ABSTRACT

FACTORS AFFECTING THE HEATING AND DAMAGE OF MERION KENTUCKY BLUEGRASS (Poa pratensis L.) SOD UNDER SIMULATED SHIPPING CONDITIONS

By

John William King

Merion Kentucky bluegrass sod may heat and be damaged during shipment from commercial production fields to market.

The effects of cutting height, nitrogen rates, and N^6benzyladenine treatments on sod heating and damage were investigated under simulated shipping conditions in a series of experiments. Shipping conditions were simulated by stacking 12 sod pieces in insulated plywood boxes (20 inches square by 30 inches deep) and placing 255 lb of weight over the sod. Temperature, carbon dioxide, oxygen, and ethylene levels within the sod stacks were measured. Sod pieces were removed from the boxes at 24 hour intervals. Six inch diameter plugs were transplanted to pots in the greenhouse. Percent leaf kill, percent leaf cover, and root organic matter production data were obtained.

The effects of carbon dioxide, oxygen, and ethylene were investigated in controlled atmosphere studies. Sod pieces were removed from the chambers at 24 hour intervals and transplanted to pots in the greenhouse. Percent leaf kill, percent leaf cover, and root production data were obtained.

Inhibition of respiration from oxygen starvation or from high carbon dioxide levels was not a cause of sod injury. Carbon dioxide levels increased to 13 to 19% and oxygen levels decreased to 2 to 5% during storage under simulated shipping conditions. Controlled atmosphere studies showed that sod survived longest when stored at 18% carbon dioxide and 2% oxygen. The respiration rate of sod cut at 2 inches averaged 74 ml CO_2/kg/hr.

The decreases in total available carbohydrate levels were well correlated with increases in percent leaf kill and decreases in root production for a sod heating box experiment conducted late in the season. Carbohydrate levels were not reduced to a consistent low level before sod death occurred for sod stored in controlled atmospheres at 104 and 83° F. Available carbohydrates were not exhausted in either experiment. Direct high temperature injury occurred at 104° F.

Ethylene production is not a factor affecting sod injury in commercial sod loads. High ethylene production (2 to 5 ppm) occurred where high rates of nitrogen were applied. The ethylene production was usually less than 2 ppm where normal levels of nitrogen (150 lb/A/yr) were applied. Controlled atmosphere studies showed that a sharp decrease in root production occurred between 2 and 4 ppm of ethylene. Ethylene production was independent of temperature.

N^6benzyladenine, a respiration inhibitor, did not affect carbon dioxide and oxygen levels, temperature, or injury of sod during storage.

Root production was higher for sod produced with below normal nitrogen fertilization. The application of a very high rate of nitrogen (215 lb/A) within a few days before harvest resulted in more injury and less root production than for sod produced with normal (150 lb/A/yr) nitrogen fertilization.

Sod cut at 0.75 inch within a few days before harvest survived storage longer than sod cut at 2 inches. The low cutting treatment reduced respiration rate and temperature levels during storage and resulted in reduced percent leaf kill and increased root production.

Sod injury increased progressively in relation to increased temperature levels occurring during storage. Sod survived 5 days with less than 10% leaf kill where storage temperature reached only 87° F. The percent leaf kill reached 80 to 90% after 3 to 4 days of storage where storage temperatures reached 95° F. The rate of sod injury was greater relative to temperature in early June when maximum seedhead production occurred and in early August when soil temperatures were higher. Ventilation tubes inserted into commercial sod loads did not reduce temperature effectively. High temperature was the most important cause of sod injury.

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INTRODUCTION

Commercial sod production is Michigan's fifth ranking agricultural crop in terms of economic return. Eighty-five percent of the sod acreage is on organic soil. Marketable sod can be produced in a shorter period of time on organic soils than on mineral soils. Also, the shipping weight of sod grown on organic soil is less than for sod grown on mineral soil. Michigan has a longer effective growing season for Kentucky bluegrass sod than other nearby states since the moderating influence of Lake Michigan results in cooler midsummer temperatures than in other mid-western states. Major urban population centers within Michigan, Ohio, and other nearby states provide an accessible market for Michigan grown sod. It has been estimated that in 1966 the Michigan commercial sod crop comprised more than 20,000 acres with an annual gross income of over $26 million to the commercial sod producers (Beard and Hogland, 1966).

Commercial sod heats in the load during shipment from production fields to market. Sod heating damage is more likely to occur during periods of seedhead production in late May and early June or during periods of unusually hot, humid weather in midsummer. Since many sod loads are lost each year because of sod heating, the development of techniques of harvesting and shipping which enable sod to survive longer under load conditions is of importance to growers.

The objectives of this research were (1) to describe the sod heating process, (2) to evaluate cultural practices which affect sod heating in the load, and (3) to delineate the mechanisms involved in sod heating injury.

REVIEW OF LITERATURE

The experiments reported in this thesis are the first detailed observations and scientific studies of sod heating or spoilage in the load. Therefore, no scientific literature on this topic exists.

Literature citations of the analytical procedures utilized will be cited in methods and materials section of this thesis. Also, some literature citations covering general principles of plant physiology will be made in the results and discussion sections.

DEVELOPMENT OF METHODS

The two basic problems involved in developing suitable research methods were (1) developing an experiment apparatus or unit which simulated commercial sod load conditions during shipment, and (2) quantitatively measuring temperature and gaseous changes during storage, and sod recovery after storage. Methods used to solve these problems evolved gradually while many experiments were being conducted.

1966 Season

Investigations of the sod heating process were initiated in mid-August of 1966. In these experiments Merion Kentucky bluegrass sod was stacked on pallets in (a) rolls and (b) flat (Figure 1). The pallets of sod were left uncovered or wrapped with black polyethylene plastic in various ways. The temperature was measured at various locations within the stacks at 3 hour intervals using 18 gauge copper-constantan thermocouples connected to a Honeywell Brown recording potentiometer. A sod piece was removed from the central part of each sod stack and transplanted in mid-afternoon of each day.

Figure 1. Flat and roll stacked sod with plastic covers used in a preliminary experiment in August 1966.

After 2 days of storage the initial injury symptoms appear as chlorotic and limp or water soaked grass leaves. The temperatures reached about 100° F. The grass leaves were extremely chlorotic, limp, and moldy after 4 days of storage. The temperatures reached about 105° F. Most plants died after transplanting. The mold growth increased rapidly up to the seventh day of storage when the sod was discarded. An odor similar to that of spoiled silage developed and temperatures as high as 130° F were recorded. The fungus, which belonged to the form-genus *Fusarium*, developed as or after the grass died and, therefore, was not the cause of injury.

Some temperature differences resulted from the various stacking and wrapping procedures. The temperature in the center of the rolled sod was 115° F compared to 100° F for flat stacked sod after 3 days of storage. This difference may be partially attributed to the greater mass of sod on the roll stacked pallet. In another experiment where all the sod was stacked flat, the sod on pallets which were not wrapped with plastic was 15° F cooler (100 vs 115° F) after 4 days of storage. This sod also dried more rapidly.

This method for studying the sod heating process was unsuitable because it required too much time for injury to occur and excessive quantities of sod. These initial experiments did show the suitability of flat stacking and the value of enclosing the sod to accelerate the heating process.

1967 Season

Sod heating boxes were designed and built to increase the rate of heating and reduce the amount of sod required for each experiment. Eight boxes having inside dimensions of 20 inches square by 30 inches deep were constructed from 3/8 inch plywood. The lids had foam rubber gasket seals. This reduced gas exchange between the sod stack and the normal atmosphere. Twenty-five 16 inch square sod pieces cut at a 0.75 inch thickness were stacked flat within these boxes. The boxes were kept in an 80° F constant temperature room during the experiments. Temperature was measured at levels of 5, 12, and 20 sod pieces from the bottom with thermocouples and the recording potentiometer. Each day the thirteenth sod piece from the bottom was removed and transplanted to a prepared soil area. Visual observations of injury and leaf recovery were made. Quantitatively measuring the damage was difficult because injury symptoms began with a blanched appearance of the grass, followed by browning at the leaf tip and then progressive browning down the leaf blade toward the stem. Also, injury was greater in the center of the sod piece.

Using the above techniques, several experiments comparing 0 versus 80 lb/A of nitrogen and 2 versus 0.75 inch cutting heights were conducted in various combinations. In most experiments, the mean temperatures were slightly higher for the high nitrogen and 2 inch cutting treatments. No conclusions could be drawn from these experiments since the results were rarely statistically significant.

1968 Season

Three important improvements in the experimental methods for the sod heating studies were made during the 1968 season. They were (1) applying 255 lb of weight over the sod within each sod heating box, (2) sampling and measuring carbon dioxide levels within the sod stack, and (3) measuring root organic matter production after transplanting sod pieces from the heating boxes to 4 inch diameter pots filled with sand. Also, the number of sod heating boxes was increased to sixteen.

Calculations indicated that pressures of about 1 lb/sq in occurred at the bottom of typical sod loads stacked 6 feet high. The application of 255 lb of weights over the sod within each box gave pressures of approximately 1 lb/sq in at the bottom of the sod stack. For experiments conducted during 1968 and 1969, six 30 lb and three 25 lb weights were spaced symetrically over a 16x16x3/16 inch plywood board placed over the twelve sod pieces (Figure 2). Then the boxes were closed and sealed with the lids.

The problem of obtaining relatively easily handled and inexpensive weights that would fit inside the sod heating boxes was solved in the following way. Four inch diameter scrap artillery shell casings were purchased. Two hundred were 16 inches long and 60 were 10 inches long. Two holes were drilled across the top of each shell casing

Figure 2. Weights (255 lb) in sod heating box.

and a large nail was inserted. Each shell casing was nearly filled with steel punch press slugs and capped with cement. An eye bolt having a ½ inch diameter hole was inserted into the cement. The weights were handled with small hand hooks.

The carbon dioxide concentration within the sod stack was measured by the acetone-sodium methylate method (Blom and Edelhausen, 1955). Gas samples from the center of the stack and 6 sod pieces from the bottom were obtained after 72 hours of storage by drawing through 20 inch long Tygon tubes having a 0.12 inch inside diameter (Figure 3). The tubes were kept plugged between samplings. The first 10 cc of gas collected was discarded. The carbon dioxide in the second 10 cc gas sample was dissolved in acetone by bubbling through a micropore filter inserted in the bottom of a large test tube containing 50 ml of acetone. The acetone solution was titrated with a 0.1 N sodium methylate in methanol solution using a thymol blue indicator. The percent CO_2 was determined from a standard curve. Ten replications were used in constructing the standard curve. The precision was $\pm$5%. It was difficult to achieve a consistent rate and size of bubbles through the acetone. This probably accounts for most of the error since CO_2 absorption depended on bubble size and rate of ascent through the acetone. This method gave valuable preliminary information on the general levels of carbon dioxide occurring within the sod during heating.

Figure 3. Gas sampling tube, thermocouple, and injured Merion Kentucky bluegrass in the center of the sod piece in a sod heating box are shown.

A third important innovation in methods, initiated midway through the 1968 season, involved measuring sod recovery in pots. Plugs taken from the center of each stored sod piece were transplanted to pots filled with sand. The pots were placed in a 70-80^{o} F greenhouse room under a mist irrigation system. Data taken included (a) estimates of percent leaf kill and cover and (b) weight of root organic matter production. Details of the method will be described in the general methods section.

Injury to the sod was easier to estimate visually when using the newer methods of simulating shipping conditions. The weight flattened the grass plants. The injury symptoms were more pronounced and uniform. When injury occurred to the individual plant the whole leaf blade and usually the stem as well would turn brown after transplanting. Injured stems did not stand upright. Surviving plants regained their upright growth habit and bright green color within 2 days. Some blanching could occur without death. Injury symptoms were uniform since only the central portion of the original sod piece was transplanted. More injury would have occurred if the sod had been exposed to direct sunlight and the dryer environment of field conditions.

<u>1969 Season</u>

The most important improvement in technique was the use of gas chromatography to measure the percent CO_2 and O_2 and ppm ethylene occurring within the sod stack in the sod heating boxes. Ten cc gas samples were collected from each box at intervals of 24 hours or less. Each of the 0.12 inch inside diameter by 20 inch long Tygon sampling tubes was capped with a sleeve type rubber stopper, which was taped in place. A 0.62 inch, 25 gauge hypodermic needle attached to a 10 ml syringe was inserted through the cap to draw out gas samples. The first 10 cc sample was discarded and the second 10 cc sample retained for analysis. Removal of the needle and capping of the syringe was done under water to prevent contamination of the sample.

The gas samples were stored under water until the analysis could be made in the evening. The rubber stoppers were wet when the gas was transferred to the injection syringe. The water formed a seal around the needle. The small injection syringes were flushed once with the current sample before injection and analysis. To analyze for percent CO_2 and O_2, a 1 cc aliquot was injected into a Vapor Fractometer Model No. 154B gas chromatograph connected to a Honeywell Brown Electronik single point recorder. To calculate the results, the deflection peaks were measured and compared with peaks obtained from a standard gas mixture containing known percentages of CO_2 and O_2. Ppm ethylene was determined by injection 100 µl of each sample into a Varian Aerograph Series 1200 gas chromatograph connected to a Sargent Recorder Model SR and comparing the readout peak with that for a known concentration of ethylene.

On May 26-28, 1969, the sod heating boxes and lids were insulated on the inside with a 0.62 inch layer of bonded polyurethane having a polyethylene coating on the inner surface.

General Methods for Sod Heating Box Experiments

The following paragraphs describe the general methods used for the 1968 and 1969 sod heating box experiments. Variations in these methods will be described in the methods and materials sections for each experiment. The arrangement of sod heating boxes and other equipment in the greenhouse is shown in Figure 4. Information on sod source as well as rates and timing of cultural treatments will be given for each experiment.

Merion Kentucky bluegrass (Poa pratensis L. var. "Merion") sod of good marketable quality and grown on organic soil was donated by commercial sod producers. Uniform plot sites were selected. Prior to applying cultural treatments, 2x20 foot plots (usually 16) were laid out and outlined with a Paraquot solution. The most commonly applied cultural treatments were arranged in a randomized block factorial design with two replications.

Mowing treatments.--The mowing treatments were (a) the standard 2 inch height of cut and (b) a low height of 0.75 inch (Figure 5). The 2 inch cutting height plots were normally mowed every 3 days with reel-type gang mowers as part of the regular mowing program on the sod farm. Clippings were not removed. The 0.75 inch treatment was done with an 18 inch reel-type power lawn mower. Each low cut

Figure 4. The arrangement of sod heating boxes, weights to hold lids tightly closed, thermocouple wires, recording potentiometers, and protruding gas sampling tubes is shown in the greenhouse room.

Figure 5. Merion Kentucky bluegrass sod cut at 0.75 versus 2 inches.

plot was mowed to the full 24 inch width. Clippings were collected and discarded. All plots were vigorously raked with a bamboo leaf rake to remove any residual clippings and mowed again to insure uniform mowing height. If more than one low mowing was required before harvest,the clippings were removed by catching, raking, and re-mowing at each cutting.

Nitrogen treatments.--The nitrogen treatments will be referred to as zero versus some specified nitrogen rate. The "zero" nitrogen treatment was a base level which included all the nitrogen fertilizer that the sod producer applied as part of the regular production fertilization program. This nitrogen level will be stated in the sod source information. The specified nitrogen rate refers to the additional nitrogen applied at a specified number of days before harvest. The nitrogen source for experimental treatments was a prilled, 45% N urea fertilizer. The urea was applied with a 2 foot wide, drop-type spreader. Records of the weight of urea applied showed that the proper rate of application was attained. The urea was applied when the turfgrass was dry. Immediately afterward, the fertilized plots were raked gently three times with a bamboo leaf rake which knocked most of the prills off the leaves. Foliar burn did not occur in spite of nitrogen rates as high as 215 lb/A. No turfgrass response to the additional nitrogen was visually evident.

