in organic matter than either Lawn Restore or C-50-treated thatch. This result was not surprising since the Rx product contained more inorganics (i.e., Lawn Rx = 55% O.M. vs. Lawn Restore = 83% O.M. and C-50 = 78%). The difference in thatch organic matter here simply reflects the addition of clay to the Rx treated plots.

When thatch was washed free from soil and debris, no differences of any kind were detected by analysis of variance. Treatment values (see Table 14) ranged from 76% to 88% O.M., which were consistent with untreated bluegrass values reported by Danneberger (13), but considerably higher than values reported by Ledeboer and Skogley (33).

Thatch bulk density (g cm^{-3}) analyses detected no significant differences of any kind. Treatment mean values (see table 14) ranged from 0.21 to 0.35 g cm^{-3}, consistent with values reported by Hurto et al. (25) and Danneberger (13). Values were extremely variable. Density values for the Lawn Rx treatments reflects the addition of clay. Again, all null hypotheses failed to be rejected.

Thatch volumetric water content (see Table 15 and Figure 1) treatment means ranged from 113% to 24% volumetric content.

Highly significant rate of application induced differences in moisture retention (see Figure 1) when averaged over carriers were detected at all tensions except saturation. Specifically, thatch treated at the high rate of application (i.e., 390.3 kg N ha^{-1} per application) held significantly more water than the thatch treated at the medium rates (i.e., 195.3 kg N ha^{-1} per application) which held significantly more moisture than either thatch at the low rate

Table 14. Kentucky bluegrass thatch variable mean values as influenced by repeated applications of the Ringer Corporation products for field thatch decomposition study 4.

Carrier treatment	Nitrogen rate per application	Variables			
		Thickness	OM %	OM %	Bulk Density
	kg ha^{-1}	- M -	- unwashed -	- washed -	- g cm^{-3} -
Lawn Restore™	0	0.0241	52.0	81.7	0.21
	97.6	0.0224	42.7	84.1	0.25
	195.3	0.0183	49.8	83.4	0.30
	390.6	0.0149	51.6	83.6	0.24
Lawn Rx™	0	0.0237	50.0	77.9	0.23
	97.6	0.0189	40.8	75.8	0.27
	195.3	0.0161	37.4	80.9	0.35
	390.6	0.0152	38.7	81.4	0.34
C-50	0	0.0217	55.1	87.8	0.22
	97.6	0.0199	56.8	86.0	0.24
	195.3	0.0181	64.4	80.5	0.23
	390.6	0.0161	61.1	88.6	0.22
LSD*		0.002	23.0	NS	NS
LSD**		0.003	31.3	NS	NS

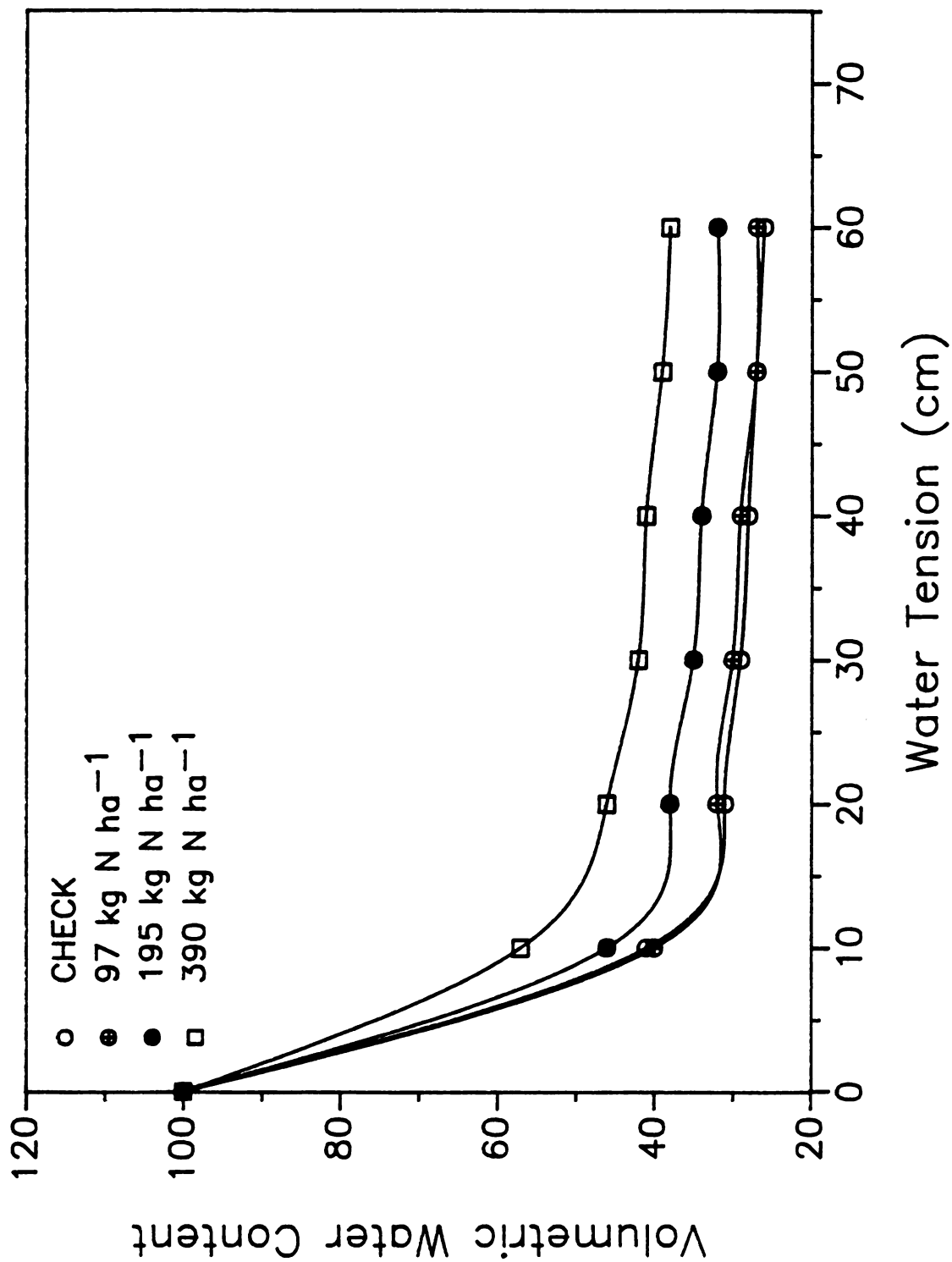
* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = organic matter determined by L.O.I.
NS = not significant

Table 15. Kentucky bluegrass thatch mean volumetric water content values as influenced by repeated applications of Ringer Corporation products for field thatch decomposition in study 4.

Carrier treatment	Nitrogen rate per application	Water tensions						
		0	10	20	30	40	50	60
	kg ha^{-1}	% [a]						
Lawn Restore[tm]	0	107.0	41.7	32.0	30.0	29.0	27.3	27.0
	97.6	104.7	40.0	37.3	30.3	29.3	28.0	27.7
	195.3	105.0	44.0	36.0	33.7	32.7	30.7	30.3
	390.6	107.3	56.7	45.0	41.7	41.0	38.7	38.3
Lawn Rx[tm]	0	100.6	41.7	30.0	28.3	27.3	26.3	25.7
	97.6	100.6	37.0	29.3	27.0	26.0	24.3	24.0
	195.3	102.0	48.0	40.0	36.7	35.7	34.0	33.3
	390.6	108.0	63.7	50.7	46.7	45.3	42.7	41.7
C-50	0	111.3	39.7	31.0	28.6	28.0	26.7	26.3
	97.6	113.3	41.7	34.3	31.6	31.3	29.3	28.7
	195.3	112.0	47.0	37.3	35.0	34.0	32.3	31.3
	390.6	100.6	51.3	41.0	38.0	37.7	35.0	34.3
LSD*		17.1	8.8	8.7	8.3	8.1	7.8	7.7
LSD**		23.3	11.9	11.8	11.3	11.0	10.6	10.5

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes volumetric water content expressed as a percent

Figure 1. Mean Kentucky bluegrass thatch volumetric water retention as influenced by rate of application averaged over N carrier type for field thatch decomposition study 4.


Volumetric Water Content
120
100
80
60
40
20
0
10
20
30
40
50
60
70
Water Tension (cm)
CHECK
97 kg N ha⁻¹
195 kg N ha⁻¹
390 kg N ha⁻¹

treatments (i.e., 97.6 kg N ha^{-1} per application) or in the check plots (i.e., no applied nitrogen), at all tensions (except saturation).

Observation of the data suggests that thatch had the capacity to adsorb large amounts of water (i.e., at saturation), similar to organic soils described by Hillel (22). The adsorbed water was thought to be held in large thatch pore spaces, in agreement with results published by Hurto et al. (25). The idea was supported by the magnitude of water loss with 10 cm (-.0097 bar) applied tension (see Figure 1) regardless of rate of application. It was, however, clear that as rate of carrier increased, so did moisture holding capacity, regardless of carrier type. Speculation was that, with enhanced decay and subsequent collapse of the thatch macro structure, smaller size pores were created, thus effectively creating a more uniform pore size distribution. Since moisture retention characteristics in soils are largely dependent on pore size distributions (22), it follows that any modification of thatch which decreases macro-pore space and increases meso-pore and micro-pore spaces should enhance thatch water holding capacity. The possibility also exists that the thatch tissue became chemically more conducive to holding moisture as decay advanced. Also, additions of large amounts of the carriers may have directly influenced moisture retention by adding organic and inorganic constituents. The concept of increasing water holding capacity in thatch is important, since increased susceptibility to wilt in Kentucky bluegrass thatched situations is a common problem (25).

Treatment mean values for cellulose ranged from 23.6% to 29.9% and for lignin ranged from 11.5% to 16.6%, consistent with values reported by Ledeboer and Skogley (33) and Martin (38). Study design replication

differences were detected at the 5% level for both cellulose and lignin analyses. In each determination replication 3 ranked higher in cellulose and lower in lignin than replications 1 and 2, indicating some natural thatch variability.

Highly significant rate of application induced differences, in cellulose and lignin content were detected, when averaged over carriers. Specifically, the check plot thatch was significantly higher in cellulose than either low rate treated or medium rate treated thatch, which was significantly higher than the thatch treated at the high rate (see Table 16). Conversely, thatch treated at the high rate of application was significantly higher in lignin content than medium or low rate treated thatch, which was significantly higher in lignin content than the check plot thatch. A highly significant negative correlation ($r = -0.82$) was established between cellulose and lignin content. Thus, as rates of application increased, decomposition was enhanced, cellulose content waned and the overall proportion of lignin accumulated. Lignin accumulation reflected the loss of easily degradable glucose and cellulose by the activity of cellulytic bacteria and fungi, and macro-decomposers such as earthworms. The lignin component probably remained unaffected due to the complexity of it's molecular structure, which has been hypothesized to be significant in providing resistance to microbially induced decay (12, 29).

Considering earthworm population analyses (numbers of earthworms per square meter, see Table 16), worm numbers in underlying soil showed no treatment related differences of any kind. In thatch, the only treatment related differences were seen between the untreated check plots and treated plots, regardless of carrier type. Treatment means

Table 16. Kentucky bluegrass thatch variable mean values as influenced by repeated application of the Ringer Corporation products for field thatch decomposition study 4.

Carrier treatment	Nitrogen rate	Variables			
		Cellulose	Lignin	Earthworms[a]	
	kg ha^{-1}	%		- Thatch -	- Soil -
Lawn Restore™	0	29.9	12.2	74.1	86.3
	97.6	26.5	13.4	259.3	98.5
	195.3	28.2	14.6	271.5	74.1
	390.6	23.7	15.8	296.3	49.3
Lawn Rx™	0	28.8	11.5	123.3	37.0
	97.6	27.2	13.9	148.1	25.9
	195.3	29.2	13.9	296.3	98.5
	390.6	23.6	16.6	285.2	98.5
C-50	0	28.9	12.1	86.3	48.1
	97.6	28.5	14.0	259.3	74.1
	195.3	28.9	14.8	174.1	24.4
	390.6	26.3	15.4	148.1	12.2
LSD*		2.7	2.3	163.0	101.4
LSD**		3.7	3.1	222.2	137.9

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes number of earthworms per square meter in defined thatch and to a depth of approximately 15 cm in soil

ranged from 297 to 74 in thatch and from 99 to 13 in sub-soil. There were, however, trends in thatch for seeing greater numbers in Lawn Restore and Lawn Rx-treated turf (as rates of application increase) when compared to C-50-treated turf (see table 16). Apparently, ammonium sulfate present in C-50 was irritating to the worm population, which would be consistent with the conclusions of Potter et al. (49).

In conclusion, application of the Ringer products enhanced thatch control. It was not determined whether decay was enhanced by physical product addition, through the activities of micro-decomposers or macro-decomposers or by some other mechanism. More than likely, all three components collectively played a role. Thatch was reduced, but turf quality at all but the low application rates was not adequate. In view of the results, light frequent applications of the products may be more effective in terms of turf quality.

Laboratory Thatch Response

Greenhouse Thatch Decomposition Studies 5a and 5b

The data suggest that higher rates of nitrogen application produced more total carbon evolution from thatch than lower rates, but lower rates were more effective in producing thatch decay regardless of carrier (see Tables 17 through 24). This conclusion is substantiated by the thickness measurements of the treated thatch (see Tables 20 and

24). Thatch treated at higher rates of added N remained significantly thicker than thatch treated at the lower rates of N regardless of carrier. The higher rates of carbon evolution, produced from the higher rates of added nitrogen carrier application reflect the mineralization of greater amounts of added product carbon and increased plant respiration (except where ammonium sulfate was used). Added carbon from urea applications (in study b), at both rates, was substantially less than additions from the bio-organics but since carrier types did not differ statistically in carbon evolution, urea efficiencies in thatch decay, especially at the lower rates of application were assumed to be theroetically much greater (see Table 23). The same was generally true for ammonium sulfate treated thatch in study 5a. Non treated check thatch had no added carbon or nitrogen (i.e., no added N carrier) and the least total carbon evolved. However, these treatments tended to have the least amount of measurable thatch. All of the carbon evolution in the checks was assumed to come from the thatch (plant + bio-mass respiration), while a substantial portion of the carbon dioxide in the N carrier treated units was assumed to come from mineralization of the carriers. Thus, estimated efficiency of thatch carbon decay was the greatest for the untreated checks.

Study 5a

Treatment means for each variable are presented in tables 17 through 20; differences were detected by analysis of variance. Each variable will be presented independently.

For carbon dioxide evolution measurements (see Tables 17 and 19), results and discussion of the first and third sampling times will be

Table 17. Mean log values of carbon dioxide evolution from Kentucky bluegrass thatch as influenced by applications of differing nitrogen carriers over one week at time 1 (hour 1) for greenhouse thatch decomposition study 5a.

Carrier treatment	Nitrogen rate per application	Sampling dates					
		1	2	3	4	5	6
	kg ha^{-1}	Log PA[b]					
Lawn Restore[tm]	24.4	5.45	5.48	5.44	5.35	5.41	5.32
	122.0	5.65	5.75	5.73	5.62	5.67	5.65
C-50	24.4	5.45	5.42	5.40	5.30	5.34	5.23
	122.0	5.75	5.77	5.75	5.67	5.75	5.74
Ammonium Sulfate	24.4	5.60	5.62	5.56	5.49	5.56	5.45
	122.0	5.80	5.77	5.71	5.66	5.79	5.68
LSD*		0.11	0.11	0.09	0.10	0.10	0.11
LSD**		0.15	0.15	0.13	0.14	0.14	0.16

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes the six consecutive days after treatment in 24-hour intervals
b = denotes log integrator peak area from IRGA analysis

Table 18. Analysis of variance summary for carbon dioxide evolution for time 1 (hour 1) in greenhouse thatch decomposition study 5a.

Factor	Level	Source of variation	Sampling dates[a] 1	2	3	4	5	6
			Log PA[b]					
Carrier	Lawn Restore[tm]		5.6	5.6	5.6	5.5	5.5	5.5
	C-50		5.6	5.6	5.6	5.5	5.5	5.5
	Ammonium Sulfate		5.7	5.7	5.6	5.6	5.7	5.6
Rate	24.4 kg N ha		5.5	5.5	5.5	5.4	5.4	5.3
	122.0 kg N ha		5.7	5.8	5.7	5.7	5.7	5.7
		Carrier	**	*	NS	*	**	NS
		Rate	**	**	**	**	**	**
		Carrier x Rate	NS	*	*	*	*	*
		LSD[c]	0.08	0.08	0.05	0.08	0.08	0.08
		LSD[d]	0.06	0.06	0.07	0.06	0.06	0.06

a = denotes the 6 consecutive days after treatment application
b = log integrator peak area
c = least significant difference carrier P = 0.05
d = least significant difference rate P = 0.05
*,** = denote differences at the 5% level and 1% levels respectively
NS = not significant

presented since time 2 AOV results were exactly the same as time 1 AOV results, only at higher carbon dioxide levels.

For time 1 (i.e., 1 hour after container closure), significant factor interactions were detected in 83% of analyses (N=6), all after day 1 (see Table 18). Of these differences, 20% were highly significant.

Highly significant differences in carbon dioxide evolution induced by carrier types averaged across rates of application, and rate of application induced differences when averaged over carrier types were detected in the majority of analyses. However, due to the presence of the interactions, rates of application differed depending on carrier type and vice versa.

Highest treatment related carbon dioxide evolution values (see Table 17) were on day 2 with decline thereafter. Values ranged from 5.80 to 5.23 (i.e., log peak area). There was a clear failure for carbon dioxide levels evolved in response to ammonium sulfate applications at the low rate of application (i.e., 24.4 kg N ha^{-1} per application) to be similar to those levels produced in response to application of the Ringer products at the low rate. Each Lawn Restore or C-50 carbon dioxide evolution measurement at the low rate was less than corresponding measurements of ammonium sulfate treated thatch in all detected interactions. The results indicated that ammonium sulfate was possibly more effective in providing the thatch/biomass system with easily available nitrogen, which narrowed C:N values enhancing microbial respiration. Since the available nitrogen pool was large, competition between turf plants and biomass was minimized. It was assumed that active plant uptake of N proceeded unimpaired and plant respiration increased. Where the Ringer products were applied (at the low rate),

Table 19. Mean log values of carbon dioxide evolution from Kentucky bluegrass thatch as influenced by applications of differing nitrogen carriers over one week at time 3 (hour 3) for greenhouse thatch decomposition study 5a.