Respiration inhibitor.--The respiration inhibitor, N^6benzyladenine, was dissolved in water by magnetic stirring for several hours in water heated to 80° F. A fine droplet spray was achieved from a knapsack sprayer equipped with a pressure regulator. Three passes with the sprayer gave thorough leaf coverage with very little runoff. The water solution of N^6benzyladenine was applied at 65 gallons per acre.

Sod harvesting.--The sod was harvested with a Ryan sod cutter having a 16 inch width of cut and adjusted to cut at a 0.75 inch depth. The sod used was cut from the center of the two foot wide plots. The sod was then cut perpendicularly with the sod cutter. Thirteen of the resulting 16 inch square sod pieces from each plot were stacked into correspondingly numbered sod heating boxes and transported to the Plant Science greenhouse.

Temperature measurement.--Temperature was measured and recorded at intervals (usually 6 hour) by two recording potentiometers. A 24 point Leeds-Northrup Speedomax W and a single point Honeywell Brown Electronik recorder Model No. K153X12-PH-II-III-6 equipped with a switching device which handled 25 points were used. When compared to the sixth sod piece, temperatures at the third sod piece were about 0.5° F lower and at the ninth sod piece about 1° F higher. These differences in temperature were very consistent over the experiments so only the temperatures recorded at the sixth sod piece will be reported.

Atmospheric measurements.--The atmospheres within the sod stacks were usually sampled at 0, 3, and 6 hours during the first 24 hours of the experiments and at 24 hour intervals thereafter. Data from the 24 hour, 48 hour, etc. sampling times were from samples collected just prior to opening the boxes. The methods used for collecting and analyzing the gas samples were described previously. Percent CO_2 and O_2 and ppm ethylene data were obtained for 1969 experiments.

Sod sampling.--The sod heating boxes were opened at 24 hour intervals and the seventh sod piece from the bottom removed. A 6 inch diameter plug was cut from the center of each sod piece and transplanted to a pot filled with sand. The pots were placed in a 70 to 80° F greenhouse and watered for 10 minutes at 10 a.m. and 2 p.m. with a mist irrigation system. Approximately 0.12 inch of water was applied daily. The percent leaf kill was estimated visually 2 days after transplanting. The percent cover was estimated visually 20 days after transplanting. At that time the sand was washed away from the new roots. Broken roots were collected on a screen having 0.12 inch square openings. The new roots were cut off at the bottom of the original sod piece, washed, dried in a forced air oven at 100° F for 2 days, and ashed at 600° F. The root organic matter production was then calculated and recorded.

The data were analyzed by analysis of variance.

Other supporting experiments.--Experiments with controlled atmospheres, respiration rates, and measurements of changes in actual load conditions were performed. The methods used will be described as these experiments are presented in the thesis.

1968 SOD HEATING BOX EXPERIMENTS

A large confounded experiment and a sod heating box conditions experiment were conducted during the 1968 growing season. The general methods used were as described in the development of methods section. Specific cultural treatments and results of each experiment will be discussed in this section.

The Merion Kentucky bluegrass sod used for these experiments was grown on organic soil at Halmich Sod Farm near East Lansing, Michigan. One thousand lb/A of 5-20-20 fertilizer was tilled into the seedbed. The field was seeded to Merion Kentucky bluegrass at a rate of 50 lb/A on August 25, 1966. In late April of 1967, 300 lb/A of 16-8-8 fertilizer was applied. Another 200 lb/A of 16-8-8 fertilizer was applied on August 30, 1967. Prilled urea was broadcast at a rate of 200 lb/A in late April of 1968. No irrigation was used during the sod establishment of production periods. It was mowed 3 times weekly at a 2 inch height. The sod was of high quality with good sod strength.

Confounded Experiment

The cultural treatments included in this experiment were (a) 0 versus 130 lb/A of nitrogen, (b) none versus 2 inches of irrigation water, (c) none versus removal of leaf clippings, (d) 2 versus 0.75 inch cutting heights, and (e) none versus 0.0055 lb/A of N^6benzyladenine. The nitrogen treatment was applied 8 days before harvest. The irrigation water was applied in two 1 inch applications during the week before harvest. The leaf clippings were removed with a power rake. The 0.75 inch cutting was done 8 days before harvest and clippings removed. These plots were mowed again at 3 and 1 days before harvest, but the clippings were not removed unless required by the clipping removal part of the treatment plan. The N^6benzyladenine solution was applied 15 minutes before harvest.

Sod pieces were removed after 24 and 48 hours of storage and transplanted to a prepared soil area in the field. They received 0.2 inch of water daily. Percent carbon dioxide was measured with the acetone-sodium methylate method described earlier. New root production was measured for 4 inch diameter sod pieces that had been transplanted to pots filled with sand. The carbon dioxide and root production measurements were initiated mid-way through the experiment.

The experimental design was a 2^5 in blocks of 16 units with the 5-way interaction confounded. Each of the 16 unit blocks were repeated twice over a 4 week period to give 2 replications. The harvest dates were July 31, and August 6, 13, and 20, 1968. The mean squares for the 4-way interactions were used to estimate the probability of F significance for the carbon dioxide and root production data.

Results and discussion.--The main effect means for percent moisture, temperature, and percent leaf kill are presented in Table 1. The initial percent moisture was greater for sod that had been irrigated. Rainfall totaled about 5.5 inches during the 4 week period of this experiment. Low cutting apparently resulted in greater evaporation from the soil. Nitrogen, irrigation, and clipping removal treatments did not affect temperature. Low cutting reduced temperatures probably because of reduced biomass. N^6benzyladenine reduced temperatures after 48 hours of storage. No leaf kill was apparent on sod stored 24 hours. The mean leaf kill was 55% and cultural treatments did not affect leaf kill for sod stored 48 hours.

The main effect means for percent carbon dioxide and root production are presented in Table 2. Irrigation increased the carbon dioxide level and increased root production. Low cutting tended to reduce carbon dioxide levels. Removal of the leaf clippings resulted in increased root production. None of the main effect means for percent leaf kill and cover were significantly different for sod transplanted to the pots.

Box Conditions Experiment

This experiment compared the effects of (a) 255 versus 345 lb of weight, (b) no insulation versus insulation with 4 layers of burlap at the bottom and sides, and (c) open stacked sod pieces versus sod pieces individually enclosed in polyethylene bags. The sod was from the source

Table 1. Percent moisture, temperature, and percent leaf kill in relation to nitrogen, irrigation, clipping removal, cutting height, and N^6benzyladenine (N^6BA) treatments on Merion Kentucky bluegrass sod for the 1968 confounded experiment

			Nitrogen (lb/A)		Irrigation (in)		Clipping Removal		Cutting Ht. (in)		N^6BA (lb/A)	
Measurement	Hours of Storage	Mean	0	130	0	2	-	+	2	0.75	0	0.0055
% Moisture	0	57	57	57	54	59***	57	57	59	55***	57	56
Temp. ($^{\circ}$F)	12	90	90	89	90	89	90	90	91	89*	91	89†
	24	96	96	95	96	95	96	95	97	94*	96	95
	48	100	101	100	100	100	100	100	103	98***	101	99**
% Leaf kill	48	55	59	51	54	56	57	52	61	49	58	51

†, *, **, ***Differences between main effect means are significant at the .10, .05, .01, and .001 level of probability, respectively, for given hours of storage.

Table 2. Percent carbon dioxide and root production in relation to nitrogen, irrigation, clipping removal, cutting height, and N^6benzyladenine (N^6BA) treatments on Merion Kentucky bluegrass sod for the 2nd replication of the 1968 confounded experiment

Measurement	Hours of Storage	Nitrogen (lb/A)		Irrigation (in)		Clipping Removal		Cutting Ht. (in)		N^6BA (lbs/A)	
		0	130	0	2	-	+	2	0.75	0	.0055
% CO_2	48	15.8	14.7	14.1	16.4*	16.1	14.1	16.3	14.2†	15.4	15.1
Roots (mg/pot)	48	37	41	45	33	30	49*	32	46†	42	36

†, *Differences between main effect means are significant at the .10 and .05 level of probability, respectively, for given hours of storage.

described for 1968 experiments and was harvested in August 26, 1968. The treatments were arranged in a randomized block 2^3 factorial design with 2 replications.

Results and discussion.--The main effect means for changes in temperature, carbon dioxide, and moisture levels that occurred during storage are presented in Table 3. The temperature was not affected by the weight treatment until after 96 hours of storage when the heavier weight resulted in 1° F lower temperature. Weight did not affect carbon dioxide or moisture level. Insulation resulted in significantly higher temperatures after 48, 72, and 96 hours of storage. Insulation resulted in a higher carbon dioxide level after 72 hours of storage. Enclosing sod pieces individually in polyethylene bags resulted in decreased temperatures after 24, 48, 72, and 96 hours of storage. The carbon dioxide level was significantly higher after 72 and 96 hours of storage in the plastic bags. Sod pieces enclosed in plastic bags contained more moisture after 96 hours of storage. The mean moisture level of the sod was 46.7% at the beginning of the experiment and 46.1% at the end. This shows drying was not a factor contributing to injury in sod heating box experiments.

The main effect means for percent leaf kill and cover and root production after storage are presented in Table 4. Weight and insulation treatments did not affect sod injury significantly. Significantly more leaf kill and

Table 3. Temperature, percent carbon dioxide, final percent moisture in relation to weight, insulation, and plastic bag enclosing treatments on Merion Kentucky bluegrass sod harvested on August 26, 1968 and stored in sod heating boxes for 4 days

Measurement	Hours of Storage	Mean	Weight (lb)		Insulation		Plastic Bags	
			255	345	-	+	-	+
Temp. (^{o}F)	0	68.7	68.1	69.3	69.2	69.2	68.4	69.0
	12	74.2	74.1	74.3	73.9	74.5	74.7	73.7
	24	29.4	78.8	80.1	80.0	78.9	81.4	77.4*
	48	89.3	89.3	89.3	88.6	90.0*	94.8	83.9***
	72	92.6	92.8	92.4	92.1	93.1*	98.5	86.8***
	96	92.6	93.1	92.1*	91.8	93.4**	98.5	86.8***
% CO_2	48	9.0	11.1	6.8	6.0	12.0	6.4	11.5
	72	14.2	14.8	13.5	13.0	15.3*	9.9	18.4***
	96	13.1	13.9	12.4	12.5	13.9	10.6	15.7**
% Moisture	96	46.1	46.7	45.5	45.5	46.7	44.9	47.3*

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for given hours of storage.

Table 4. Percent leaf kill and percent leaf cover outdoors and in the greenhouse and root production in relation to weight, insulation, and plastic bag enclosing treatments on Merion Kentucky bluegrass sod harvested on August 26, 1968 and stored in sod heating boxes for 4 days

Measurement	Hours of Storage	Mean	Weight (lb)		Insulation		Plastic Bags	
			255	345	-	+	-	+
% Leaf kill	72	28.2	28.1	28.4	27.5	29.0	0.9	55.6***
	96	55.0	53.1	56.9	54.4	55.6	16.9	93.1***
Greenhouse	96	28.8	34.2	23.4	16.2	41.4	15.9	41.8
% Leaf cover	72	87.2	89.4	85.0	90.0	84.4	100.0	74.4*
	96	62.2	68.1	56.2	61.2	63.1	95.6	28.8***
Greenhouse	96	68.1	66.2	70.0	80.6	55.6	78.8	57.5
Roots (mg/pot)	96	57	54	61	70	46	78	37*

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for given hours of storage.

less leaf cover occurred for sod enclosed in plastic bags for 72 and 96 hours and then transplanted to a prepared soil area outdoors. Sod pieces transplanted to 4 inch diameter pots in the greenhouse had much less leaf injury. This shows that exposing the sod to the higher leaf temperatures and drier outdoor conditions after storage caused more injury than the milder conditions in the greenhouse. Root production was less for sod that had been enclosed in plastic.

Enclosing sod pieces individually in polyethylene bags resulted in lower temperatures, but higher levels of carbon dioxide and leaf kill. Based on the results of this experiment alone one would conclude that high carbon dioxide levels inhibited respiration and injured the turfgrass. However, when the results of 1969 sod heating box and controlled atmosphere studies are considered, one must conclude that high ethylene concentrations and possibly oxygen starvation caused these results. The new polyethylene bags used may have contributed ethylene to the system. Enclosing the sod pieces individually in polyethylene bags was considered to be a more severe restriction on gas exchange than typically occurs in commercial sod loads. Therefore, the sod was not enclosed in polyethylene bags during 1969 sod heating box experiments.

For 1969 sod heating box experiments 255 lb of weights were used since the additional 90 lb used in this experiment did not have much effect on the sod. The sod heating boxes were insulated for the 1969 experiments since insulation increased sod temperature during storage.

1969 SOD HEATING BOX EXPERIMENTS

A series of 11 sod heating box experiments were conducted during the 1969 growing season. The general methods used were as described in the Development of Methods section. Specific cultural treatments and results of each experiment will be discussed in this section.

The Merion Kentucky bluegrass sod used for the first seven experiments, conducted from May 16 to June 24, 1969, was grown on organic soil at Green Acres Turf Farm, Mason, Michigan. The sod was produced by rhizome regrowth from a sod field harvested in December, 1967. No irrigation or overseeding was used in establishing this sod. It was mowed twice weekly at a 2 inch height. The 1969 fertilizer applications were 400 lb/A of 5-20-20 in early April and 150 lb/A of 45% N urea on May 1st. The sod was strong and of high quality.

<u>Experiment I (May 16, 1969)</u>

The cultural treatments included in this experiment were (a) 2 versus 0.75 inch cutting heights and (b) 0.0, 0.0055, 0.0275, and 0.0550 lb/A of N^6benzyladenine. The 0.75 inch cutting height was done 2 days before harvest. The N^6benzyladenine solution was applied a few minutes before harvest. The cutting and respiration inhibitor treatments were arranged in a randomized block factorial design with 2 replications. The Merion Kentucky bluegrass sod was harvested on May 16, 1969, and stored in heating boxes under simulated load conditions for 4 days.

Results and discussion.--The mean percent moisture of the sod pieces at the beginning of the experiment was 63.1 (range 65.2 to 60.5%) and differences due to treatments were not significant. The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

0	12	24	48	72	96	Hours
92	74	81	76	74	80	^{o}F

The main effect means for temperature, percent carbon dioxide, and percent oxygen are presented in Table 5.

The mean temperature within the sod heating boxes increased rapidly during the first 24 hours. The cool weather which began during the second day would explain the gradual decline in mean temperature during the last 3 days of the experiment. Normally, the temperature would have continued to rise slowly. From 12 hours onward significantly lower temperatures were recorded for the lower height of cut treatment. The smaller quantity of respiring tissue is the probable explanation for this response. The main effect means for N^6benzyladenine levels did not show significant differences in temperature until the fourth day. Then a

Table 5. Temperature (^{o}F), percent carbon dioxide, and percent oxygen changes occurring during storage in relation to cutting height and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on May 16, 1969, and stored under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		N^6benzyladenine (lb/A)			
			2	0.75	0	.0055	.0275	.0550
Temperature (^{o}F)	0	73.5	73.2	73.8	73.9	73.6	73.1	73.2
	12	82.1	82.8	81.5*	81.8	83.0	82.2	81.5
	24	91.3	93.1	89.6***	91.0	92.1	91.5	90.6
	48	90.6	92.8	88.4***	91.6	91.2	90.2	89.4
	72	87.5	89.4	85.6***	88.2	88.1	87.5	86.2
	96	86.5	88.5	84.4***	87.5a	86.8ab	86.5ab	85.1b*
% CO_2	24	14.3	14.6	14.0	14.0	14.0	14.7	14.4
	72	14.4	14.9	13.9**	14.5ab	14.4ab	15.0a	13.7b*
	96	15.2	15.5	15.0	16.2	15.8	14.5	14.4
% O_2	24	4.8	4.5	5.1	5.0	4.6	4.6	5.0
	72	6.0	5.2	6.8**	5.8	5.9	5.4	6.9
	96	6.2	5.4	7.1*	5.7	5.9	6.5	6.7

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letters are not significantly different according to Duncan's Multiple Range Test at the 5% level.

significant decrease in temperature with increased N^6benzyladenine interaction occurred for temperature during the last 3 days of storage (Table 6). Examination of the simple effects for N^6benzyladenine showed that the 0.055 lb/A rate of N^6benzyladenine reduced temperatures significantly when applied to a low cut sod. Low mowing in the presence of 0.0055 lb/A and 0.0550 lb/A of N^6benzyladenine reduced temperature significantly. Based on these results the 0.055 lb/A rate of N^6benzyladenine was used in further 1969 sod heating box experiments.