Carrier treatment	Nitrogen rate per application	Sampling dates[a]					
		1	2	3	4	5	6
	$kg\ ha^{-1}$	Log PA[b]					
Lawn Restore™	24.4	5.51	5.61	5.40	5.38	5.51	5.54
	122.0	5.68	5.84	5.67	5.68	5.75	5.83
C-50	24.4	5.47	5.48	5.32	5.33	5.40	5.44
	122.0	5.78	5.83	5.71	5.75	5.84	5.90
Ammonium Sulfate	24.4	5.62	5.70	5.51	5.53	5.65	5.67
	122.0	5.82	5.86	5.69	5.74	5.88	5.89
LSD*		0.12	0.13	0.11	0.12	0.12	0.11
LSD**		0.16	0.18	0.16	0.16	0.16	0.15

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes the six consecutive days after treatment in 24-hour intervals
b = denotes log integrator peak area from IRGA analysis

nitrogen release was slower, competition between plants and biomass for free nitrogen was greater, thus each component of the system received less nitrogen for any given time. Plant uptake of nitrogen was assumed to be limited (compared to the ammonium sulfate treated units) so plant respiration was less. C:N ratios were theoretically widened, hence microbial respiration was lessened. This result was supported by observation of the treatment data at the high rate (i.e., 122.0 kg N ha^{-1} per application) of application when compared to the low rates. Less of a relative increase in thatch component respiration was seen in response to increased ammonium sulfate application when compared to the Ringer products. The physical addition of more added bio-organic material provided for slower release of more total nitrogen allowing an incresase in thatch component respiration. Higher rates of ammonium sulfate provided a larger free nitrogen pool, which was assumed subject to greater loss (i.e., leaching, denitrification, etc.). The slower release of more bio-organic nitrogen became as effective in providing free nitrogen in the system as quick release of greater amounts of ammonium sulfate. The size of the available nitrogen pool was considered important in regulating thatch respiration (20).

For time 3 (i.e., 3 hours after container closure, see table 19) significant factor interactions were detected in a majority of analyses. Simple effects of the factors differed and main effects were not considered good estimates of the true differences.

The same general trend (see table 19) toward the bio-organic treated thatch responding more to increases in rates of application were observed. However, a different trend time wise was discovered. As time increased (i.e., days after treatment application) so did carbon

dioxide evolution rates. The increasing carbon dioxide values within treatments across time was, more than likely, reflective of increased error in the analytical equipment due excess amounts of carbon dioxide. Results regarding rate and carrier type differences were identical to time 1.

When experimental units were measured for thickness (see table 20), a significant factor interaction was detected. Again simple effects differed by more than chance, and main effects were not good estimates of the differences. Therefore, differences in thickness due to carrier type were dependent on rates of application and vice versa. Thatch treated with Lawn Restore at the low rate of application (i.e., 24.4 kg N ha^{-1} per application) was significantly "thinner" than thatch treated with ammonium sulfate at the low rate. The effects of neither carrier differed at the high N rate (i.e., 122 kg N ha^{-1} per application). The size of the free nitrogen pool undoubtedly influenced thatch production. The data clearly show trends for decreasing thickness with low N rates and greater thickness with high rates, which may be a function of increased plant production. However, high rate treatments tended to be thinner than check plot thatch in field thatch decomposition study 4, indicative of some decomposition.

Study 5b

Regarding carbon evolution measurements, results and discussion of time 1 only (i.e., 1 hour after container closure) will be presented since AOV results for all times are the same. Treatment mean values were in milligrams of carbon evolved per liter of container atmosphere per hour (see table 21).

Table 20. Kentucky bluegrass thatch thickness values as influenced by application of differing nitrogen carriers for greenhouse thatch decomposition study 5a.

Carrier treatment	Nitrogen rate per application	Thickness
	kg ha^{-1}	— m^a —
Lawn Restore^{tm}	24.4	0.01280
	122.0	0.01640
C-50	24.4	0.01400
	122.0	0.02165
Ammonium Sulfate	24.4	0.01655
	122.0	0.01895
LSD*		0.003
LSD**		0.004

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes thatch thickness in meters

Table 21. Mean milligrams carbon evolved from Kentucky bluegrass thatch per liter of container atmosphere per hour of closed container atmosphere influenced by application of differing nitrogen carriers for time 1 (hour 1) in study 5b.

Carrier treatment	Nitrogen rate per application	Sampling dates[a] 0	1	2	3	5	7	11	17	31
	kg ha^{-1}	mg C L^{-1} hr^{-1}[b]								
Urea	0	2.04	2.12	2.20	2.77	1.57	1.76	1.42	1.48	1.25
	24.4	2.72	2.69	3.19	4.61	2.92	3.75	3.33	2.89	1.82
	122.0	4.15	3.19	4.32	5.93	4.46	4.22	3.90	3.52	2.87
C-50	0	1.91	2.05	1.92	2.55	1.46	1.73	1.48	1.54	1.39
	24.4	4.17	5.62	5.40	6.54	3.73	3.42	3.14	2.98	1.90
	122.0	5.33	7.93	8.15	10.61	5.99	5.29	4.89	4.80	3.39
Lawn Restore^{tm}	0	2.53	2.42	2.54	3.14	2.05	2.74	2.31	1.80	1.46
	24.4	3.42	4.26	4.53	5.29	3.33	4.11	3.54	2.69	1.82
	122.0	5.69	9.31	9.54	11.10	6.67	5.86	5.24	5.53	3.10
Lawn Rx^{tm}	0	1.99	2.08	2.24	2.63	1.44	1.75	1.45	1.67	1.15
	24.4	2.79	3.24	3.56	4.89	3.37	3.71	2.68	2.49	1.51
	122.0	5.18	7.01	8.04	10.77	6.49	6.04	5.03	4.85	3.39
LSD*		1.23	1.41	1.86	2.01	1.19	1.46	1.50	1.26	0.50
LSD**		1.67	1.92	2.52	2.72	1.62	1.98	2.04	1.71	0.68

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes time in days after treatments were applied, treatments were applied directly after day 0
b = denotes milligrams carbon per liter of container atmosphere per hour

Highly significant factor interactions were detected in 33% of the analyses (N=9 see Table 22). All detected interactions occurred during the three analyses directly after treatment application (i.e., days 1, 2 and 3). As the effect of the carriers decrease, so do the interactive effects.

The data show the failure of the effect produced in response to urea application to be similar to effects produced in response to the bio-organics, at the medium (i.e., 24.4 kg N ha^{-1} per application) and high rates (i.e., 122.0 kg N ha^{-1} per application). Urea treated thatch evolved significantly less carbon than any of the bio-organic treated thatch, in contrast to results obtained in study 5a. The reasons for the urea/ammonium sulfate treated thatch respiration differences were not determined but volatilization of ammonia may have been a part. It should be mentioned that the check rates in this study (i.e., no applied nitrogen) displayed the least amount of carbon evolution (see Table 21). This suggests that use of a particular source of nitrogen may change biomass ecology thereby influencing specie populations, ultimately affecting decomposition potential.

Carrier type induced differences (averaged over rates of application) in thatch carbon evolution occurred in 44% (N= 4 of 9) of total analyses, but none occurred after day 4 (see Table 22). Thus, carrier effects were different depending on rate of application since differences were detected when interactions occurred.

Rate of application induced differences in carbon evolution (see Table 22), averaged across carrier types, occurred in 100% of analyses. Thus, after the interactive effects, rates of application differed. Thatch at the high rate treatments (i.e., 122.0 kg N ha^{-1} per

Table 22. Analysis of variance summary for carbon evolution values for time 1 (hour 1) in greenhouse thatch decomposition study 5b.

Factor	Level	Source of variation	Sampling dates[c] 0	1	2	3	5	7	11	17	31
			mg C $L^{-1}hr^{-1}$[d]								
Carrier	Urea		3.0	2.7	3.2	4.4	3.0	3.2	2.9	2.6	2.0
	C-50		3.8	5.2	5.2	6.6	3.7	3.5	3.2	3.1	2.2
	Lawn Restore™		3.9	5.3	5.5	6.5	4.0	4.2	3.7	3.3	2.1
	Lawn Rx™		3.3	4.3	4.6	6.1	3.8	3.8	3.1	3.0	2.0
Rate	0.0 kg N ha		2.1	2.2	2.2	2.8	1.6	2.0	1.7	1.6	1.3
	24.4		3.3	4.0	4.2	5.3	3.3	3.7	3.2	2.8	1.8
	122.0		5.1	7.0	7.5	9.6	5.9	5.3	4.8	4.8	3.2
		Carrier	NS	**	**	**	*	NS	NS	NS	NS
		Rate	**	**	**	**	**	**	**	**	**
		Carrier x Rate	NS	**	**	**	NS	NS	NS	NS	NS
		LSD[a]	0.7	0.8	1.1	1.2	0.7	0.8	0.9	0.7	0.3
		LSD[b]	0.6	0.7	0.9	1.0	0.6	0.7	0.8	0.6	0.2

a = least significant difference for carrier P = 0.05
b = least significant difference for rate P = 0.05
c = denotes days after treatment application
d = denotes milligrams carbon per liter of container atmosphere per hour
*,** = significance at the 5% and 1% levels respectively
NS = not significant

application) evolved significantly more carbon per hour than thatch at the medium rates (i.e., 24.4 kg N ha^{-1} per application) which evolved significantly more carbon than thatch at the low rate treatments (i.e., no applied nitrogen).

When carbon evolution values (see Table 21) within treatment conditions for days 0 through 7 were averaged (thus effectively yielding average carbon evolution through the course of one treatment application cycle) gross estimations of treated thatch carbon turnover could be made (see Table 23). It was possible to estimate the total addition of applied carbon (through the carrier application to thatch) and since rates of thatch carbon evolution per hour and length of study were known (in hours), calculation of total carbon evolution for each treatment during the entire study was possible. When all added carbon (from the N carriers) was theoretically exhausted, it was assumed that a gross separation of thatch carbon and added product carbon could be estimated (by subtraction). Efficiencies based on the ratios of added carbon to total evolved carbon for each treatment were made. Since plant respiration, which increases with added nitrogen (5) was not corrected for, it was assumed that increases in respiration associated with higher nitrogen levels may have been reflective of some component plant respiration.

Carrier type induced differences in thatch thickness (see Table 24), averaged over rates of application, were detected at the 1% level. C-50-treated thatch measured significantly thicker than thatch treated with any other carrier.

Rate of application induced differences in thatch thickness, when averaged over carrier types, were detected at the 1% level. High rates

Table 23. Estimated carbon evolution from Kentucky bluegrass thatch as influenced by application of differing nitrogen carriers greenhouse thatch decomposition for study 5b.

Carrier treatment	N rate	Estimated Carbon Values					
		Carbon* evolution rate	Total carbon added	Total carbon evolved	Thatch carbon evolved	Carbon from carriers	Carbon from thatch
	kg ha^{-1}	mg C $L^{-1}hr^{-1}$	mg[a]			%	**
Lawn Restore[tm]	24.4	4.16	3240	17272	14032	18.8	81.2
	122.0	8.03	16200	33341	17140	48.6	51.4
Lawn Rx[tm]	24.4	3.59	3316	14906	11590	22.3	77.7
	122.0	7.26	16578	30144	13566	55.0	45.0
C-50	24.4	4.81	3110	19971	16861	15.6	84.4
	122.0	7.22	15552	29977	14425	51.9	48.1
Urea	24.4	3.31	297	13743	1345	2.0	98.0
	122.0	4.38	1485	18186	16700	8.2	91.8
Check	0.0	2.15	0	8927	8927	0.0	100.0

* = mean treatment induced rate in mg carbon L^{-1} hr^{-1}
** = percentage of carbon estimated from carrier contribution and thatch contribution
a = denotes mg carbon evolved over the life of the study
b = denotes check values were averaged across all carriers

Table 24. Mean Kentucky bluegrass chemical and physical thatch variable response to repeated nitrogen carrier application for greenhouse thatch decomposition study 5b.

Carrier treatment	Nitrogen rate per application	Variables[a]			
		Thickness	Cellulose	Lignin	Ash
	kg ha^{-1}	— M —		%	
Lawn Restore™	0	0.0075	15.7	22.0	8.5
	24.4	0.0084	12.9	19.4	22.3
	122.0	0.0149	14.1	22.8	14.7
Lawn Rx™	0	0.0064	13.9	21.0	11.2
	24.4	0.0080	12.8	22.1	14.5
	122.0	0.0149	16.4	18.8	20.8
C-50	0	0.0095	16.5	22.6	9.1
	24.4	0.0136	14.5	18.3	24.5
	122.0	0.0193	17.9	20.5	12.7
Urea	0	0.0078	14.9	20.9	11.0
	24.4	0.0064	13.2	26.4	9.3
	122.0	0.0152	14.8	22.5	17.2
LSD*		0.003	NS	NS	NS
LSD**		0.004	NS	NS	NS

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes thatch thickness in meters and percent by weight cellulose, lignin and ash

of application, regardless of carrier types, retained significantly more thatch than thatch treated at the low rate or the zero rate. Check treatment thatch tended to be "thinner" than thatch treated at the low rate (i.e., 24.4 kg N ha^{-1} per application), but differences were not significant. Values ranged from 0.0193 M to 0.0078 M, somewhat "thinner" than thicknesses measured in field thatch decomposition study 4 but consistent with values reported in greenhouse study 5a.

No differences of any kind were detected in cellulose, lignin and organic matter determinations (see Table 24). It was thought that since check and low application rates produced a very thin thatch, muck underlying the thatch interfered with the determinations. This confounding was not seen in the field study 4 fiber measurements because the thinnest field thatch was not comparably reduced in thickness. The underlying muck was able to be discarded more effectively in field thatch samples and consequently did not interfere in the determinations.

In summary, it was apparent that in both studies 5a and 5b, high rates of nitrogen carriers produced high levels of respiration (plant and biomass) but allowed thatch to remain significantly thicker. Lower levels of nitrogen did not produce as much respiration but thatch thickness decreased significantly. Non treated checks evolved the least amount of carbon but tended to be the most decomposed. Urea treated thatch had less total added carbon applied but no differences in evolution between the carrier types were detected. Urea efficiency was thus greater. Therefore, as rates of added nitrogen or carbon increased, thatch carbon decay efficiency decreased. As rates of added nitrogen or carbon were less, thatch decay efficiency increased. In treatments where no added carbon or nitrogen was applied, rates of

carbon evolution were smallest but efficiency in producing thatch decay was greatest. Hence, it may be concluded that the indigenous thatch microbial populations were more efficient in encouraging decay when given environmental conditions more conducive to decay. The bio-organics were effective in encouraging decay when applied lightly and frequently but excessive application may have been conducive to retaining thatch.

Isotope Study #6

Decay values (dps) for each sampling date and subsequent decay curve half lives for each experimental unit were obtained and curve peeling analysis was performed on each curve to identify tissue components and subsequent rate constants.

Results from the analyses (see Table 25 and 26) suggested that soil types initially influenced rates of plant tissue decay more than did carrier types. When soil was added to the decay system, higher rates of carbon evolution were detected than when sand was used alone. Even though analyses suggest the sand + soil conditions to be more effective in decaying plant tissue, a trend began (with all 3 nitrogen carriers) for carbon evolution in the sand + soil condition to become "inhibited" and for carbon evolution in the sand only condition to become

Table 25. Analysis of variance summary for carbon isotope decay values for isotope study 6.

Factor	Level	Source of Variation	Sampling dates[c] 1	2	3	4	5	6	7	11	14
			dps[d]								
Carrier	Lawn Restore[tm]		1834	1874	1006	894	784	568	565	307	253
	Milorganite[tm]		1576	2004	1040	954	850	563	490	274	235
	Blank[e]		2018	1775	1038	941	796	528	485	351	292
Soil	Sand		849	1956	961	815	641	426	392	221	213
	Sand & Soil		2777	1813	1095	1044	979	680	635	400	307
		Carrier	*	NS	NS	NS	NS	NS	*	NS	NS
		Soil	**	NS	*	**	**	**	**	**	**
		Carrier x Soil	NS	**	NS	NS	NS	NS	NS	NS	NS
		LSD[a]	316	309	157	112	94	75	70	80	49
		LSD[b]	258	252	128	91	76	62	57	65	40

a = least significant difference for carriers P = 0.05
b = least significant difference for soils P = 0.05
c = denotes time in days after initial treatment application
d = disintegrations per second
e = treatments in which no No carrier was applied
*,** = significance at 5% and 1% levels respectively
NS = not significant

Table 25 (cont'd.).

Factor	Level	Source of variation	Sampling dates[c] 20	27	29	30	31	32	55
			dps[d]						
Carrier	Lawn Restore[tm]		152	93	155	123	114	86	72
	Milorganite[tm]		138	96	139	124	118	98	37
	Blank[e]		192	115	113	110	115	111	62
Soil	Sand		149	114	125	119	120	101	73
	Sand & Soil		172	89	146	119	112	96	41
		Carrier	**	NS	*	NS	NS	*	**
		Soil	*	**	NS	NS	NS	NS	**
		Carrier x Soil	**	**	**	**	**	**	NS
		LSD^a	24	20	26	26	24	15	16
		LSD^b	20	16	22	21	20	12	13

a = least significant difference for carriers P = 0.05
b = least significant difference for soils P = 0.05
c = denotes time in days after initial treatment application
d = disintegrations per second
e = treatments in which no N carrier was applied
*,** = significance at the 5% and 1% levels respectively
NS = not significant

Table 26. Mean wheat straw 14-carbon decay values in disintegrations per second for each sampling date as influenced by nitrogen carrier application for isotope study 6.

Carrier treatment	Soil type	Sampling dates[a] 1	2	3	4	5	6	7	11	14	20
		dps[c]									
Lawn Restore[tm]	sand	900	1737	946	845	675	436	411	206	172	111
	sand & soil	2789	2013	1068	943	895	701	719	409	335	194
Milorganite[tm]	sand	670	2279	967	798	640	438	387	191	209	150
	sand & soil	2483	1730	1113	1111	1060	689	594	357	261	126
Blank[b]	sand	977	1854	971	803	609	406	378	267	258	187
	sand & soil	3059	1697	1106	1079	984	652	594	435	326	199
LSD*		447	437	221	157	132	107	99	112	69	33
LSD**		613	599	304	216	181	146	135	154	95	46

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes time in days from onset of carrier application
b = denotes treatments in which no N carrier was added
c = disintegrations per second

Table 26 (cont'd.).