The percent carbon dioxide determined in the sod stack in the sod heating boxes was significantly lower for the low cutting height treatment at 72 hours (Table 5). The reduced amount of respiring plant tissue present provides a satisfactory explanation. The 48 hour gas samples were not analyzed because of equipment breakdown. The mean percentages of carbon dioxide were similar at all three sampling times. Statistically significant differences in percent carbon dioxide in relation to the N^6benzyladenine rates was found at 72 hours. Significantly more carbon dioxide was found where 0.0275 lb/A of N^6benzyladenine was applied than for 0.0550 lb/A, but it seems unlikely that these results are physiologically valid.

The percent oxygen was significantly greater for the lower height of cut after 72 and 96 hours (Table 5). Less oxygen was required when less plant tissue was respiring.

Table 6. Significant cutting height x N^6benzyladenine rate interactions on Merion Kentucky bluegrass sod harvested on May 16, 1969, and stored under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Cutting Ht. (in)	N^6benzyladenine (lb/A)				Simple Effects					
			0	.0055	.0275	.0550						
			a_1	a_2	a_3	a_4	a_2-a_1	a_3-a_1	a_4-a_1	a_3-a_2	a_4-a_2	a_4-a_3
Temp. (^oF)	48	2	92.8	94.2	91.0	93.5	1.4	-1.8	0.7	-3.2	-0.7	2.5
		0.75	90.5	88.5	89.5	85.2	-2.0	-1.0	-5.3**	1.0	-3.3*	-4.3**
		Simple Effects	-2.3	-5.7**	-1.5	-8.3**						
	72	2	89.5	90.2	88.0	90.0	0.7	-1.5	0.5	-2.2	-0.2	2.0
		0.75	87.0	86.0	87.0	82.0	-1.0	0.0	-5.0**	1.0	-4.0*	-5.0**
		Simple Effects	-2.5	-4.2**	-1.0	-8.0**						
	96	2	88.8	89.0	87.5	88.8	0.2	-1.3	0.0	-1.5	-0.2	1.3
		0.75	86.2	84.5	85.5	81.5	-1.7	-0.7	-4.7**	1.0	-3.0**	-4.0**
		Simple Effects	-2.6*	-4.5**	-2.0	-7.3**						

*, **Differences are larger than LSD at the .05 and .01 level of probability, respectively.

The N^6benzyladenine treatments did not affect oxygen use significantly.

The mean ppm ethylene found in the gas samples were 0.66 and 0.32 for 24 and 72 hours, respectively. The low values for ppm ethylene were not significantly related to treatments. The 48 and 96 hour gas samples were not analyzed because of equipment breakdown.

The second major aspect of data was the sod recovery after being transplanted from the sod heating boxes. The most important factor in the recovery data was that no browning injury to the turfgrass leaves was detected visually after transplanting. Two factors may account for this result. One is that the temperature levels within the heating boxes remained at relatively low, non-lethal levels. Secondly, the oxygen levels remained relatively high. The percent leaf cover was significantly higher when the sod was cut at the standard 2 inch height (Table 7). The root organic matter production was lower at 24 hours than at 48 hours. Root production was greatest at 48 hours and declined thereafter. Root production was greater at the 2 inch cut.

Experiment II (May 21, 1969)

This experiment compared the effects of (a) 2 inch versus 0.75 inch cutting heights, (b) 0 versus 215 lb/A of nitrogen, and (c) 0 versus 0.055 lb/A of N^6benzyladenine on Merion Kentucky bluegrass sod harvested on May 21, 1969, and stored under simulated load conditions for 4 days. The low cutting treatment was done at 5 and 2 days prior to harvest.

Table 7. Percent leaf cover and root production in relation to cutting height and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on May 16, 1969, and stored under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		N^6benzyladenine (lb/A)			
			2	0.75	0	.0055	.0275	.0550
% Leaf cover	24	71.6	80.6	62.5*	78.8	65.0	73.8	68.8
	48	74.1	83.1	65.0**	82.5	67.5	73.8	72.5
	72	87.5	93.8	81.2**	86.2	85.0	88.8	90.0
	96	77.8	88.1	67.5**	82.5	72.5	71.2	85.0
Root organic matter (mg/pot)	24	46	55	37	65	45	42	33
	48	102	129	76†	126	75	108	101
	72	82	88	75	93	75	84	74
	96	40	54	27†	44	32	45	40

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

The nitrogen fertilizer treatment was applied 5 days before harvest. The N^6benzyladenine solution was sprayed on immediately before harvest. The cultural treatments were arranged in a randomized block factorial design having 2 replications.

Results and discussion.--The mean percent moisture of the sod at harvest time was 65.6. None of the treatments significantly affected the moisture content. The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

6	24	48	72	96	Hours
71	80	90	89	69	^{o}F

The changes in temperature in the sod heating boxes are presented in Table 8. The mean temperature increased steadily to 85^{o} F during the first 48 hours of storage and then leveled off. The 0.75 inch cutting height gave a significant decrease in temperature after 12 hours. The nitrogen and N^6benzyladenine treatments did not affect temperature.

The mean percent carbon dioxide found within the sod stacks increased during the first 48 hours and then declined (Table 9). The low cutting treatment resulted in significantly lower levels of carbon dioxide during the first 24 hours. Nitrogen rate did not affect carbon dioxide levels significantly, but at 48 hours the trend was toward a higher

Table 8. Temperature (^{o}F) changes occurring during storage in relation to cutting height, nitrogen rate, and N^6benzyladenine (N^6BA) treatments on Merion Kentucky bluegrass sod harvested on May 21, 1969, and stored under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
			2	0.75	0	215	0	.055
Temperature (^{o}F)	6	71.4	72.2	70.6†	71.6	71.3	71.5	71.4
	12	74.5	75.9	73.1*	74.9	74.2	74.4	74.6
	24	81.5	83.1	79.9**	82.1	80.9	81.6	81.4
	48	85.5	87.2	83.7**	86.2	84.8	85.8	85.1
	72	85.9	87.6	84.2**	86.1	85.7	85.8	86.1
	96	86.0	87.1	84.8**	86.1	85.9	85.8	86.2

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

Table 9. Percent carbon dioxide, percent oxygen, and ppm ethylene changes occurring during storage in relation to cutting height, nitrogen rate, and N^6benzyladenine (N^6BA) treatments on Merion Kentucky bluegrass sod harvested on May 21, 1969, and stored under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
			2	0.75	0	215	0	.055
% CO_2	7.5	13.8	14.9	12.8***	14.2	13.5	13.9	13.8
	24	16.7	17.4	16.1**	16.8	16.6	16.9	16.5
	48	19.4	19.9	18.9	18.5	20.3†	19.1	19.6
	72	16.5	16.6	16.5	16.5	16.6	16.4	16.6
	96	15.9	16.3	15.5	15.3	16.5	16.4	15.4
% O_2	7.5	6.8	5.8	7.8*	7.4	6.1*	6.7	6.8
	24	4.3	3.7	4.9**	4.4	4.2	3.9	4.7*
	48	4.5	4.5	4.6	5.5	3.6*	4.3	4.8
	72	4.5	4.2	4.8	4.8	4.2	4.3	4.7
	96	5.3	5.1	5.6	6.5	4.1	4.9	5.7
ppm C_2H_4	7.5	0.88	1.04	0.71*	0.41	1.34***	0.84	0.91
	24	1.44	1.52	1.35	1.00	1.88**	1.48	1.40
	48	0.77	0.75	0.80	0.32	1.22***	0.74	0.81
	72	1.58	1.41	1.74	1.45	1.70	1.44	1.71
	96	0.94	0.89	0.99	0.68	1.20*	0.95	0.92

†, *, **, ***Differences between main effect means are significant at the .10, .05, .01, and .001 level of probability, respectively, for designated hours of storage.

carbon dioxide level at the high nitrogen rate. The N^6benzyladenine did not affect the carbon dioxide level.

The percent oxygen data are presented in Table 9. During the first 24 hours, more oxygen was present in sod heating boxes containing sod cut at 0.75 inch. This indicates that less respiration occurred where less green tissue was present. These differences had disappeared after 2 days. Less oxygen was found where the sod received the high nitrogen treatment at the 7.5 and 48 hour sampling times. This suggests that the high nitrogen rates increased respiration. At all sampling times, more oxygen was present where the N^6benzyladenine had been applied, but the differences were significant only for the 24 hour measurement. These results provide some evidence for inhibition of respiration by N^6benzyladenine.

The mean ppm ethylene found in the atmosphere within the stack of heating sod did not follow a consistent pattern over time (Table 9). Cutting height did not affect ethylene levels, except at the 7.5 hour measurement when less ethylene was found where the sod was cut at 0.75 inch. The high nitrogen treatment markedly stimulated ethylene production. N^6benzyladenine did not affect ethylene levels.

The data gathered to evaluate the recovery of sod after storage under simulated shipping conditions and transplanting to pots in the greenhouse are presented in Table 10.

No leaf injury was observed, except for sod which had been stored for 96 hours. More leaf injury was observed for sod treated with the high rate of nitrogen. Leaf injury tended to be greater at the low cutting height and less for sod treated with N^6benzyladenine. The mean percent leaf cover after 20 days growth in the pots declined as time of storage increased to 72 hours. The percent leaf cover was the same for sod stored 72 and 96 hours. Cutting height treatments did not affect the leaf cover results. However, the 2 inch cutting treatment tended to result in better leaf cover for sod stored 72 hours. Nitrogen rate did not affect the percent leaf cover, except for sod which had been stored for 72 hours. Then the leaf cover was lower for sod treated with the high nitrogen rate. N^6benzyladenine treatment did not affect leaf cover although the leaf cover tended to be greater for sod stored 96 hours and treated with N^6benzyladenine.

The mean root production was similar for sod stored 1, 2, and 3 days (Table 10). The mean root production was much less for sod stored 4 days. Cutting height did not affect root production. The root production was greater at the high nitrogen rate for sod stored one day. Nitrogen rate did not affect root production for longer storage times. N^6benzyladenine treatments did not affect root production.

Table 10. Percent leaf kill, percent leaf cover, and root production after storage in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on May 21, 1969, after storage under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
			2	3/4	0	215	0	.055
% Leaf kill	96	5.9	4.4	7.5†	3.1	8.8**	7.4	4.4†
% Leaf cover	24	85.6	88.1	85.0	95.0	88.1	88.8	84.4
	48	82.8	83.8	81.9	80.6	85.0	80.6	85.0
	72	70.6	77.5	63.8†	78.8	62.5*	66.9	74.4
	96	71.9	71.9	71.9	76.9	66.9	63.8	80.0†
Root organic matter (mg/pot)	24	90	96	83	73	106*	95	84
	48	82	81	84	99	66	72	93
	72	92	104	81	80	105	89	96
	96	49	58	41	44	54	49	50

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

Experiment III (May 29, 1969)

This experiment compared the effects of (a) 0 versus 0.055 lb/A of N^6benzyladenine and (b) 2 inch versus 0.75 inch cutting at 10, 5, and 1 day before harvest. The N^6benzyladenine solution was sprayed onto the plots 5 days before harvest. The 0.75 inch mowing for the 10 days before harvest treatment was done at 10, 5, and 1 days before harvest. The 0.75 inch mowing for the 5 days before harvest treatment was done at 5 and 1 days before harvest. The treatments were arranged in randomized block factorial design. Many seedheads were showing in the turf. The sod was harvested on May 29, 1969 and stored under simulated shipping conditions for 5 days.

For this and subsequent sod heating box experiments the boxes were insulated with a 0.62 inch layer of polyurethane foam.

Results and discussion.--No difference in turfgrass appearance due to the N^6benzyladenine treatment was detected. At harvest time the turfgrass mowed at 0.75 inch 10 days earlier appeared to have less green leaf tissue than turfgrass mowed short 5 days before harvest because the browning from scalping was more fully developed. Among the short mowed plots those cut the day before harvest appeared the greenest on May 29. The sod cut regularly at 2 inches had the best appearance. The mean percent moisture of the sod at the beginning of the experiment was 66.9 and no significant differences occurred among the treatments.

The main effect means for changes in temperature, percent carbon dioxide and oxygen, and ppm ethylene that occurred in the sod heating boxes are presented in Table 11.

The mean temperatures increased to about 95° F at the 24, 48, and 72 hour times and then declined. The air temperatures at 3 p.m. in the greenhouse room were as follows:

0	24	48	72	96	120	Hours
78	100	98	90	78	72	°F

The lower air temperatures during the last two days explain the decline in sod temperatures. The N^6benzyladenine treatment did not affect temperature significantly. But the temperatures were always somewhat higher where N^6benzyladenine was applied, and statistical significance was approached (0.082 level) for the 48 hour temperatures. Temperatures in relation to mowing height and times were significantly higher for the 2 inch treatment at 0 and 96 hours.

N^6benzyladenine treatment did not affect carbon dioxide release from the sod. After 24 hours a highly significant difference in CO_2 levels in relation to mowing treatments were found. Sod that had been severely defoliated only one day before harvest released the most CO_2. The plants which had 5 days to heal after low cutting released the least CO_2. In spite of the fact that the plots cut at 0.75 inch 10 days before harvest appeared to have the least green leaf tissue this sod released the same amount of CO_2 during the first 24 hours as sod regularly mowed at 2

Table 11. Temperature (^{o}F) changes occurring during storage related to N^6benzyladenine and time and height of cutting treatments on Merion Kentucky bluegrass sod harvested on May 29, 1969, and stored under simulated shipping conditions for 5 days

Measurement	Hours of Storage	Mean	N^6BA (lb/A)		Cutting Ht. (in) and Time (days)			
					2	0.75	0.75	0.75
			0	.055	2	10	5	1
Temp. ^{o}F	0	85.0	84.7	85.2	86.6	84.0	84.6	84.6**
	24	94.0	93.0	94.9	96.1	93.0	94.9	91.2
	48	95.0	93.8	96.3†	95.0	95.8	96.4	93.0
	72	95.8	95.2	96.3	98.9	95.6	95.8	92.8
	96	93.2	92.4	93.9	96.6	92.1	93.1	90.8*
	120	87.3	86.4	88.2	87.5	87.5	87.5	86.9
% CO_2	24	13.3	13.3	13.3	13.5	13.5	11.0	15.3**
	48	13.7	13.2	14.2	15.7	13.8	11.0	14.2
	72	16.2	16.4	16.1	17.2	15.5	16.2	16.1
	96	17.5	18.0	17.1	18.5	17.9	16.1	17.6*
	120	16.4	16.1	16.6	17.4	16.4	15.3	16.2
% O_2	24	3.6	3.8	3.5	3.3	3.7	4.6	2.9
	48	2.3	2.3	2.3	2.3	2.2	1.9	2.7
	72	2.8	2.4	3.2	1.9	3.8	3.0	2.4
	96	3.0	2.0	4.1*	2.2	3.0	4.7	2.2
	120	3.3	3.5	3.1	2.2	3.3	4.4	3.4
ppm C_2H_4	24	2.66	3.10	2.21	2.88	2.85	1.70	3.20
	48	1.79	2.06	1.52†	2.17	1.48	1.70	1.82
	72	1.37	1.63	1.10*	1.72	1.17	1.22	1.35
	96	0.62	0.65	0.60	0.92	0.62	0.45	0.50*
	120	0.68	0.71	0.63	1.05	0.58	0.50	0.58

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

inches. At the 96 hour measurement the percent CO_2 within the sod stack for sod cut at 0.75 inch 5 days before harvest was lowest and that cut at 2 inch was highest. Consistent reciprocal, though nonsignificant, levels of oxygen were found at 24 and 96 hours.