Carrier treatment	Soil type	Sampling dates[a] 27	29	30	31	32	55
		dps[c]					
Lawn Restore[tm]	sand	86	122	91	91	71	95
	sand & soil	100	189	155	138	102	50
Milorganite[tm]	sand	133	163	164	150	119	48
	sand & soil	59	116	85	86	78	26
Blank[b]	sand	121	92	104	118	114	75
	sand & soil	109	135	116	112	107	48
LSD*		28	37	36	34	21	22
LSD**		39	51	50	47	29	31

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = denotes time in days from onset of carrier application
b = denotes treatments in which no N carrier was added
c = disintegrations per second

"enhanced." Determination of the half life for each total decay curve and subsequent curve peeling analysis (47) of plant tissue fractions within each supported the trend (see Tables 27 and 28 and Figures 2 through 7). Resistant plant tissue in sand became more conducive to decay on a longer term basis. Data would further suggest that the use of Milorganite, especially in the sand + soil produced an "inhibition" to rate of tissue decay. In the sand only treatments, plant tissue under Milorganite had a half life generally equivalent to other sand treatment conditions but curve peeling analysis suggested that, even in sand, Milorganite had a pronounced effect in subduing decay compared to other treatments. The use of Lawn Restore did not enhance decay rates significantly over the untreated units (blanks), but did resist the previously described trend the longest.

Caution should be used in interpreting the statistical interactions seen in Table 25. Biological interactive effects were statistically significant but very subtle. The statistical interactions showed the slow onset of the sand + soil induced "inhibition" to decay (or the sand "enhancement "). Once easily degradable plant tissue constituents decayed (i.e., after day 14), carbon turnover as influenced by carrier type depended on soil type and vice versa. There was a trend for plant tissue incorporated in Milorganite treated sand to decay significantly more labelled carbon than in either Milorganite treated sand + soil or other equivalently treated sand conditions. There was also a trend for plant tissue in Milorganite treated sand + soil to evolve less labeled carbon than in either of the other sand + soil conditions. Specifically, when interactions were detected (N = 7 of 16), differences in rates of labelled carbon decay between Lawn Restore and Milorganite treatments

Table 27. Decay curve mean half lives, rate constants and coefficients of determination as influenced by nitrogen carriers and soil types for isotope study 6.

Carrier type	Soil type	C_o	k^d	$T_{\frac{1}{2}}{}^c$	R^{2b}
			- day^{-1} -	- da -	
Lawn Restore™	sand	88.0	0.0089	80.4	0.86
	sand & soil	79.2	0.0156	45.8	0.83
Milorganite™	sand	73.3	0.0095	73.3	0.83
	sand & soil	59.1	0.0117	59.1	0.75
Blank™	sand	66.4	0.1400	66.4	0.84
	sand & soil	45.1	0.0154	45.1	0.82
LSD*				14.7	
LSD**				20.2	

* = least significant difference P = 0.05
** = least significant difference P = 0.01
a = treatments in which no N carrier was applied
b = coefficient of determination
c = half life in days
d = rate constant ($days^{-1}$)

Table 28. Percent labeled carbon remaining in soil at time (t.) influenced by applications of differing nitrogen carriers for isoptope study 6.

Carrier treatment	Soil type	Tissue Fractions*								
		F1			F2			F3		
		%								
Lawn Restore^{tm}	sand	C	=	$79.3e^{-0.0056t.}$	+	$23.1e^{-0.3303t.}$				
	sand & soil	C	=	$53.8e^{-0.0043t.}$	+	$38.5e^{-0.1417t.}$	+	$8.6e^{-0.7034t.}$		
Milorganite^{tm}	sand	C	=	$68.8e^{-0.0030t.}$	+	$29.3e^{-0.1756t.}$				
	sand & soil	C	=	$58.9e^{-0.0019t.}$	+	$40.8e^{-0.1842t.}$				
Blank^{a}	sand	C	=	$72.7e^{-0.0048t.}$	+	$28.1e^{-0.1553t.}$				
	sand & soil	C	=	$53.3e^{-0.0042t.}$	+	$35.4e^{-0.1288t.}$	+	$19.6e^{-0.4200t.}$		

* = denotes tissue components in order of increasing ease of decay (ie. F1 would be lignin and microbial bodies, F2 would be lignocellulose and F3 would be simple sugars)
** = corresponds to amount of carbon 14 remaining at time t.
a = denotes treatments in which no N carrier was added

Figure 2. Percent of ^{14}-C label remaining in sand and subsequent curve peeling analysis as influenced by Lawn Restore.

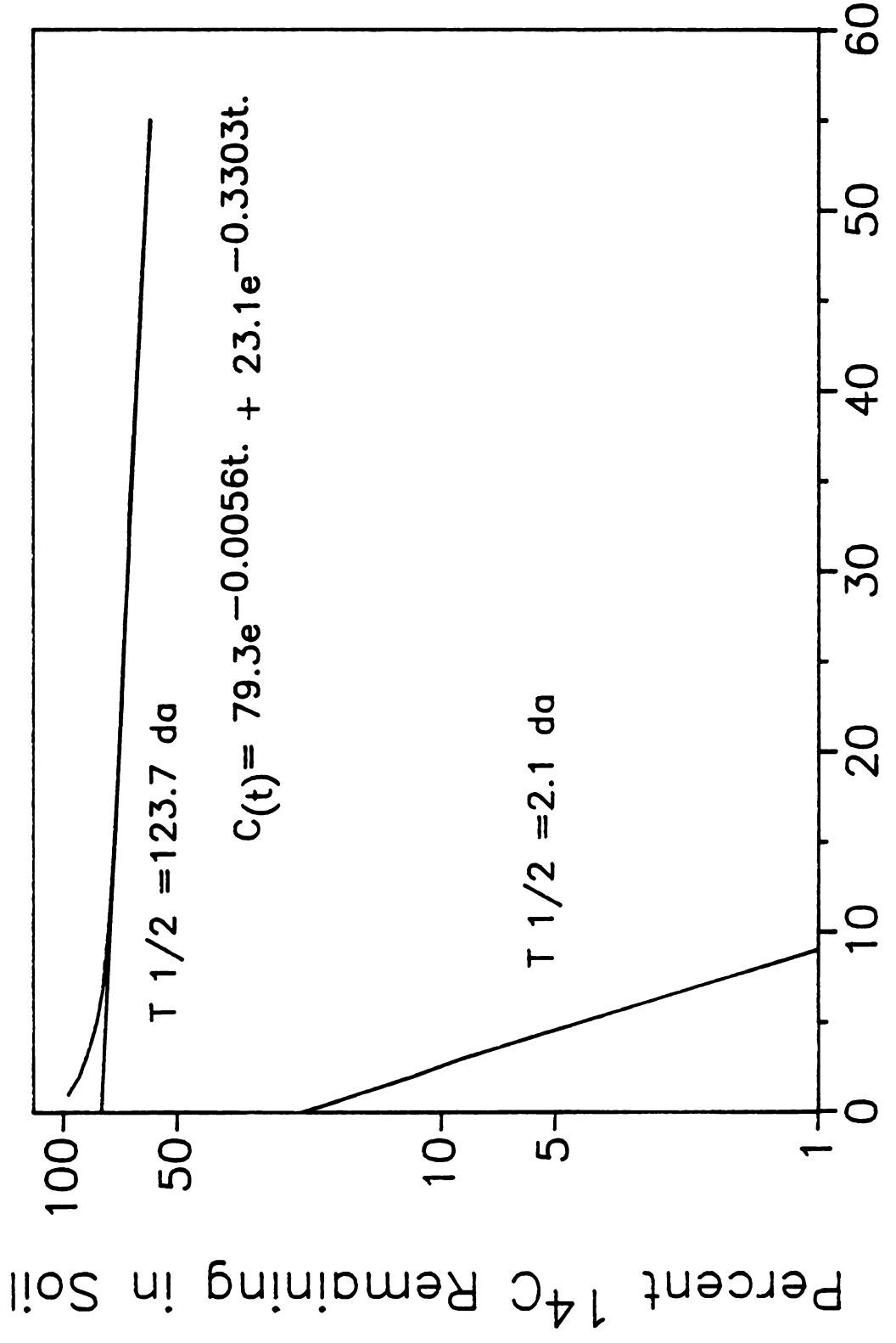

Percent ^{14}C Remaining in Soil
100
50
10
5
1
0
10
20
30
40
50
60
Time (days)
T 1/2 =123.7 da
C(t)= 79.3e$^{-0.0056t.}$ + 23.1e$^{-0.3303t.}$
T 1/2 =2.1 da

Figure 3. Percent of ^{14}-C label remaining in sand + soil and subsequent curve peeling analysis as influenced by Lawn Restore.

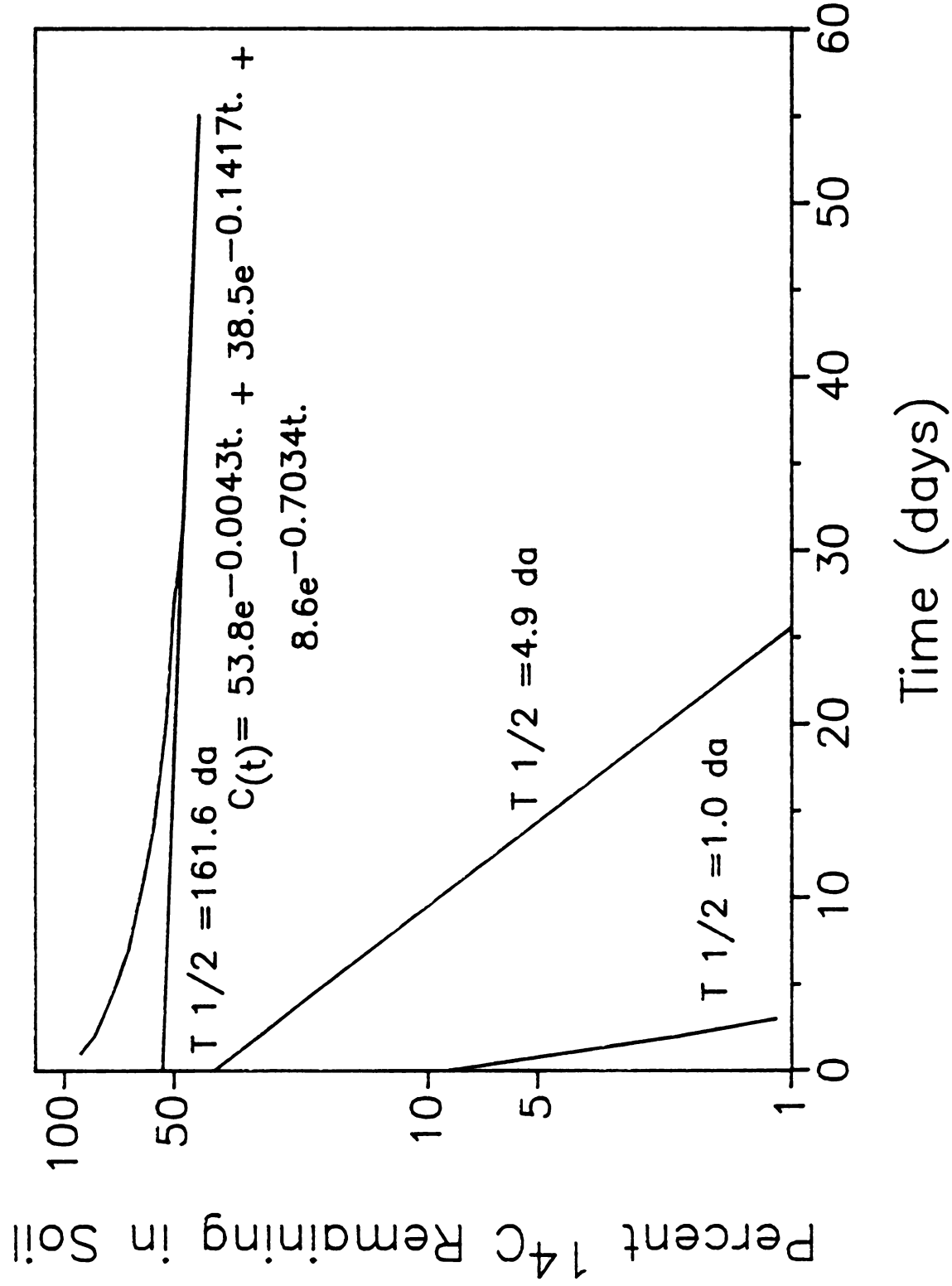

Percent ^{14}C Remaining in Soil
100
50
10
5
1
0
10
20
30
40
50
60
Time (days)
T 1/2 =161.6 da
C(t)= 53.8e$^{-0.0043t.}$ + 38.5e$^{-0.1417t.}$ +
8.6e$^{-0.7034t.}$
T 1/2 =4.9 da
T 1/2 =1.0 da

Figure 4. Percent of ^{14}-C label remaining in sand and subsequent curve peeling analysis as influenced by Milorganite.

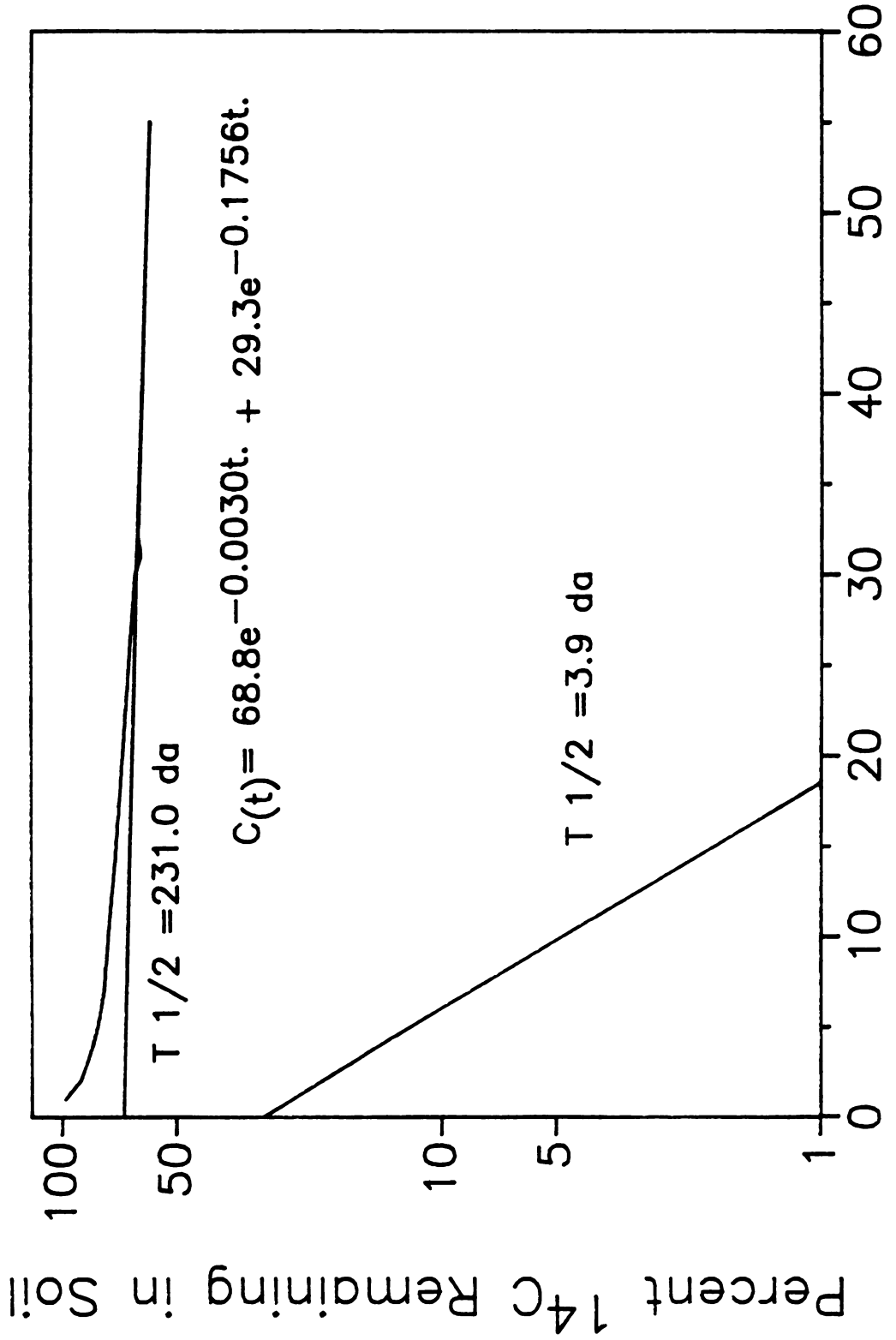

Percent ^{14}C Remaining in Soil
100
50
10
5
1
0
10
20
30
40
50
60
Time (days)
T 1/2 =231.0 da
C(t)= 68.8e$^{-0.0030t.}$ + 29.3e$^{-0.1756t.}$
T 1/2 =3.9 da

Figure 5. Percent of ^{14}-C label remaining in sand + soil and subsequent curve peeling analysis as influenced by Milorganite.