The main effect mean for percent O_2 was significantly higher for the N^6benzyladenine treatment at 96 hours. Cutting treatments did not affect the oxygen levels significantly.

The mean ppm ethylene found steadily among the 24 to 96 hour measurements. At all times less ethylene was found where the sod was treated with N^6benzyladenine. This difference was significant at 72 hours and approached statistical significance at 48 hours. Sod cut at 2 inches released more ethylene at the last 4 times of measurement. This difference was significant for the 96 hour measurement.

In three instances significant N^6benzyladenine x mowing treatment interactions occurred for data gathered within the sod heating boxes (Table 12). Higher temperatures occurred for the 0.75 inch 10 day and 0.75 inch 5 day cutting treatments when N^6benzyladenine was present. Some form of respiration must accompany energy release. The most important feature of 96 hour percent O_2 interaction was that more oxygen was present for the 10 and 5 day 0.75 inch cutting treatments. This combination of higher temperatures and oxygen levels suggests the possibility that N^6benzyladenine

Table 12. Significant (.05 level) N^6benzyladenine x cutting height interactions on Merion Kentucky bluegrass sod harvested on May 29, 1969, and stored under simulated shipping conditions

			Cutting Ht. (in) & Time (days)			
	Hours of	N^6BA	2	0.75	0.75	0.75
Measurement	Storage	(lb/A)	2	10	5	1
Temp. (^oF)	96	0	97.8	89.2	90.8	92.0
		.055	95.5	95.0	95.5	89.5
% O_2	96	0	1.8	1.5	1.7	2.8
		.055	2.6	4.6	7.7	1.7
ppm C_2H_4	48	0	2.80	1.50	2.55	1.40
		.055	1.55	1.45	0.85	2.25

promoted anaerobic respiration when relatively small amounts of green leaf tissue were present.

The interaction for ppm ethylene at 48 hours showed that N^6benzyladenine decreased ethylene evolution for the 2 inch and 0.75 inch 5 day mowing treatments and increased it for the 0.75 inch 1 day mowing treatment.

The main effect means for recovery of the sod after removal from the sod heating boxes are presented in Table 13. As storage time increased the mean values for percent injury increased. The mean values for leaf cover after 20 days and root production decreased as the number of days in storage increased. N^6benzyladenine significantly decreased the percent leaf kill for sod stored 120 hours. The decreased leaf

Table 13. Percent leaf kill, percent leaf cover, and root production in relation to N^6benzyladenine and time in days before harvest, and height of cutting treatments on Merion Kentucky bluegrass sod harvested on May 29, 1969 after storage under simulated shipping conditions for 5 days

			N^6BA (lb/A)		Cutting Ht. (in) & Time (day)			
					2	0.75	0.75	0.75
Measurement	Hours of Storage	Mean	0	.055	2	10	5	1
% Leaf kill	72	8.8	9.4	8.1	7.5	12.5	6.2	8.8
	96	45.3	50.0	40.6	60.0	52.5	50.0	18.8†
	120	90.9	98.1	83.8*	87.5	98.8	90.0	87.5
% Leaf cover	24	76.9	76.2	77.5	73.5	80.0	81.2	75.5
	48	55.0	58.1	51.9	47.5	60.0	51.1	61.2
	72	32.8	26.2	39.4	17.5	21.2	55.0	37.5
	96	12.2	13.1	11.2	1.2	7.5	17.5	22.5
	120	4.4	2.5	6.2	2.5	3.8	7.5	3.8
Root organic matter (mg/pot)	24	49	48	50	68	44	36	49
	48	47	43	52	42	44	48	56
	72	35	27	42	17	30	48	44
	96	18	24	12	1	14	30	29
	120	20	14	26	10	11	47	10

†, *Differences between main effect means are significant at the .10 and .05 level of probability, respectively, for designated hours of storage.

kill for sod cut at 0.75 inch 1 day before harvest and stored 96 hours was approaching statistical significance. Percent leaf cover and root production were not affected by the two cultural treatments.

Experiment IV (June 4, 1969)

This experiment compared the effects of (a) 2 versus 0.75 inch cutting heights, (b) 0 versus 215 lb/A nitrogen, and (c) 0 versus 0.055 lb/A of N^6benzyladenine. The 0.75 inch cutting was done 5 and 1 days before harvest. The nitrogen was applied 5 days before harvest. The N^6benzyladenine was applied immediately before harvest. These treatments were arranged in a randomized block factorial design. This study was conducted during the period of maximum seedhead development for Merion Kentucky bluegrass. A heavy stand of well-developed seedheads was present in the plots cut at 2 inches. Most of the seedheads were removed by the 0.75 cutting treatment. The sod was harvested on June 4, 1969, and stored under simulated load conditions for 4 days.

Results and discussion.--The mean percent moisture of the sod at the beginning of the experiment was 67.6. The percent moisture where sod was cut at 2 inches was 68.3 versus 66.9% for low cut sod; this difference was significant at the 5% level. The mean percent moisture of the sod after 4 days of storage was 65.2 and none of the main effect means were significantly different. The sod cut at 2 inches had 65.0% moisture which showed that it dried slightly faster.

This loss of only 2.5% moisture during the experiment shows that the rate of drying during storage was very small. It seems clear that drying of the sod during storage did not contribute to sod injury.

The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

0	6	12	24	48	72	96	Hours
77	77	78	85	86	121	77	^{o}F

The main effect means for changes in temperature that occurred during storage are presented in Table 14. The mean temperature rose steadily over a 20^{o} F range during the 4 days. The sod cut at 0.75 inch had a lower temperature at every measuring time than sod cut at 2 inches. The differences were significant at 0, 3, 6, and 12 hours and approached significance at 24 and 96 hours. The sod temperature was higher at every measurement where high rate of nitrogen was applied. The differences were significant at 0, 6, 12, and 24 hours and approached significance at 3 hours. The N^6benzyladenine treatment did not affect temperature.

The main effect means for changes in percent carbon dioxide and oxygen during storage are presented in Table 15. The mean percent CO_2 present increased very rapidly during the early hours of storage and then reached an equilibrium at about 19%. Conversely, the mean percent O_2 content decreased very rapidly during the early hours of storage

Table 14. Temperature (^{o}F) changes occurring during storage in relation to mowing, nitrogen, and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on June 4, 1969, and stored under simulated shipping conditions for 4 days

Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
		2	0.75	0	215	0	.055
0	69.2	70.1	68.4*	68.5	70.0*	69.0	69.5
3	71.2	72.3	70.0*	70.2	72.1†	70.9	71.4
6	73.3	74.8	71.8*	72.1	74.4*	73.0	73.6
12	77.2	78.6	75.8*	75.8	78.7*	77.0	77.4
24	80.8	81.8	79.9†	79.3	82.4**	80.4	81.2
48	87.1	88.2	86.0	86.5	87.8	86.6	87.7
72	88.0	88.6	87.4	88.0	88.1	87.8	88.2
96	89.0	89.6	88.4†	88.6	89.4	89.4	88.7

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

Table 15. Percent carbon dioxide, percent oxygen changes occurring during storage in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on June 4, 1969 and stored under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
			2	0.75	0	215	0	.055
% CO_2	0	4.6	5.1	4.2**	4.7	4.6	4.7	4.6
	3	12.2	13.7	10.8*	12.6	11.9	11.8	12.7
	6	14.7	16.1	13.3*	14.6	14.7	14.8	14.6
	12	15.6	16.3	15.0**	15.8	15.5	15.4	15.8
	24	17.3	17.4	17.3	17.7	17.0	17.3	17.4
	48	19.0	19.4	18.6*	18.9	19.1	19.1	18.9
	72	18.2	18.5	17.8*	18.1	18.2	18.2	18.1
	96	19.1	19.6	18.5**	18.8	19.3	19.2	19.0
% O_2	0	14.9	14.4	15.3†	14.6	15.1	14.6	15.2
	3	7.2	5.9	8.7*	7.5	7.0	7.2	7.2
	6	4.1	3.1	5.1†	4.7	3.5	4.1	4.1
	12	2.3	2.2	2.5	2.4	2.3	2.4	2.3
	24	2.0	2.0	2.1	1.8	2.2	2.0	2.1
	48	1.8	1.8	1.8	1.8	1.7	1.8	1.8
	72	1.9	1.7	2.1	1.9	1.9	1.8	2.0
	96	1.7	1.6	1.8	1.8	1.6	1.8	1.6

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

and reached an equilibrium at about 1.9%. These reciprocal changes in percent CO_2 and O_2 were the result of aerobic respiration.

At all times of measurement the percent CO_2 found was lower for sod cut at 0.75 inch. These differences were significant except for the measurements taken after 24 hours of storage. The percent O_2 content was greater for sod cut at 0.75 inch at all times of measurement except at 48 hours. The difference was significant only for the measurement taken at 3 hours. For measurements taken at 0 and 6 hours the differences approached significance. The fact that less respiring tissue was present after cutting at 0.75 inch explains these results. Nitrogen and N^6benzyladenine treatments did not affect CO_2 and O_2 levels in the sod heating boxes.

The main effect means for ppm ethylene found during the course of the experiment are presented in Table 16. The mean ppm ethylene present increased erratically over time to a maximum of 2.21 ppm at 48 hours then decreased sharply. For sod cut at 0.75 inch the amount of ethylene found was less than for sod cut at 2 inches except for the 48 hour measurement. The differences were significant for measurements taken at 0, 3, 6, and 12 hours and nearly significant at 96 hours. The reduced amount of respiring tissue present explains these results satisfactorily. More ethylene was found at all times of measurement where the sod had been treated with the high nitrogen application. The differences

Table 16. Ppm ethylene changes occurring during storage in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on June 4, 1969, and stored under simulated shipping conditions for 4 days

Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
		2	0.75	0	215	0	.055
0	0.48	0.58	0.39*	0.39	0.58*	0.45	0.51
3	0.79	0.99	0.59**	0.45	1.12***	0.78	0.80
6	0.57	0.78	0.36**	0.30	0.84**	0.58	0.56
12	1.94	2.65	1.24**	1.82	2.06	1.99	1.90
24	1.91	2.25	1.58	1.54	2.29	2.18	1.65
48	2.21	2.12	2.29	1.59	2.82*	2.36	2.05
72	0.88	1.02	0.74	0.56	1.20*	0.90	0.86
96	0.86	0.99	0.72†	0.58	1.14**	0.94	0.78

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

were significant for the 0, 3, 6, 48, 72, and 96 hour measurements. Note that the high nitrogen treatment resulted in higher temperatures but did not affect CO_2 and O_2 levels. One possible explanation for these results is that high nitrogen promotes a form of anaerobic respiration which has ethylene as an end product. The main effect means for ethylene levels in relation to N^6benzyladenine treatment were not significantly different.

At 96 hours a significant nitrogen x N^6benzyladenine interaction showed that N^6benzyladenine decreased temperature in the presence of high nitrogen and that in the absence of N^6benzyladenine high nitrogen increased temperature (Table 17). At 72 hours a significant cutting height x N^6benzyladenine interaction showed that with low mowing N^6benzyladenine increased temperature (Table 18).

Table 17. Significant (.05 level) nitrogen x N^6benzyladenine interaction on Merion Kentucky bluegrass sod harvested on June 4, 1969, and stored under simulated shipping conditions

Measurement	Hours of Storage	Nitrogen (lb/A)	N^6BA (lb/A) 0	N^6BA (lb/A) .055	Simple Effects
Temp. (^oF)	96	0	88.1	89.1	1.0
		215	90.6	88.2	-2.4*
Simple Effects			2.5*	-0.9	

*Differences are larger than LSD at the .05 level of probability.

Table 18. Significant (.01 level) mowing x N^6benzyladenine interactions on Merion Kentucky bluegrass sod harvested on June 4, 1969, and stored under simulated shipping conditions

Measurement	Hours of Storage	Cutting Ht. (in)	N^6BA (lb/A) 0	N^6BA (lb/A) .055	Simple Effects
Temp. (°F)	72	2	89.8	87.5	-2.3
		0.75	85.9	89.0	3.1*
Simple Effects			0.1	1.5	

*Differences are larger than LSD at the .05 level of probability.

The main effect means for data collected after the sod was transplanted to the pots are presented in Table 19. After 48 hours of storage only a small amount of leaf injury was present. This injury was worse for the 2 inch cutting height, high nitrogen level, and N^6benzyladenine treatments. A substantial increase in leaf injury occurred after 72 hours of storage. Significantly more injury occurred on sod treated with high nitrogen. The mean leaf injury was 85.9% after 96 hours of storage, but the difference resulting from mowing treatments was small.

The mean percent cover after 20 days of growth in the pots decreased steadily in relation to increased time of storage. Even though no injury was detected after 24 hours, the percent cover was significantly less for sod cut at 0.75

Table 19. Percent leaf kill, percent leaf cover, and root production in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on June 4, 1969, after storage under simulated shipping conditions for 4 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
			2	0.75	0	215	0	.055
% Leaf kill	48	5.6	11.2	0.0**	1.9	9.4*	2.5	8.8*
	72	41.2	57.5	25.0	18.8	63.8*	41.2	41.2
	96	85.9	87.5	84.4	91.2	80.6	86.2	85.6
% Leaf cover	24	95.9	98.8	93.1*	94.4	97.5	93.8	98.1†
	48	64.7	54.8	75.0†	81.2	48.1*	75.6	53.8†
	72	42.2	25.6	58.8	66.9	17.5*	36.2	48.1
	96	7.8	5.6	10.0	5.0	10.6	5.6	10.0
Root organic matter (mg/pot)	24	34	40	29	28	41	34	35
	48	31	24	38	39	22	28	34
	72	32	15	48†	44	19	26	37
	96	6	5	8	3	10	6	7

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage.

inch. This represents a lack of full development of new leaves. More leaf cover was observed after 48 hours on sod originally cut at 0.75 inch. The difference approached significance for sod stored 48 hours. Significantly less leaf cover was present for sod treated with the high nitrogen level and stored 48 and 72 hours.

Root organic matter production was not affected by the treatments.

Experiment V (June 11, 1969)

This experiment compared the effect of (a) 0 versus 0.055 lb/A of N^6benzyladenine and (b) 0 versus 215 lb/A of nitrogen. The N^6benzyladenine solution was sprayed onto the plots a few minutes before harvest. The nitrogen fertilizer was applied 4, 8, and 18 days before harvest. All plots were cut at 2 inches 2 days before harvest. The mowing frequency had been twice per week. The cultural treatments were arranged in a randomized block factorial design. Only a few seedheads were present. The sod was harvested on June 11, 1969, and stored in the sod heating boxes for 3 days.

Results and discussion.--No response to nitrogen was visible at harvest time. The mean percent moisture at harvest was 64.9. The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

0	6	12	24	48	72	Hours
96	88	76	98	92	93	°F

The mean temperatures in the sod heating boxes were as follows:

0	6	12	24	48	72	Hours
74	79.7	84.2	88.1	93.1	90.1	^{o}F

The temperatures were not affected by the treatments.

The main effect means for levels of carbon dioxide, oxygen, and ethylene found in the sod heating boxes are presented in Table 20. The mean percentages for CO_2 and O_2 show that CO_2 levels increased to 16.2% within 6 hours while the O_2 levels decreased to 1.8%. The mean ppm ethylene increased steadily to 4.0 ppm at 24 hours then decreased. The main effect means for N^6benzyladenine were never significantly different.

Initially, the CO_2 percentage was significantly higher where 215 lb/A of nitrogen was applied 18 days before harvest than for the other nitrogen treatments. More respiration occurred initially where this treatment was applied. Thereafter, nitrogen treatments did not affect CO_2 levels significantly. The percent O_2 at the zero hour of measurement was significantly greater where no nitrogen was applied than where 215 lb/A nitrogen was applied 18 days before harvest. Between 6 and 48 hours the O_2 levels were quite low and not significantly different. The increased O_2 level found at 72 hours probably resulted from having the sod

Table 20. Percent carbon dioxide, percent oxygen, and ppm ethylene changes occurring during storage in relation to N^6benzyladenine treatment and nitrogen rates and time of nitrogen applications in days before harvest on Merion Kentucky bluegrass sod harvested on June 11, 1969, and stored under simulated shipping conditions for 3 days

Measurement	Hours of Storage	Mean	N^6BA (lb/A)		Nitrogen Treatments			
			0	.055	0	215	215	215 lb/A
						4	8	18 days
% CO_2	0	5.6	5.3	5.7	5.5b	4.6b	4.9b	7.3a**
	6	16.2	16.0	16.5	16.3	15.6	15.3	17.8
	12	16.2	16.1	16.3	16.5	15.5	15.8	17.0†
	24	18.1	18.1	18.1	18.4	17.7	17.6	18.4
	48	19.3	19.3	19.2	18.8	19.4	18.4	20.5
	72	15.7	15.6	15.7	15.5	15.6	15.2	16.5†
% O_2	0	13.0	13.2	12.8	13.9a	12.8ab	13.4ab	11.7b*
	6	1.8	1.8	1.7	2.1	1.8	1.6	1.4†
	12	2.0	2.0	2.1	2.3	1.8	2.0	2.0
	24	1.8	1.8	1.9	1.8	2.0	1.8	1.7
	48	1.6	1.7	1.6	1.6	1.6	1.5	1.7
	72	2.4	2.4	2.3	2.5a	2.4a	2.3b	2.2c*
ppm C_2H_4	0	0.81	0.81	0.81	0.50b	0.88ab	1.00a	0.88ab*
	6	1.50	1.35	1.65	0.72b	1.60a	1.45ab	2.22a**
	12	2.92	2.81	3.04	1.82b	3.40ab	2.70ab	3.78a*
	24	4.00	3.59	4.41	2.68a	3.40a	5.35a	4.58a*
	48	2.50	2.58	2.40	1.15b	3.00ab	3.22ab	2.60ab*
	72	2.22	2.20	2.24	1.68b	2.45a	2.70a	2.05ab**

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range test at 5% level.

heating boxes open a little longer than usual while removing the 48 hour sod pieces.

The ethylene level was always numerically lowest where no nitrogen was applied. However, it was usually statistically equal to one or more of the 215 lb/A nitrogen treatments according to Duncan's Multiple Range Test.

The main effect means for percent leaf kill, percent leaf cover, and root production of sod that had been stored 24 hours were not significantly different (Table 21). Only a small degree of injury (9.1%) occurred during the first 24 hours of storage. The average leaf kill was about 90% for sod that had been stored 48 and 72 hours. However, the sod that received no N^6benzyladenine and the "zero" nitrogen treatment showed less injury during storage. The 48 and 72 hour main effect means for percent leaf kill, percent leaf cover, and root production illustrate this.

Experiment VI (June 17, 1969)

This experiment compared (a) 0 versus 0.055 lb/A of N^6benzyladenine and (b) 2 versus 0.75 inch cutting heights. The N^6benzyladenine was applied just prior to and 5 and 10 days before harvest. The 0.75 cutting was done 5 days before harvest. The cultural treatments were arranged in a randomized block factorial design. The sod was harvested on June 17, 1969, and stored in the sod heating boxes for 4 days.

Table 21. Percent leaf kill, percent leaf cover, and root production in relation to N^6benzyladenine treatment and nitrogen rates and time of nitrogen application in days before harvest on Merion Kentucky bluegrass sod harvested on June 11, 1969, and stored under simulated shipping conditions for 3 days

Measurement	Hours of Storage	Mean	N^6BA (lb/A) 0	N^6BA (lb/A) .055	Nitrogen Treatments 0	Nitrogen Treatments 215, 4	Nitrogen Treatments 215, 8	Nitrogen Treatments 215 lb/A, 18 days
% Leaf kill	24	9.1	8.1	10.0	7.5	11.2	7.5	10.0
	48	88.1	77.5	98.8***	53.8	100.0	98.8	100.0***
	72	90.0	80.6	99.4***	61.2	98.8	100.0	100.0***
% Leaf cover 20 days	24	84.7	81.9	87.5	86.2	90.0	83.8	78.8
	48	8.1	14.1	1.9	27.5	2.5	2.5	0.0†
	72	2.5	5.0	0.0***	10.0	0.0	0.0	0.0***
Root organic matter (mg/pot)	24	60	60	61	51	81	58	51
	48	9	18	1†	34	2	2	0†
	72	14	28	0***	55	0	0	0***

†, ***Differences between main effect means are significant at the .10 and .001 level of probability, respectively, for given hours of storage.

<u>Results and discussion</u>.--No response to N^6benzyladenine was visible at harvest time. The mean percent moisture was 63.7. The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

0	6	12	24	48	72	96	Hours
90	80	66	98	102	96	108	^oF

The mean temperatures in the sod heating boxes were as follows:

0	6	12	24	48	72	96	Hours
68.2	71.4	76.7	82.0	88.3	91.2	90.1	^oF

The temperatures were not affected by the treatments.

The main effect means for percent CO_2 and O_2 found over time in relation to cutting height are presented in Table 22. More carbon dioxide and less oxygen was found during the first 72 hours of storage where the sod was cut at 2 inches. The differences in main effect means were significant at 48 hours for carbon dioxide and 24 hours for oxygen. These results gave strong evidence for a reduced rate of aerobic respiration where the sod was cut at 0.75 inch.

The mean ppm ethylene in the sod heating boxes were as follows:

0	12	24	48	72	96	Hours
0.28	0.21	1.31	1.26	1.13	1.04	ppm C_2H_4

Table 22. Percent carbon dioxide and oxygen changes occurring during storage in relation to cutting height on Merion Kentucky bluegrass sod harvested on June 17, 1969, and stored under simulated shipping conditions for 4 days

Hours of Storage	Percent Carbon Dioxide			Percent Oxygen		
		Cutting Ht. (in)			Cutting Ht. (in)	
	Mean	2	0.75	Mean	2	0.75
0	2.9	3.3	2.6**	17.0	16.5	17.5*
6	11.8	13.0	10.7**	7.4	5.9	9.0***
12	14.0	15.2	12.8***	4.5	3.1	5.8**
24	16.9	17.3	16.4*	2.0	1.7	2.4*
48	17.3	18.0	16.6*	2.7	2.1	3.3
72	18.4	18.7	18.0†	2.5	2.2	2.8
96	12.6	12.4	12.7	3.5	3.7	3.2

†, *, **, ***Differences between main effect means are significant at the .10, .05, .01, and .001 level of probability, respectively, for designated hours of storage.

The main effect means were not significantly different. At 48 hours the mean ppm ethylene in relation to N^6benzyladenine treatments were as follows:

0.85	2.60	1.15	0.04	ppm C_2H_4
0.0	.055	.055	.055	lb/A N^6benzyladenine
	0	5	10	application time in days before harvest

The differences between the main effect means were significant at the .10 level of probability. The ppm ethylene means were similar at 72 hours. This suggests that N^6benzyladenine may have more effect on ethylene production when applied immediately before harvest.

The percent leaf kill and root organic matter production data are presented in Table 23. The percent leaf kill tended to be less for sod cut at 0.75 inch. Also, the root production was less for sod cut at 0.75 inch. The degree of injury was quite low. Apparently, the sod cut at 2 inches was able to photosynthesize more carbohydrates for root production than sod cut at 0.75 inch. The mean percent leaf cover 20 days after transplanting was 92, 83, 69, and 56 after 24, 48, 72, and 96 hours of storage, respectively. Less injury occurred after 4 days of storage in this experiment than for other experiments. Possible explanations include (1) more than 6 weeks since a nitrogen application to the sod field, (2) no nitrogen in experimental treatments, (3) no seedhead production occurring. The initial soil and greenhouse temperatures were similar.

Table 23. Percent leaf kill and root production in relation to cutting height on Merion Kentucky bluegrass sod harvested on June 17, 1969, after storage under simulated shipping conditions for 4 days

Hours of Storage	Percent Leaf Kill			Root Organic Matter (mg/pot)		
		Cutting Ht. (in)			Cutting Ht. (in)	
	Mean	2	0.75	Mean	2	0.75
24	0.0	0.0	0.0	.043	.059	.026**
48	0.9	1.9	0.0†	.093	.122	.064**
72	2.8	5.6	0.0†	.110	.130	.091
96	30.0	40.0	20.0	.079	.079	.078

†, **Differences between main effect means are significant at the .10 and .01 level of probability, respectively, for designated hours of storage.

The most important result of this experiment was that N^6benzyladenine application at harvest or 5 or 10 days before harvest did not significantly affect temperature, carbon dioxide, oxygen, or ethylene levels during storage or leaf injury and cover and root production after transplanting.

Experiment VII (June 24, 1969)

This experiment compared 5 mowing treatments. They were cutting to (a) 0.50 inch the day of harvest, (b) 0.75 inch the day of harvest, (c) 0.75 inch 5 days before harvest, (d) 0.75 inch 10 days before harvest, and (e) the normal 2 inch height. The sod cut at 0.50 inch was severely defoliated with scarcely any green leaves remaining. The treatments were arranged in a randomized block design having three replications. The sod was harvested on June 24, 1969, and stored in the sod heating boxes for 4 days.

Results and discussion.--The mean moisture content of the sod at harvest was 65.4%. The air temperatures at 2 p.m. in the greenhouse where the sod was stored were as follows:

0	6	24	48	72	96	Hours
75	74	106	99	78	92	^{o}F

The main effect means for temperatures are presented in Table 24. The mean temperature increased rather slowly during the first 24 hours, but increased more rapidly during the second day. The sod mowed at 2 inches had the highest temperature at all times of measurement. The temperature of the sod cut at 2 inches was significantly higher than for low cut sod during the first 24 hours. None of the main effect means for the low cutting treatments were significantly different. Sod having the most green leaf tissue present had the highest temperatures.

The main effect means for percent carbon dioxide and oxygen are presented in Table 25. The rate of increase in CO_2 level and the rate of decrease in O_2 level over time was slower in this experiment than in the previous ones. Also, the level of O_2 remained somewhat higher than usual. There was significantly more CO_2 present in boxes containing sod cut at 2 inches than for any of the lower cutting heights

Table 24. Temperature (^{o}F) changes occurring during storage in relation to cutting heights and times on Merion Kentucky bluegrass sod harvested on June 24, 1969, and stored under simulated shipping conditions for 4 days

Hours of Storage	Mean	Cutting Ht. (in) and Time (days before harvest)				
		0.50 0	0.75 0	0.75 5	0.75 10	2 2
0	69.4	69.3b	69.3b	69.2b	69.3b	70.0a*
3	71.1	70.8b	71.0b	70.7b	70.8b	72.2a**
6	72.4	72.0b	72.3b	72.0b	71.8b	73.7a**
9	74.2	73.7b	74.0b	73.8b	73.5b	76.2a***
24	77.8	77.3b	77.2b	77.7b	77.3b	79.7a*
48	87.5	87.0	86.7	88.2	85.5	90.0
72	93.0	92.2	92.5	93.3	92.3	94.5
96	94.4	94.5	93.8	95.3	93.0	95.4

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for designated hours of storage.

Table 25. Percent carbon dioxide and oxygen changes occurring during storage related to cutting treatments on Merion Kentucky bluegrass sod harvested on June 24, 1969, and stored under simulated shipping conditions for 4 days

			Cutting Height (in) and Time (days)				
	Hours of		0.50	0.75	0.75	0.75	2
Data	Storage	Mean	0	0	5	10	2
% CO_2	0	3.0	3.3	3.0	2.8	2.7	3.3
	3	7.4	7.3bc	7.6b	6.8c	6.3c	9.1a**
	6	10.8	10.3c	10.9b	10.0cd	9.6d	13.3a**
	9	13.6	12.5	14.3	13.3	12.8	15.2
	24	17.3	16.5	17.4	16.9	17.1	18.6
	48	16.5	16.2	16.8	16.7	16.1	16.9
	72	19.5	19.2	19.4	19.1	19.0	20.6
	96	20.6	18.9d	20.3b	19.3cd	19.8b	24.5a**
% O_2	0	16.6	16.2	16.4	16.7	17.1	16.5†
	3	10.0	9.9c	9.9c	11.0b	11.5a	7.8d**
	6	6.3	7.7ab	5.4c	7.2b	8.0a	3.4d**
	9	4.7	5.9	4.4	4.5	5.5	3.2†
	24	4.3	6.4a	4.5b	4.2bc	3.6cd	2.9d*
	48	3.1	3.9	3.5	3.0	2.7	2.7†
	72	2.3	2.6	2.5	2.0	2.3	2.2
	96	2.4	3.1	2.5	2.9	2.0	1.7

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level or probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

at the 3, 6, and 96 hour CO_2 measurements. The pattern of differences among sod cut low was not consistent. Significantly less O_2 was present for the sod cut at 2 inches at the 3, 6, and 24 hour measurements. The pattern of differences in O_2 levels among sod mowed low was not consistent. The level of O_2 was significantly higher for sod cut at 0.50 inch than for sod cut at 0.75 inch after 24 hours of storage. In general the sod cut at 0.50 inch was statistically equal in CO_2 and O_2 level to one or two of the 0.75 inch mowing treatments according to Duncan's Multiple Range Test. Again, the evidence shows that CO_2 and O_2 levels were closely related to the amount of respiring tissue present.

No ethylene was found in gas samples collected at 0, 3, 6, and 9 hours. Only 0.27 ppm ethylene was found in samples collected at 24 hours. None of the main effect means were significantly different. The Varian Aerograph was not working when the 48, 72, and 96 hour samples were collected. Nevertheless, the very low levels of ethylene found at the beginning of the experiment suggest that the levels would also have been low at the end of the experiment. This sod had not received any nitrogen fertilization since May 1, 1969. Generally when the level of nitrogen nutrition was low in these experiments the ethylene content during storage was also low.

The main effect means for percent leaf kill and cover and root production are presented in Table 26. Sod was not removed from the boxes after 24 hours because of the

Table 26. Percent leaf kill, percent leaf cover, and root production in relation to cutting treatments on Merion Kentucky bluegrass sod harvested on June 24, 1969 after storage under simulated shipping conditions for 4 days

Data	Hours of Storage	Mean	Cutting Ht. (in) and Time (days)				
			0.50	0.75	0.75	0.75	2
			0	0	5	10	2
% Leaf kill	48	10.0	0.0	11.7	15.0	8.3	15.0
	72	22.7	0.0b	13.3b	15.0b	18.3b	66.7a*
	96	51.3	16.7	55.0	60.0	30.0	95.0†
% Leaf cover	48	74.0	55.0b	75.0a	75.0a	81.7a	83.3a**
	72	67.7	66.7	76.7	71.7	83.3	40.0†
	96	53.0	66.7	60.0	55.0	78.3	5.0†
Root organic matter (mg/pot)	48	40	28	32	34	43	64
	72	75	41	116	72	82	63
	96	38	52ab	49ab	13cd	69a	4d*

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

slow temperature increase. An average of only 10% leaf kill was observed on sod stored 48 hours. Sod stored 72 hours averaged 22% leaf kill. Significantly more sod injury occurred when cut at 2 inches than for any of the lower mowing treatments. Even though no injury was observed on sod cut at 0.50 inch, its percent injury was not statistically different according to Duncan's Multiple Range Test from that for the 0.75 inch mowing treatments. While not statistically significant, the trend was similar for sod stored for 96 hours.