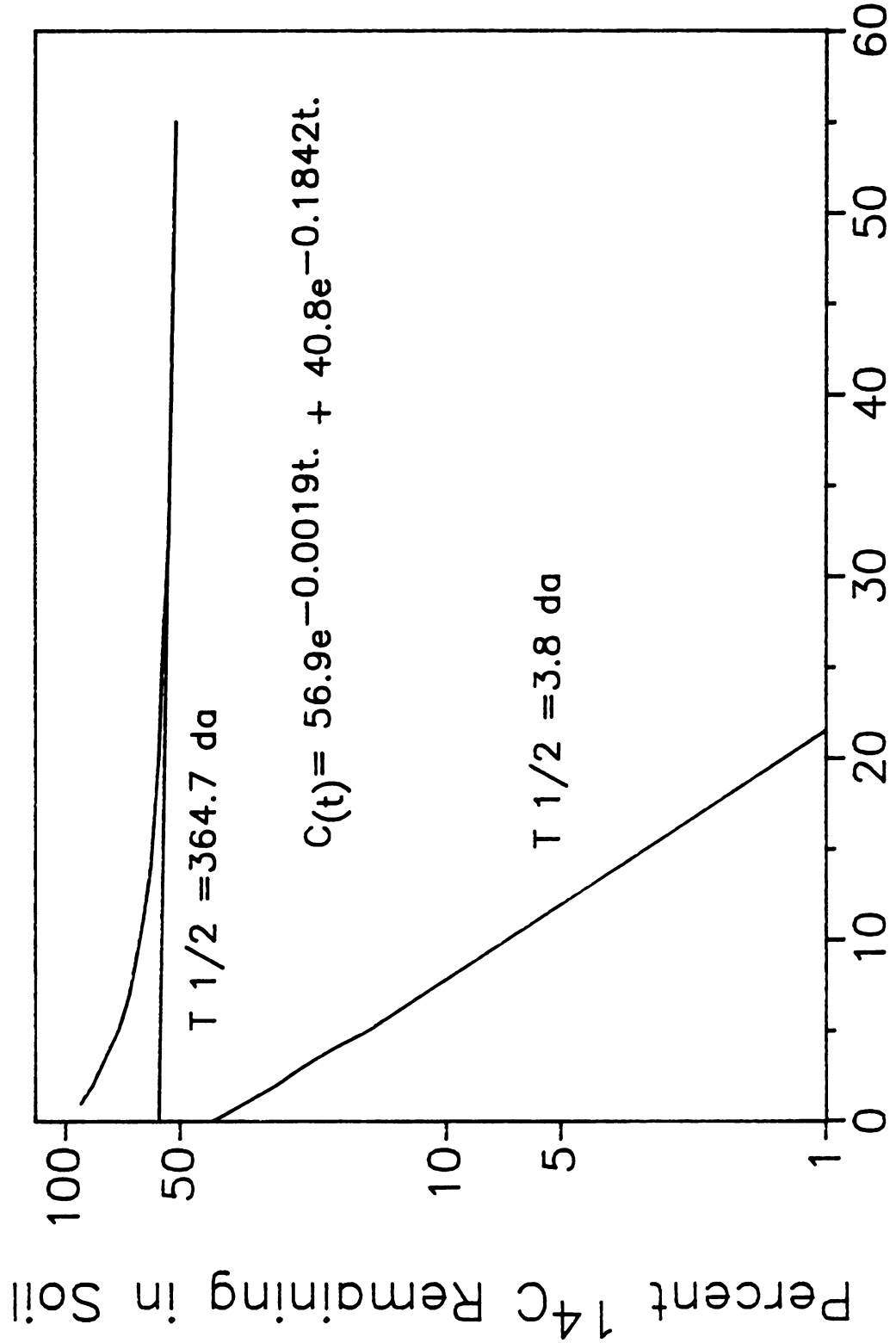

Percent ^{14}C Remaining in Soil
100
50
10
5
1
0
10
20
30
40
50
60
Time (days)
T 1/2 =364.7 da
C(t)= 56.9e$^{-0.0019t.}$ + 40.8e$^{-0.1842t.}$
T 1/2 =3.8 da

Figure 6. Percent of ^{14}-C label remaining in sand and subsequent curve peeling analysis as influenced by non-treatment (i.e., no applied N).

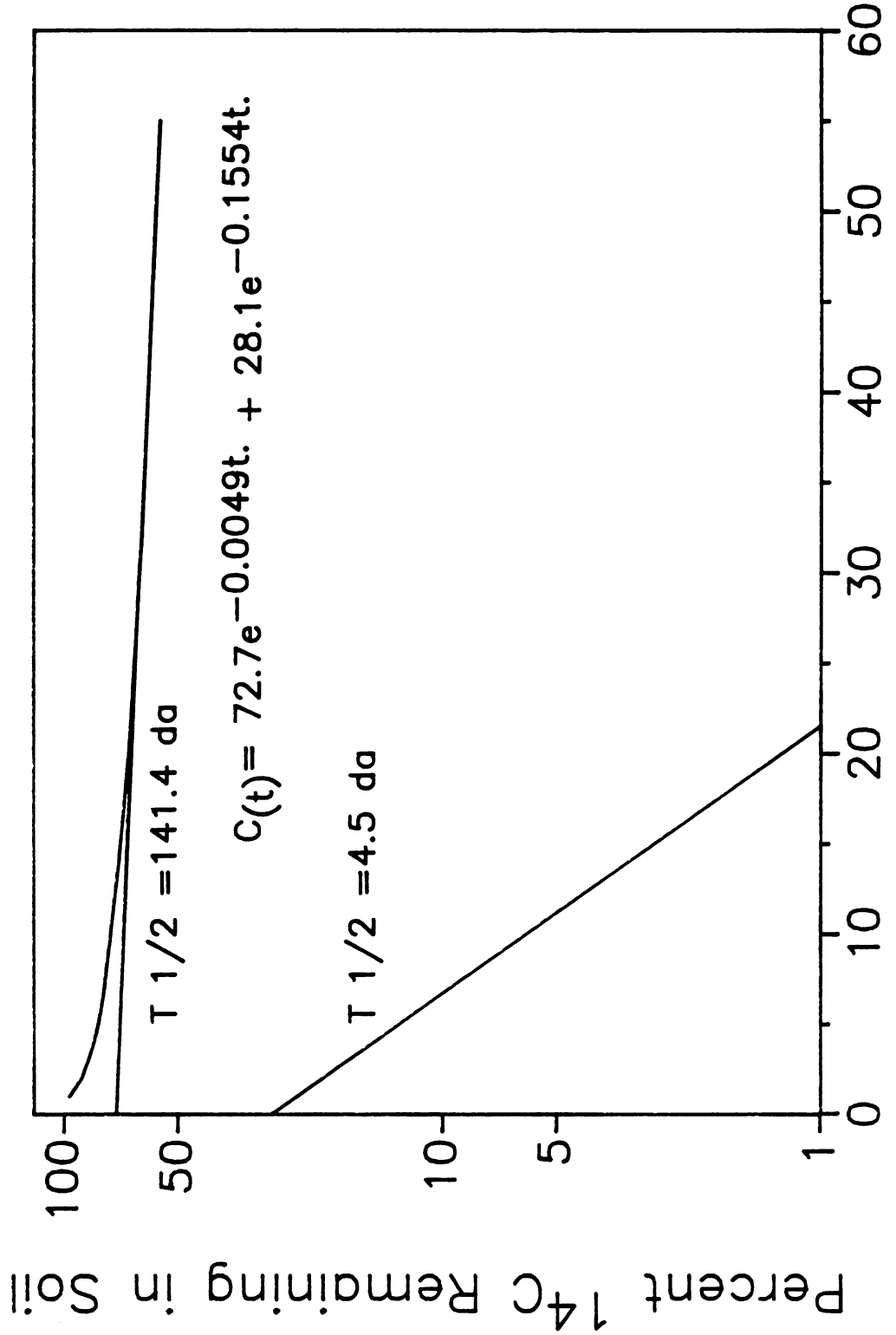
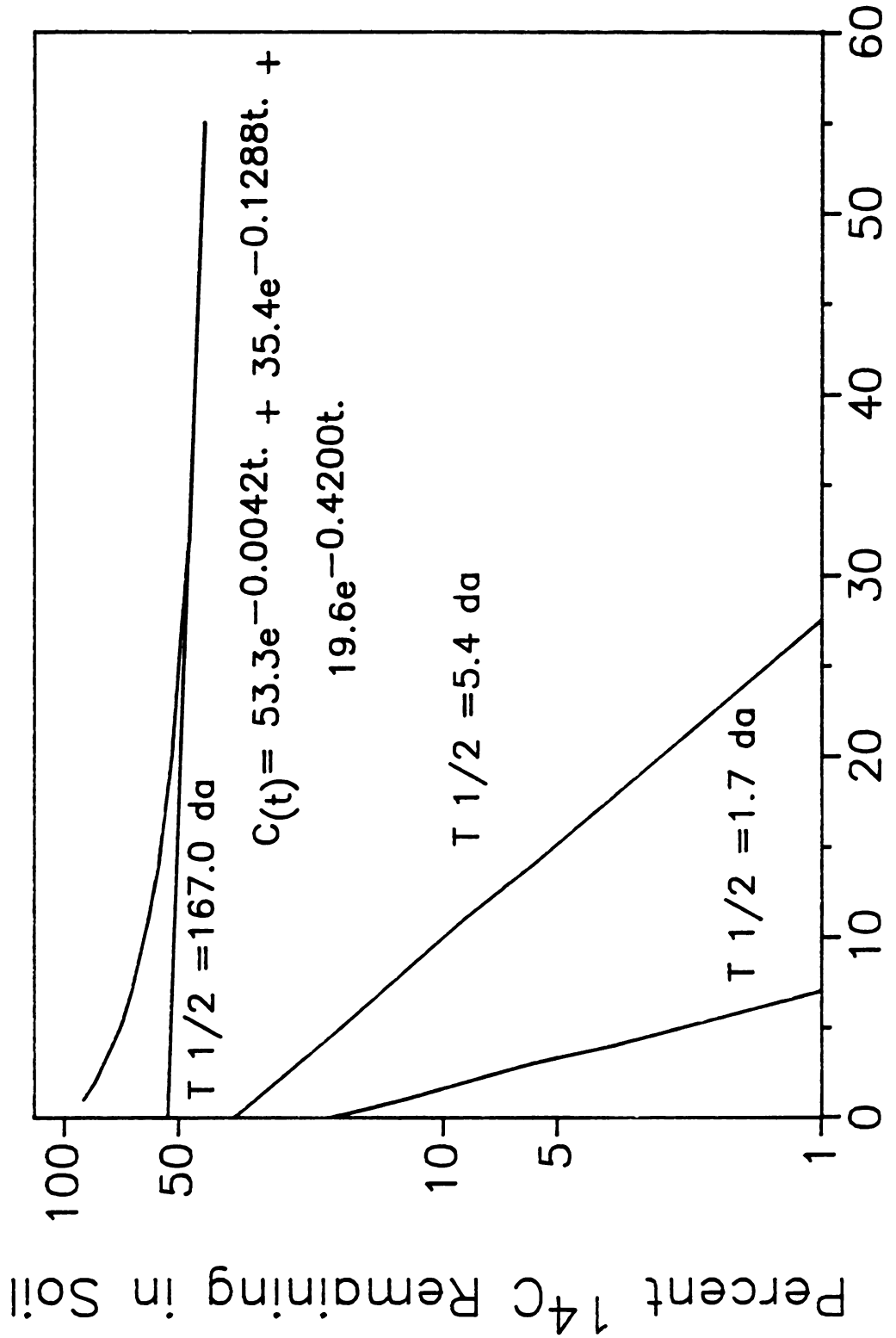

Percent ^{14}C Remaining in Soil
100
50
10
5
1
0
10
20
30
40
50
60
Time (days)
T 1/2 =141.4 da
T 1/2 =4.5 da
C(t)= 72.7e$^{-0.0049t.}$ + 28.1e$^{-0.1554t.}$

Figure 7. Percent of ^{14}-C label remaining in sand + soil and subsequent curve peeling analysis as influenced by non-treatment (i.e., no applied N).


Percent ^{14}C Remaining in Soil
100
50
10
5
1
0
10
20
30
40
50
60
Time (days)
T 1/2 =167.0 da
$C(t) = 53.3e^{-0.0042t.} + 35.4e^{-0.1288t.} + 19.6e^{-0.4200t.}$
T 1/2 =5.4 da
T 1/2 =1.7 da

(in the sand condition) occurred in all cases with Milorganite influenced rates always higher. In the sand + soil condition , differences in carbon decay between Lawn Restore and Milorganite were detected in 87% of analyses with Lawn Restore influenced decay values ranked significantly higher than Milorganite influenced values. When compared to rates of carbon decay produced by the untreated blank treatments (in sand), differences to Lawn Restore treatments were seen in 57% of analyses with Lawn Restore influenced values significantly higher 75% of the time. Differences between Milorganite treatments and the blank treatments (in sand), were detected in 43% of analyses with Milorganite influenced treatments ranked higher 33% of the time. In sand + soil comparisons, LSD differences in rates of labelled carbon turnover occurred in 29% of analyses with Lawn Restore values significantly higher than blank values which were significantly higher than Milorganite values consistently.

When no interactions were detected, soil types were highly significant in influencing rates of labelled plant carbon turnover. The trend was for sand + soil treatments to evolve significantly more labelled carbon than sand treatments, when averaged over carrier types. Thus, soil added to sand was initially effective in enhancing decay rate. Carrier types, when averaged over soils seldom differed in rates of carbon turnover (see tables 25 and 25 cont'd.).

The complex interactive response effects (see Figures 2 through 7 and Table 27) were seen quite clearly when treatments averaged over replications were plotted graphically as log of percent of the label remaining in soil against time. It should be emphasized that the derived curves were not the true decay curves since microbial

assimilation of the label and subsequent decay added a substantial amount (i.e., dps) to each curve. Paul (47) cites microbial assimilation efficiencies of 20% to 60% depending on tissue component. Comparison of the figures shows a distinct suppression of plant carbon decay in Milorganite treated sand + soil when compared to sand + soil treated by the other carriers. Approximately 16% more label remained under the Milorganite treated soil. The blank sand + soil treatment and the Lawn Restore sand + soil treatments did not appear to differ. Sand type treatments averaged over carrier types did not appear to differ. The percent of label remaining in the sand was, on the average, 21% more than in the sand + soil condition.

Rate of decay constants and subsequent half lives derived from each exponential curve (see table 27) were calculated and subjected to analysis of variance. Results indicated that plant tissue incorporated in Milorganite treated sand tended to have a half life equivalent to tissue in other sand conditions, supporting previous data (see Tables 25 and 26). Plant tissue in the untreated units had the shortest sand influenced half life, but differences were not detected. However, plant tissue in Milorganite treated sand + soil had a significantly longer half life than tissue in other equivalent sand + soil conditions, indicative of suppressed decay. In the analysis, no interactive effects or carrier type induced differences in labelled carbon turnover were detected. Soil type induced differences were, however, considered highly significant with sand + soil conditions averaged over carrier types being significantly higher in rates of labelled carbon turnover than the sand conditions.

Previous data based on carbon dioxide trapping and decay curve half

life analyses (see Tables 25 and 26), is somewhat misleading. Data suggested that carrier type did not influence carbon turnover as much as soil type, with exception to Milorganite. When carrier type induced effects were different, interactions ensued and a response effect dependency with soil was observed. Therefore, effect of carrier type depended on soil type and vice versa. Sand + soil treatments tended to enhance plant decay compared to straight sand, with exception to Milorganite treated sand + soil. However, close scrutiny of the carbon evolution data and curve peeling analysis (see Paul, 47) of the decay curves suggest that longer term turnover of resistant plant tissue fractions were enhanced in the sand situation, particularly in the Lawn Restore and blank treatments (see tables 26 and 28 and figures 2 through 7). Data in table 26 show the trend for Milorganite treated sand (initially lacking in carbon turnover influence) to become more conducive to labelled tissue decay. As time progressed (i.e., past day 20), the influence became more substantial, and the same trend began for both untreated blank and Lawn Restore treatments. Data in Table 28 (also see Figures 2 through 7) reflect this trend. Derived equations were similar to those published by Voroney (70) regarding wheat tissue residue decay, but k values were higher than those reported for maize residue decay. Rate constant values (k) of fraction 1 (i.e., lignin and microbial bodies) for sand conditions, averaged over carrier types, tended to be higher than the sand + soil rate constants. This suggested that in longer term resistant fraction decay, sand was possibly becoming more conducive to decay or that the added soil had a subduing effect. It also appeared that regardless of soil type, plant tissues under Milorganite treatments had longer half lives than tissue under other

carriers (for fraction 1).

The reasoning for the Milorganite induced "inhibition" in plant carbon decay was never adequately determined. A reasonable explanation was that Milorganite, especially in conjunction with soil, was chemically binding labelled tissue decay intermediates. Previous research (47) showed that, in decay, labelled cellulose and lignin were cleaved first to phenolic compounds and eventually to non-hydrolyzable fractions of humic acid. It was shown that proteins could be stabilized by adsorption to soil humic substances and it was also demonstrated that a substantial portion of the lignino-cellulose decay intermediates were present in microbially produced proteins and polysaccharides (47). Since Milorganite is partially decayed (i.e., assumed high in humic substances), it is reasonable that a portion of the labelled tissue decay intermediates (phenols and proteins) could bind to the Milorganite (and humic constituents in soil), but evidence for this in our study was not obtained. The fact that the Milorganite sand + soil treatments had the longest half life (see Table 27) and resistant fractions within other sand + soil treatments regardless of carrier also had smaller relative rate constants compared to sand only treatments (see Tabes 28) is supportive.

In conclusion, when soil was added to the sterile unwashed sand, the combination initially was more conducive to enhancing decay of easily degradable plant tissue. As time progressed, soil decay effects on plant tissue waned (or the soil had a subtle binding influence on decay products) and tissue in sand became more conducive to enhanced rate of decay since the binding effect did not occur. Lawn Restore did not enhance tissue decay over the untreated blank treatments but was more

effective in enhancing decay than was Milorganite. Milorganite treated soils, regardless of type, showed slower rates of tissue decay. Reasoning for the result was physical/chemical binding of phenolic decay substances to the already partially decayed Milorganite.

CONCLUSIONS

The Ringer Corporation products Lawn Restore, Lawn Rx and C-50 demonstrated the capability to be as effective in providing an adequate degree of nitrogen response as sulfur coated urea, but were not as effective as soluble urea. Kentucky bluegrass turf treated *in situ* with Ringer's products scored favorably on test variables such as visual quality, percent tissue nitrogen, tissue chlorophyll concentration and clipping yield when compared to the coated carrier.

Application of the products to thatched Kentucky bluegrass turf *in situ* effected changes in the thatch, such as decreased thickness, increased water retention, increased lignin accumulation, increased bulk density and increased earthworm activity in one years time. Rates of product application used in the field study were considered excessive by conventional standards but were necessary since experimental time was limited. It was not adequately determined whether the products *per se* effected the changes or whether increased earthworm activity was responsible. It appeared that the contribution from the worm activity may have been substantial.

Application of the products (and other carriers such as urea or ammonium sulfate) to thatched Kentucky bluegrass *in vitro* effected

an increase in carbon dioxide evolution with increasing rates. It was not determined whether the plant or the biomass respiration was enhanced, but both were assumed to be affected. Higher rates of applied nitrogen and carbon (from the products) were associated with higher rates of carbon dioxide evolution but allowed thatch to remain thicker than thatch treated at the lower rates or untreated control units, suggesting that nitrogen may be causative in thatch accumulation or retention. Untreated controls were assumed to be more efficient in allowing thatch to decay than thatch treated with any carrier, when given a more proper environment, since controls were the most highly decomposed.

Application of Lawn Restore to ^{14}-C labelled wheat straw *in vitro* did not enhance decay over untreated (blank) units but did increase rate of decay compared to Milorganite treated units regardless of soil type. Binding of phenolic decay intermediates to humified Milorganite (and humic substances in the sand + soil conditions) was reasoned to be causative.

As a general conclusion, the Ringer products are acceptable turfgrass amendments, providing nitrogen and enhancing thatch decomposition. More research in the thatch decomposition area is needed to furthur substantiate the long term effects of the amendments to soil and turf.

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