The percent leaf cover 20 days after transplanting was significantly less for sod cut at 0.50 inch than for higher heights of cut for sod stored 48 hours. Trends in the data for sod stored 72 and 96 hours suggested that the 2 inch cutting height resulted in greater injury. This trend in the leaf cover data compliments the results of the leaf kill estimates.

The significant results for rooting of sod stored 96 hours do not reveal a pattern that can be explained.

The overall results of this experiment showed that low mowing within a few days of sod harvest was beneficial. The exact time and height of the low mowing were not critical.

Experiment VIII (July 30, 1969)

The Merion Kentucky bluegrass sod used in this experiment and the August 4, 1969 experiment came from a different field at Green Acres Turf Farm, Mason, Michigan than the sod used in the previous 1969 experiments. This field was seeded to Merion Kentucky bluegrass on August 12, 1968. Four hundred lb/A of 6-24-24 fertilizer was tilled into the organic soil during seedbed preparation. An additional 400 lb/A of 5-20-20 fertilizer was broadcast over the sod in early April of 1969. On April 21, May 5, June 2, and June 30, 1969, 150 lb/A of 45% N urea fertilizer was broadcast. The appearance of the sod was excellent. Its texture was finer than that of the sod used in the earlier 1969 experiments. Although the sod strength was adequate for marketing, it was not as strong as the sod used in the earlier experiments.

This experiment compares the effects of (a) 2 versus 0.75 inch cutting height, (b) 0 versus 215 lb/A nitrogen, and (c) 0 versus 0.055 lb/A of N^6benzyladenine. The 0.75 inch mowing was done 7 and 2 days before harvest. The nitrogen was applied 7 days before harvest. The N^6benzyladenine solution was applied 2 days before harvest. The sod was to have been harvested on July 28, 1969, but a sod cutter breakdown and rain caused a two day delay. The cultural treatments were arranged in a randomized block factorial design.

Results and discussion.--No response to either nitrogen or N^6benzyladenine treatments was visually detectable at harvest time. The mean percent moisture was 59.4. The sod cut at 2 inches had 61.5% moisture, while the sod cut at 0.75 inch had 57.4%. This difference in percent moisture at harvest was significant at the .001 level of probability.

The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

0	3	9	24	48	72	Hours
96	88	78	88	92	96	^oF

The mean temperatures in the sod heating boxes were as follows:

0	3	9	24	48	72	Hours
87.3	89.2	93.2	95.4	94.7	94.9	^oF

The main effect means were not significantly different. The initial sod temperature was higher than usual. Also, more sod injury occurred within 48 hours. These two factors may have prevented significant temperature differences from developing.

The main effect means for percent carbon dioxide and oxygen and ppm ethylene levels occurring during storage are presented in Table 27. At all times of measurement, except 24 hours, the percent CO_2 levels were significantly lower for sod cut at 0.75 inch. Nitrogen and N^6benzyladenine treatments did not affect either CO_2 or O_2 levels.

Table 27. Percent carbon dioxide, percent oxygen, and ppm ethylene changes during storage in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on July 30, 1969, and stored under simulated shipping conditions for 3 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
			2	0.75	0	215	0	.055
% CO_2	3	10.5	12.4	8.6***	10.8	10.2†	10.4	10.6
	9	13.4	15.4	11.4***	13.6	13.2	13.3	13.5
	24	17.3	17.6	17.1	17.9	16.8	18.2	16.4
	48	17.1	19.0	15.2**	16.8	17.4	16.9	17.3
	72	17.7	19.3	16.1**	17.9	17.5	17.4	18.0
% O_2	3	7.0	4.9	9.2***	7.1	7.0	7.3	6.8
	9	4.2	2.5	5.8***	4.0	4.3	4.2	4.1
	24	2.0	1.6	2.5**	2.0	2.1	2.0	2.0
	48	2.9	1.9	3.9*	3.0	2.9	3.1	2.7
	72	2.1	1.6	2.6*	1.8	2.4	2.3	1.9
ppm C_2H_4	3	0.21	0.26	0.16	0.11	0.31†	0.19	0.24
	9	0.67	1.11	0.22***	0.56	0.78	0.50	0.84*
	24	2.11	3.22	0.99***	2.14	2.08	2.21	2.00
	48	0.96	1.44	0.49***	0.79	1.14†	0.92	1.00
	72	1.20	1.70	0.71*	1.15	1.26	1.12	1.29

†, *, **, ***Differences between main effect means are significant at the .10, .05, .01, and .001 level of probability, respectively, for designated hours of storage.

Significantly more oxygen was found for sod cut at 0.75 inch at all times of measurement. The ppm ethylene was significantly lower for sod cut at 0.75 inch, except for the 3 hour ethylene measurement. The high nitrogen application, which usually stimulated ethylene production in earlier experiments, did not affect ethylene levels. Ethylene levels tended to be higher for high nitrogen levels at the 3 and 48 hour measurements. Significantly more ethylene was present at the 9 hour measurement where the sod had been treated with N^6benzyladenine.

A significant cutting height x N^6benzyladenine interaction occurred for ppm ethylene measured after 9 hours (Table 28). N^6benzyladenine applied to sod cut at 2 inches significantly increased ethylene level. Cutting at 0.75 inch significantly decreased the ethylene production of sod

Table 28. Significant (.05 level) cutting height x N^6benzyladenine interaction for ppm ethylene measured after 9 hours of storage of Merion Kentucky bluegrass sod harvested on July 30, 1969, and stored under simulated shipping conditions for 3 days

	N^6BA (lb/A)		
Cutting Ht. (in)	0	0.055	Simple Effects
2	0.75	1.48	+0.73**
0.75	0.25	0.20	-0.05
Simple Effects	-0.50	-1.28**	

**Differences are greater than LSD at .01 level.

treated with N^6benzyladenine. In other words, sod cut at 2 inches and treated with N^6benzyladenine produced the most ethylene in this instance. This interaction was not significant for later ethylene measurements and the only trend within those interactions was for higher ethylene levels with the 2 inch cutting height.

The main effect means for percent leaf kill and cover and root production after storage are presented in Table 29. Less leaf kill occurred on sod cut at 0.75 inch and the difference was significant after 48 and 72 hours of storage. Conversely, more leaf cover was present for low cut sod. Neither nitrogen nor N^6benzyladenine treatments affected the percent leaf kill or cover. Root production was quite low. Low cut sod stored for 48 hours produced significantly more roots than sod cut at 2 inches. Sod treated with N^6benzyladenine produced significantly less root organic matter than untreated sod after 24 hours of storage. Nitrogen level did not affect rooting.

Nitrogen fertilization did not affect any of the measurements taken during the course of the experiment. This was unusual. In previous experiments nitrogen level affected temperature, gas levels (especially ethylene), and percent leaf kill and cover. The "zero" nitrogen sod had already received 290 lb/A of nitrogen during 1969. Perhaps the sod was already so heavily fertilized with nitrogen that response to additional nitrogen could not occur. The high initial sod temperature (87° F) was a more likely cause for

Table 29. Percent leaf kill, percent leaf cover, and root production after storage in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments on Merion Kentucky bluegrass sod harvested on July 30, 1969, and stored under simulated shipping conditions for 3 days

Measurement	Hours of Storage	Mean	Cutting Ht. (in)		Nitrogen (lb/A)		N^6BA (lb/A)	
			2	0.75	0	215	0	.055
% Leaf kill	24	28.8	31.2	26.2	17.5	40.0	27.5	30.0
	48	84.4	100.0	68.8**	81.2	87.5	86.9	81.9
	72	94.4	100.0	88.8*	92.5	96.2	95.0	93.8
% Leaf cover	24	63.1	57.5	68.8	71.2	55.0	67.5	58.8
	48	18.8	0.0	37.5**	21.9	15.6	16.9	20.6
	72	2.8	0.0	5.6**	3.8	1.9	2.5	3.1
Root organic matter (mg/pot)	24	8	9	8	9	7	12	4**
	48	20	0	40***	24	16	17	23
	72	8	0	15	6	9	11	4

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for designated hours of storage.

masking or lack of nitrogen response. In the August 4, 1969 experiment which used the same sod source the high nitrogen treatments resulted in significant changes in gas levels and percent leaf kill and cover and root production; the mean initial sod temperature was 78° F.

Experiment IX (August 4, 1969)

This experiment compared the effects of (a) harvest time (9 a.m. vs 2 p.m.) and (b) 0, 130, and 215 lb/A of nitrogen. The sod was cut in the field at 9 a.m. and 2 p.m. and the boxes were closed in the greenhouse by 10 a.m. and 3 p.m., respectively. The measurements were made separately for sod cut at 9 a.m. and 2 p.m. The nitrogen was applied 5 days before harvest. The treatments were arranged factorially in a randomized block design. The sod was from the source described for the July 30, 1969 experiment. The sod was harvested on August 4, 1969, and stored in the sod heating boxes for 3 days.

Results and discussion.--No response to nitrogen was visible at harvest time. The mean percent moisture was 61.0 and the main effect means were not significantly different. The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

0	3	6	9	24	48	72	Hours
95	95	87	75	95	105	100	°F

The main effects means for temperature are presented in Table 30. Initially the sod harvested at 9 a.m. was 10° F cooler than that harvested at 2 p.m. This has great practical significance for sod producers and shippers. Clearly, early morning harvesting gives an extra margin of protection against sod heating damage during shipment. After 24 hours the sod harvested in the morning was 6° F cooler. At every time of measurement sod harvested in the morning was cooler than sod harvested in the afternoon and the difference was statistically significant during the first 48 hours. The rate of heating was greater for sod harvested in the morning. After 72 hours of storage the initial 10° F difference was reduced to only 1.5° F. This suggests that as temperatures increase within the sod stack the rate of energy release from respiration decreases.

The main effect means for percent carbon dioxide and oxygen and ppm ethylene changes occurring during storage are presented in Table 31. Significantly higher levels of CO_2 were found at 3 and 6 hours for sod harvested at 2 p.m. Significantly less O_2 was present after 3 hours of storage for sod harvested in the afternoon. As noted above, the temperatures were higher for sod harvested in the afternoon. These results suggest that sod harvested in the afternoon had a higher rate of respiration during the early hours of storage.

Table 30. Temperature (^{o}F) changes occurring during storage in relation to time of harvest and nitrogen treatments on Merion Kentucky bluegrass sod harvested on August 4, 1969, and stored under simulated shipping conditions for 3 days

Hours of Storage	Mean	Harvest Time		Nitrogen (lb/A)		
		9 a.m.	2 p.m.	0	130	215
0	78.3	73.5	83.1***	78.1	78.2	78.5
3	80.5	74.5	86.5***	80.2	80.9	80.4
6	83.1	77.6	88.6***	83.0	83.0	83.3
9	85.8	80.6	91.9***	85.9	85.5	86.1
24	90.5	87.8	93.3**	89.5	90.4	91.8
48	94.5	92.7	96.3**	94.0	94.1	95.4
72	95.6	94.8	96.3	94.9	94.5	96.4

**, ***Differences between main effect means are significant at the .01 and .001 level of probability, respectively, for designated hours of storage.

Table 31. Percent carbon dioxide, percent oxygen, and ppm ethylene changes occurring during storage in relation to harvest time and nitrogen treatments on Merion Kentucky bluegrass sod harvested on August 4, 1969, and stored under simulated shipping conditions for 3 days

Measurement	Hours of Storage	Mean	Harvest Time		Nitrogen (lb/A)		
			9 a.m.	2 p.m.	0	130	215
% CO_2	3	10.8	9.4	12.2**	10.3	11.1	10.9
	6	14.4	13.1	15.7***	13.7b	15.0a	14.5ab*
	24	16.1	15.9	16.3	16.0	16.6	15.8
	48	17.9	18.5	17.4**	17.0b	18.2a	18.6a**
	72	17.9	18.4	17.4*	17.3	18.1	18.3†
% O_2	3	5.5	6.7	4.4***	7.1a	4.6b	4.8b**
	6	2.4	2.6	2.2	3.3a	2.0b	1.9b*
	24	2.6	2.9	2.4	2.4	2.9	2.6
	48	1.9	2.1	1.8	2.1	1.8	1.9
	72	1.6	1.8	1.4	1.3	1.8	1.8
ppm C_2H_4	3	0.42	0.47	0.38	0.02b	0.68a	0.58a***
	6	0.77	0.77	0.77	0.12b	1.02a	1.15a***
	24	3.32	3.02	3.62	2.48	3.85	3.62
	48	2.29	2.27	2.32	1.40b	2.42a	3.05a**
	72	1.00	0.80	1.20	0.90	1.10	1.00

†, *, **, ***Differences between main effect means are significant at the .10, .05, .01, and .001 level of probability, respectively, for designated hours of storage. Main effects means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

The CO_2 levels in relation to time of harvest were not different at 24 hours. The sod harvested in the morning had released more CO_2 after 48 and 72 hours of storage. This suggests that sod harvested at 9 a.m. had a higher rate of respiration during the last 2 days of the experiment. Sod harvested in the morning heated faster than sod harvested in the afternoon. This was also evidence for a higher rate of respiration for sod harvested in the morning.

Nitrogen levels affected the levels of CO_2 and O_2 significantly. More CO_2 was evolved where nitrogen treatments had been made. The CO_2 level for the zero nitrogen treatment was significantly lower after 6 hours than for the 130 lb/A nitrogen treatment. The CO_2 level for the 215 lb/A nitrogen treatment was intermediate. Both the 130 and 215 lb/A nitrogen treatments resulted in higher levels of CO_2 than the zero nitrogen treatment at 48 hours. The trend was similar after 72 hours. Less O_2 was found at 3 and 6 hours for sod treated with 130 and 215 lb/A of nitrogen. These results indicate that nitrogen stimulated respiration. The significant harvest time x nitrogen rate interaction suggests that, at 6 hours, nitrogen was effective in stimulating respiration only at the higher temperature present for sod harvested at 2 p.m. (Table 32).

In spite of the fact that large differences in temperature were present, time of harvest did not affect ethylene production. Less ethylene was found for the zero

Table 32. Significant (.05 level) harvest time x nitrogen rate interaction on Merion Kentucky bluegrass sod harvested on August 4, 1969, and stored under simulated shipping conditions

			Nitrogen (lb/A)					
	Hours of		0	130	215	Simple Effects		
Measurement	Storage	Harvest Time	a_1	a_2	a_3	a_2-a_1	a_3-a_1	a_3-a_2
% CO_2	6	9 a.m.	13.0	13.4	12.8	0.4	-0.2	-0.6
		2 p.m.	14.3	16.5	16.2	2.2**	1.9*	-0.3
Simple Effects			1.3*	3.1**	3.4**			

*, **Differences are larger than LSD at the .05 and .01 level of probability, respectively.

nitrogen treatment at all times of measurement. The differences were significant at 3, 6, and 48 hours (Table 31). Ethylene production was independent of temperature and was greatest where supraoptimal levels of nitrogen were applied.

The main effect means for percent leaf kill and cover and root production are presented in Table 33. Harvest time affected temperature and CO_2 and O_2 levels during storage, but these effects were not reflected in the percent leaf kill and cover data. An unusually high percent of leaf kill (61.2%) had occurred after 24 hours of storage. The CO_2 levels were about the same. Perhaps these two factors masked the effect of harvest time (temperature) on leaf kill. Nearly all the plants were dead after 48 hours of storage. There was a tendency for more root production from sod harvested at 2 p.m. after 24 hours of storage. Significantly more leaf injury and less leaf cover and root production occurred for sod that received the supraoptimal nitrogen treatments.

Experiment X (August 18, 1969)

This experiment compared sod from two sod sources; one source was from an MSU sod production fertilization experiment and the other was from a typical commercial sod producer.

The MSU sod production fertilization experiment was conducted on organic soil at the Michigan State University Muck Experimental Farm. This soil had received very little

Table 33. Percent leaf kill, percent leaf cover, and root production after storage in relation to harvest time and nitrogen treatments on Merion Kentucky bluegrass sod harvested on August 4, 1969, and stored under simulated shipping conditions for 3 days

Measurement	Hours of Storage	Mean	Harvest Time		Nitrogen (lb/A)		
			9 a.m.	2 p.m.	0	130	215
% Leaf kill	24	61.2	61.7	60.8	5.0b	85.0a	93.8a***
	48	97.9	97.5	98.3	93.8b	100.0a	100.0a**
	72	100.0					
% Leaf cover	24	57.9	47.5	68.3	93.8a	58.8ab	21.2b*
	48	2.1	2.5	1.7	6.2a	0.0b	0.0b**
	72	0.0					
Root organic matter (mg/pot)	24	135	101	168†	270a	105a	28b**
	48	3	4	2	8a	0b	0b*
	72	0					

†, *, **, ***Differences between main effect means are significant at the .10, .05, .01, and .001 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

fertilization prior to establishing the experiment and was considered low in fertility. No fertilizer was applied to the plots during seedbed preparation or during the fall of 1968. Merion Kentucky bluegrass was seeded on August 25, 1968, at a rate of 50 lb/A. The sod production experiment was designed to compare the effects of 0, 90, 180, and 360 lb/A of nitrogen on sod strength and appearance. Nitrogen from urea fertilizer was applied on June 10, July 10, and August 15, 1969. One-third of the total nitrogen (30, 60, and 120 lb/A) was applied at each date of application. A zero nitrogen plot was included in each of the 3 replications. All the plots received one inch of irrigation water after each fertilizer application. Mowing was at a 2 inch height twice a week. All plots had an adequate stand of grass. The sod in all plots was strong enough for easy handling. The mean percent moisture of the 4 MSU sods was 58.5 when harvested for use in the sod heating experiment on August 18, 1969.

The commercial sod was produced on organic soil at the Halmich Sod Farm near East Lansing, Michigan. After tilling in 1,000 lb/A of 5-20-20 fertilizer during seedbed preparation, the field was seeded to Merion Kentucky bluegrass at a rate of 50 lb/A on August 15, 1967. In early May of 1968, 250 lb/A of 16-8-8 fertilizer was applied. Prilled urea was applied at 200, 100, 200, and 50 lb/A on June 15 and October 1 of 1968 and May 5 and August 1 of 1969, respectively. A total of 340 lb/A of nitrogen was applied during the 2 year period of sod production. No irrigation was used. Mowing was at a 2 inch height 3 times a week. This sod had outstanding turfgrass quality and was in strong, marketable condition. On August 18, 1969, the sod contained 68% moisture. This was significantly higher than for the MSU sod.

The sod from the 2 sources differed in many respects. Field history, moisture level, mowing and irrigation practices, age of the sod, and nitrogen fertilization levels differed considerably. The appearance of the sod also differed greatly. On a visual rating scale of turfgrass quality (1 to 9: 1 = best) the commercial sod was rated 1 whereas MSU sod was rated, 2, 4, 6, and 8 for sod which received 360, 180, 90, and 0 lb/A of nitrogen, respectively. Figure 6 shows a comparison of the zero nitrogen--MSU sod and the commercial sod.

The 5 sods were compared in a one-way analysis of variance randomized block experiment having 3 replications. The sod was harvested on August 18, 1969, and stored in the sod heating boxes for 5 days. The boxes were left open during the first 24 hours of the experiment because the weights were too high in some boxes.

Results and discussion.--The air temperatures at 2 p.m. in the greenhouse room where the sod was stored were as follows:

0	3	9	24	48	72	96	120	Hours
99	90	88	108	115	110	95	102	°F

Figure 6. Visual comparison of sod produced with 0 and 340 lb/A of nitrogen.

The main effect means for temperature are presented in Table 34. The temperature increased progressively with nitrogen level for 9 through 72 hours and commercial sod (designated as 340 lb/A of N in the tables) had the highest temperature. At 96 and 120 hours the temperature increased progressively with nitrogen level for the 4 MSU sods. The temperature of the commercial sod was lower. The commercial sod appeared to be the most actively growing and the temperature data suggests that it had the highest respiration rate. The commercial sod may have depleted its readily respirable carbohydrates enough to result in a temperature drop after 96 and 120 hours of storage. The overall results suggest a direct positive relationship between level of nitrogen nutrition and respiration rate.

The main effect means for percent carbon dioxide and oxygen are presented in Table 35. The CO_2 levels remained lower than for the other experiments while the O_2 levels were higher. The unusually small changes in CO_2 and O_2 levels during the first 24 hours was attributed to diffusion losses because the boxes were open. Even after closing the boxes the CO_2 level remained 5 to 7% lower than in previous experiments and the O_2 levels remained about 5% higher. Apparently the rate of respiration of the sod used in this experiment was unusually low.

Table 34. Temperature (^{o}F) changes occurring during storage in relation to nitrogen applied during production of Merion Kentucky bluegrass sod harvested on August 18, 1969 and stored under simulated shipping conditions for 5 days

Hours of Storage	Mean	Nitrogen (lb/A)				
		0	90	180	360	340
0	82.0	82.2	83.3	82.5	84.7	81.9
3	84.4	83.7	84.5	84.0	85.3	84.5
9	88.0	86.2d	86.7cd	87.8bc	89.2ab	90.2a**
24	90.4	87.8d	88.7cd	90.2bc	92.0ab	93.2a**
48	93.4	90.7c	91.7c	93.3bc	95.0ab	96.2a**
72	93.1	90.3c	91.8bc	93.5abc	94.7ab	95.3a*
96	94.6	91.7c	93.8b	95.3ab	96.7a	95.3ab**
120	93.7	90.8c	93.5b	94.8ab	96.3a	92.8bc**

*, **Differences between main effect means are significant at the .05 and .01 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

Table 35. Percent carbon dioxide and oxygen occurring during storage in relation to nitrogen applied during production of Merion Kentucky bluegrass sod harvested on August 18, 1969, and stored under simulated shipping conditions for 5 days

Measurement	Hours of Storage	Mean	Nitrogen (lb/A)				
			0	90	180	360	340
% CO_2	3	3.2	3.1b	2.5b	2.9b	2.9b	4.4a**
	9	2.8	2.9b	2.1c	2.3bc	2.6bc	4.0a**
	24	3.0	3.1b	2.2a	2.6bc	2.9bc	4.3a**
	48	11.2	9.1	9.5	9.3	12.0	16.2†
	72	9.6	8.3	9.1	9.7	10.8	10.1
	96	10.8	7.4c	10.1b	9.9bc	13.8a	12.9a**
	120	13.2	9.7	13.4	13.5	15.1	14.5†
% O_2	3	18.1	17.5bc	19.1a	18.5ab	18.3ab	17.2c*
	9	18.6	18.7ab	19.5a	18.9ab	18.5b	17.4c**
	24	17.9	17.9a	18.6a	18.2a	18.2a	16.4b*
	48	7.5	10.6	9.5	9.7	5.9	1.9
	72	7.5	10.7	7.4	7.2	5.3	6.7
	96	7.5	12.5a	8.5ab	8.1ab	3.8b	4.6b*
	120	5.9	10.2	5.6	5.3	3.8	4.6

†, *, **Differences between main effect means are significant at the .10, .05, and .01 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

The commercial sod released significantly more CO_2 during the first 24 hours than any of the other sods. The CO_2 levels were similar among the MSU sods. Commercial sod used significantly more O_2 during the first 24 hours than any of the other sods (except zero nitrogen sod at 3 hours). The O_2 levels were similar among the MSU sods. These corresponding results showed that the commercial sod was respiring faster than the other sods during the first 24 hours.

The CO_2 level was significantly higher for the 360 lb/A nitrogen treatment and the commercial sod than for any of the others at 96 hours. The zero nitrogen sod had a significantly lower CO_2 percentage than the other treatments at 96 hours, except for the 180 lb/A nitrogen level. Similar trends were evident at 120 hours. This also supports the hypothesis that respirable substrates were becoming less available in the commercial sod near the end of the experiment.

The O_2 percentage of the atmosphere within the sod stacks decreased as the nitrogen levels increased at 96 hours of storage.

The mean ppm ethylene were as follows:

9	24	48	72	96	120	Hours
.05	.05	.06	.14	.04	.05	ppm C_2H_4

These levels were much lower than usual. This was expected since the average level of nitrogen used on the sod in this experiment was less than the zero nitrogen treatment of other experiments.

The main effect means for percent leaf kill and cover and root production are presented in Table 36. The mean percent leaf kill increased slowly over time and reached about 70% after 5 days of storage. The nitrogen levels did not affect leaf injury. A trend showing a step-wise increase in percent kill with increasing nitrogen levels was present at 96 hours.

The leaf cover was significantly lower on sod that received the 2 highest nitrogen levels than for sod that received the 2 lowest nitrogen treatments, for sod that had been stored for 96 hours. Nitrogen treatment did not affect leaf cover for the other times of storage.

The root production for sod that had been stored 24 hours was higher for the sod treated with 0 and 90 lb/A nitrogen than for sod treated with 360 and 340 lb/A of nitrogen. A similar trend was present for sod that had been stored 96 hours.

In summary, the sod grown with 0 and 90 lb/A of nitrogen produced less heat during storage and more leaf cover and roots after transplanting than commercial sod. Satari (1967) found that 5-month-old sod produced on organic soil without nitrogen fertilization had high yields (a) of rhizomes and roots, (b) total available carbohydrates, and (c) sod strength. He also found that 15 lb/A/month of nitrogen gave a good balance of high sod strength, high

Table 36. Percent leaf kill, percent leaf cover, and root production after storage in relation to nitrogen applied during production of Merion Kentucky bluegrass sod harvested on August 18, 1969, and stored under simulated shipping conditions for 5 days

Measurement	Hours of Storage	Mean	Nitrogen (lb/A) 0	90	180	360	340
% Leaf kill	24	2.3	10.0	0.0	0.0	1.7	0.0
	48	6.7	18.3	0.0	1.7	11.7	1.7
	72	15.7	20.0	5.0	0.0	43.3	10.0
	96	48.3	10.0	25.0	51.7	88.3	66.7†
	120	68.7	56.7	61.7	43.3	98.3	83.3
% Leaf cover	24	96.3	91.7	98.3	98.3	96.7	96.7
	48	92.0	73.3	98.3	100.0	91.7	96.7
	72	84.3	83.3	91.7	98.3	58.3	90.0
	96	46.7	83.3a	70.0a	51.7ab	11.7b	16.7b*
	120	35.3	46.7	43.3	58.3	1.7	26.7
Root organic matter (mg/pot)	24	64	106a	114a	55ab	26b	18b*
	48	47	42	70	74	31	18
	72	54	37	75	62	82	16
	96	34	64	77	11	13	7†
	120	33	54	41	40	1	27

†, *Differences between main effect means are significant at the .10 and .05 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

yield of rhizomes, roots, and total available carbohydrates, and desirable green color. The results of both experiments suggest that it would be desirable to use less nitrogen during the production of commercial sod.

Experiment XI (October 24, 1969)

The objective of this experiment was to make a quantitative determination of the available and storage carbohydrates present during the sod heating process. Two sod heating boxes were used. The general methods of handling the sod were the same as for earlier sod heating box experiments.

The sod source was the commercial sod described for the August 24, 1969 experiment. It was 2 years old, high in quality, and had received a total of 340 lb/A of nitrogen during its production. The sod had an initial temperature of only 43° F. Two light frosts had occurred in the field. The sod still had a dark green color but the low temperature hardening process was probably under way.

Turfgrass stems were collected for carbohydrate analysis at the beginning of the experiment and after 1, 2, 3, 5, 9, 11, and 13 days when sod pieces were removed for transplanting as 6 inch diameter plugs. Individual plants were torn from the center portion of the sod piece. The roots were clipped off at the crown. Brown leaves were peeled away and the remaining leaves were cut off at a 0.75 inch height. The stems were dried in a forced air oven at

100° C for 48 hours and ground through a 40 mesh screen in a Wiley mill. The ground stems were stored in small vials at 70° F until the carbohydrate analysis was performed.

Okajima and Smith (1964) found that 85% of the storage carbohydrates in common Kentucky bluegrass stem bases were water soluble fructosans and reducing sugars. Therefore, the cold water extraction method was used (Smith, Paulsen, and Raguse, 1964). Each ground sample was redried and a weighed portion of about 100 mg was shaken vigorously for 1 hour in 15 ml of boiled distilled water in a 50 ml Erhlenmeyer flask. The mixture was filtered through Whatman No. 1 paper under suction. The filtrate was made up of 50 ml in volumetric flasks with distilled water.

The analysis for total available carbohydrate was conducted as follows: a 1 ml aliquot of the diluted filtrate was transferred to a 10 ml test tube. One ml of 0.2 N H_2SO_4 was added to hydrolyze glycosidic linkages in fructosans and other nonreducing sugars. The solution was heated for 30 minutes in a boiling water bath and then cooled in ice water. Two ml of 3,5-dinitrosalicylic acid solution was added to detect reducing sugar (Bernfeld, 1951). The solution was heated for 15 minutes in boiling water bath and then cooled. The absorbance was measured with a Coleman Spectronic 20 spectrophotometer set at 540 mμ. Two standards, one containing 0.2 mg/ml and another containing 0.5 mg/ml of Beta-D-fructose were analyzed with each group of 12 samples. Duplicate determinations were made for each sample. The percent total available carbohydrates (TAC) was calculated using the following equation.

$$\% \text{ TAC} = \left[\frac{(Std_2 - Std_1)\ A_s}{A_{Std_2} - A_{Std_1}} + b \right] \left(\frac{\text{dilution x } 100}{Wt_s} \right)$$

where: Std_2 = 0.5 mg/ml of fructose

Std_1 = 0.2 mg/ml of fructose

A_s = absorbance of sample

A_{Std} = absorbance of standard

Wt_s = weight of sample (mg)

$$b = \text{correction for slope} = \left[\frac{(Std_2 - Std_1)\ A_{Std_2}}{A_{Std_2} - A_{Std_2}} \right]$$

Results and discussion.--The data collected during this experiment are presented in Table 37. The relationship of percent TAC, leaf kill, and root production over time is presented in Figure 7. The percentage of TAC in the stem tissue remained constant during the first 5 days of storage and then declined steadily. Leaf injury occurred after 3 days of storage, increased rapidly from 20 to 90% between 5 and 9 days of storage, and increased to 100% leaf kill between 9 and 13 days of storage. The decline in TAC and the increase in leaf injury were directly proportional between 5 to 13 days of storage. The explanation for the occurrence of leaf kill 2 days before the decline in TAC is that leaf tissue was not included in the stem bases analyzed

Table 37. Percent total available carbohydrate, reducing sugar plus sucrose, fructosan, leaf kill, leaf cover, carbon dioxide, oxygen, temperature, and root production data for commercial sod harvested on October 24, 1969, and stored under simulated shipping conditions for 13 days

Days of Storage	Total Available Carbohydrate (%)	Leaf Kill (%)	Leaf Cover (%)	CO_2 (%)	O_2 (%)	Temp. (^oF)	Roots (mg/pot)
0	28.6	0	100	0.6	17.2	43	180
2	27.0	0	100	13.4	3.3	78	20
3	27.4	10	90	14.4	1.9	86	90
5	27.8	20	70	17.5	0.9	88	90
7	23.8	55	45	17.5	1.9	89	70
9	17.5	90	22	17.8	2.0	88	70
11	14.1	95	7	15.8	2.1	86	40
13	12.8	100	4	11.0	9.1	84	20

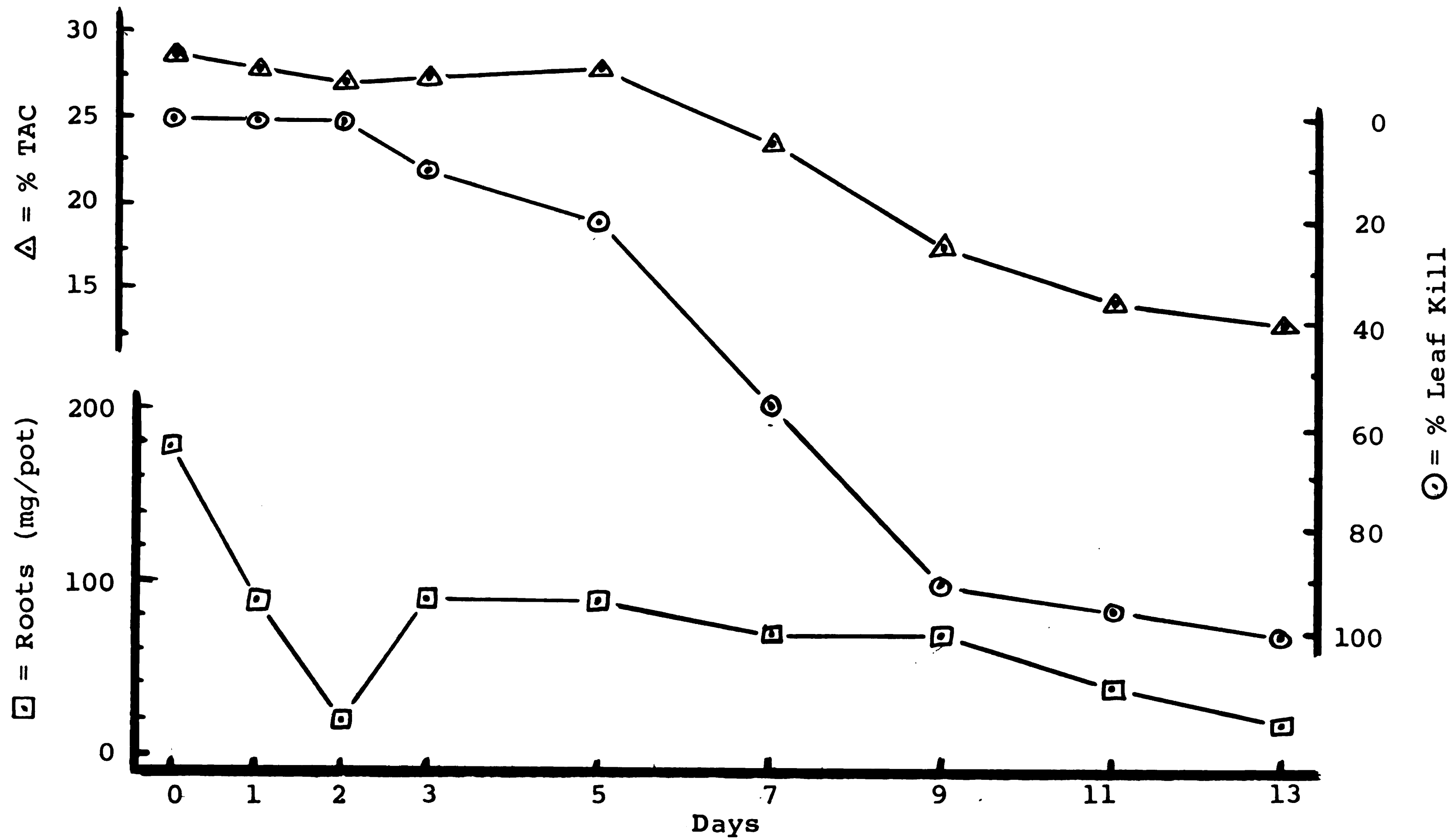

Figure 7. Percent total available carbohydrates, root production, and percent leaf cover in relation to storage under simulated shipping condition for 13 days for commercial sod harvested on October 24, 1969.

for TAC content. It seems likely that TAC levels in the leaves declined before leaf kill. The largest decline in root production occurred after only 1 day of storage. Initially, root production appeared to be more sensitive to sod temperature than to TAC. The low root production after 2 days occurred because of some unknown causes. The decline in root production that occurred between 5 and 13 days of storage was approximately proportional to the decline in TAC. A good correlation existed among TAC depletion, increased leaf kill, and reduced root production, yet water soluble carbohydrates were not exhausted. The extent, if any, of the contribution of carbohydrate depletion to sod injury can not be determined from this data.

Youngner and Nudge (1968) found 22% TAC in stem bases of 13-week-old Merion Kentucky bluegrass which had grown for 8 weeks with 45° F night and 60° F day temperatures and a 16 hour day with 3000 ft-c of light intensity. Initially, the Merion Kentucky bluegrass used in the October sod heating study contained 28.6% TAC in the stem bases. The higher TAC value was expected because the sod was growing in more intense light and was more mature. The sod temperature (43° F) was lower so more hardening was occurring.

The most unusual result of this experiment was that high percentages of leaf kill did not occur until after 9 days of storage. This was 2 to 3 times longer than for earlier experiments. The lower initial respiration rate and presumably higher levels of storage carbohydrates, because the grass was partially hardened for winter, probably contributed to the longer survival time. The build-up of carbon dioxide and depletion of oxygen was much slower than usual. The initial sod temperature of 43° F was roughly 30° F lower than for earlier experiments. The sod temperature increased to the high 80's after 3 days of storage, but this temperature level was about 7° F lower than usual. The greenhouse air temperatures were 20 to 30° F lower and this undoubtedly resulted in greater heat loss and reduced temperature build-up in the sod heating boxes. The lower temperature levels provide the most likely explanation for the longer storage life of the sod.

CONTROLLED ATMOSPHERE STUDIES

The purpose of the controlled atmosphere studies was to determine the effects of carbon dioxide (CO_2), oxygen (O_2), and ethylene (C_2H_4) levels on Merion Kentucky bluegrass sod. The sod heating box experiments gave considerable information on the levels of CO_2, O_2, and ethylene in relation to cultural treatments that occur during storage under simulated shipping conditions, but no information on the direct effects of these gases on sod injury. Further information on the physiological mechanisms involved in sod heating and damage was obtained by storing sod under controlled conditions in atmospheres containing 0, 9, 18, and 27% CO_2, and 0, 2, 4, 8, and 16% O_2, and 0, 2, 4, and 8 ppm ethylene in factorial combinations.

<u>Methods and Materials for Controlled Atmosphere (CA) Studies</u>

The following paragraphs describe the methods and materials used in these studies.

<u>Gas mixtures</u>.--Prepared gas mixtures were purchased from The Matheson Company, Inc., at Joliet, Illinois. The gas mixtures ordered and the gas content of the mixtures received are presented in Table 38. The gas content was

Table 38. Prepared gas mixtures ordered and actual analysis (in parentheses) of gas mixtures received and used

CO_2 - O_2 - C_2H_4[a] (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)
0 - 0 - 0 (0.0 - 0.0 - 0.0)		0 - 0 - 4 (0.1 - 0.9 - 4.5)	
18 - 0 - 0 (17.6 - 0.2 - 0.0)			
0 - 2 - 0 (0.1 - 2.0 - 0.0)	0 - 2 - 2 (0.1 - 2.3 - 2.3)	0 - 2 - 4 (0.1 - 2.2 - 4.2)	0 - 2 - 8 (0.1 - 2.3 - 9.1)
9 - 2 - 0 (8.6 - 2.1 - 0.0)			
18 - 2 - 0 (17.7 - 2.3 - 0.0)	18 - 2 - 2 (17.6 - 2.3 - 2.2)	18 - 2 - 4 (17.8 - 2.0 - 4.0)	18 - 2 - 8 (17.9 - 2.1 - 7.9)
27 - 2 - 0 (28.4 - 2.8 - 0.0)			
0 - 4 0 (0.1 - 4.6 - 0.0)	0 - 4 - 2 ((0.1 - 4.5 - 2.3)	0 - 4 - 4 (0.1 - 4.6 - 4.7)	0 - 4 - 8 (0.1 - 4.6 - 9.0)
18 - 4 - 0 (16.9 - 4.6 - 0.0)	18 - 4 - 2 (16.9 - 4.5 - 2.0)	18 - 4 - 4 (16.8 - 4.6 - 4.1)	18 - 4 - 8 (17.4 - 4.6 - 8.1)
0 - 8 - 0 (0.1 - 7.8 - 0.0)			
9 - 8 - 0 (8.6 - 8.7 - 0.0)			
18 - 8 - 0 (16.6 - 8.1 - 0.0)		18 - 8 - 4 (16.9 - 9.0 - 4.1)	
27 - 8 - 0 (27.6 - 9.0 - 0.0)			
0 - 16 - 0 (0.0 - 16.1 - 0.0)			0 - 16 - 8 (0.1 - 16.1 - 8.3)
18 - 16 - 0 (16.6 - 15.6 - 0.0)			

[a]The remainder of each mixture was nitrogen gas.

determined by analyzing small samples with the Vapor Fractometer and the Varian Aerograph gas chromatographs. The cylinders were the 1A size (9 inches in diameter x 52 inches in length) and contained approximately 220 cu ft of gas. The selection of gas mixtures was based on consideration of the questions to be answered by the research and statistical requirements.

General methods for CA studies.--The overall apparatus for the controlled atmosphere studies is shown in Figure 8. A two-stage pressure regulator was connected to each gas cylinder. The outlet from each regulator was equipped with a needle-type metering valve. Tygon tubing, having a 0.25 inch inside diameter was connected to the CA chambers. Three of the chambers were connected in series to each cylinder. Five 6 inch diameter sod pieces were placed in each chamber at the beginning of each gas experiment. The gas flow was measured with a small plastic flowmeter and adjusted with the metering valve. One sod piece was removed from each chamber every 24 hours and transplanted to a sand-filled pot in the greenhouse. A dark growth chamber was used to maintain a constant 86° F temperature.

CA chambers.--The CA chambers were made from 8 qt polyethylene buckets (Figure 9). Two quarts of cement were poured into each bucket to reduce the volume of the chambers and therefore the amount of gas required. The buckets were completely lined with Visqueen pressure tape to seal against ethylene loss. A small rack was built and used to hold the

Figure 8. Overall apparatus for controlled atmosphere experiments showing gas delivery and flow metering system.

Figure 9. Controlled atmosphere bucket chambers. The lid, gas inlet tube, rack, and arrangement of sod pieces are shown.

sod pieces 0.5 inch above the bottom of the chamber. The arrangement of the 5 sod pieces inside the chambers was as follows: 4 were set on edge around the wall of the chamber with the grass facing inward and the fifth was set on edge in the middle. The chamber lid was made from a fruit storage can lid which fit snugly inside the top of the bucket. Two 0.25 inch diameter by 2 inch long pipes were inserted through the lid and brazed into place. The inlet pipe had a 10 inch length of tubing attached. The end of this tubing was placed under the rack as the chambers were closed. This was done to increase the uniformity of gas flow around the sod pieces. The lids were sealed with pressure tape.

Gas flow rates.--The gas flow rate was set at 0.6 cu ft per hour. Measurements showed that each chamber contained about 0.15 cu ft of free space when the 5 sod pieces were in place. The atmosphere within each chamber was changed 4 times per hour. The gas flow rate was measured by attaching a small flowmeter to the outlet of the third chamber in each series. The needle valve was used to adjust the flow rate. The flow rate was set daily after removing the sod piece. It was checked and adjusted, if necessary, at about 8 hour intervals.

The composition of the gas in each chamber was checked each day just before removing the sod piece. The inlet and outlet pipes were capped with sleeve-type rubber stoppers. A 10 cc gas sample was withdrawn with a needle syringe and analyzed. The percent carbon dioxide generally increased a few tenths of a percent between chambers 1 and 3 of the series. The percent oxygen decreased slightly over the series. Ethylene levels decreased somewhat, especially for gas mixtures containing 8 ppm ethylene. Nevertheless, the 0.60 cu ft per hour flow rate which changed the atmosphere in the chambers 4 times per hour was satisfactory for these experiments.

Sod source.--The Merion Kentucky bluegrass sod was obtained from the source described for the August 24, 1969 experiment. It was high in quality, two years old, and had received a total of 340 lb/A of nitrogen during its production period. The sod was harvested between September 22 and October 21, 1969. Some hardening of the sod was probably occurring during this period of time.

Gas experiments.--Five gas experiments were performed. At the beginning of each gas experiment the sod was cut at a 0.75 inch depth and into 6 inch diameter pieces. Five sod pieces were arranged over the racks inside each chamber and the lids were sealed. Six gas mixtures were selected. Each cylinder was connected with tubing to a series of 3 chambers. One sod piece was removed from each chamber every 24 hours. The sod pieces were transplanted to pots filled with sand and placed under the mist irrigation system in the greenhouse. Visual estimates of percent leaf kill were made 2 days after transplanting.

Visual estimates of percent leaf cover were made 30 days after transplanting. Then the root organic matter production was determined using the methods described earlier. The initiation dates, temperature and percent moisture of the sod, and the gas mixtures used in each experiment are presented in Table 39.

Table 39. Date initiated, temperature and percent moisture of the sod, and the gas mixture used in each gas experiment

Date	Temp. (°F)	Moisture (%)	Gas Mixtures Used: $CO_2 - O_2 - C_2H_4$ (%) (%) (ppm)	Gas Mixtures Used: $CO_2 - O_2 - C_2H_4$ (%) (%) (ppm)
9/22	69	65	18 - 4 - 0	18 - 4 - 2
			18 - 4 - 4	18 - 4 - 8
			18 - 8 - 0	18 - 8 - 4
9/27	56	67	0 - 4 - 0	0 - 4 - 2
			0 - 4 - 4	0 - 4 - 8
			0 - 16 - 0	0 - 16 - 8
10/8	56	71	0 - 2 - 0	0 - 2 - 2
			0 - 2 - 4	0 - 2 - 8
			0 - 0 - 0	0 - 0 - 4
10/14	52	70	18 - 2 - 0	18 - 2 - 2
			18 - 2 - 4	18 - 2 - 8
			9 - 2 - 0	27 - 2 - 0
10/21	45	72	0 - 0 - 0	0 - 8 - 0
			9 - 8 - 0	18 - 0 - 0
			18 - 16 - 0	27 - 8 - 0

Statistical analysis.--To gain the most information about the sod response to gas levels, the results from selected gas mixtures of several gas experiments were pooled together in various ways and analyzed as factorial analysis of variance (AOV) experiments. Thus, any differences in response which may have resulted from difference in sod temperature, moisture percentage or degree of hardening were confounded with responses to gas mixtures. Matching sets of gas mixtures were included in each gas experiment to minimize this disadvantage. The data from the sod contained in each 3-chamber series were treated as 3 replications. This eliminated response differences resulting from changes in gas levels over the 3 chambers from the error term. The main effect means for replications were never different.

Results of Controlled Atmospheres Studies

The statistical analysis for one way of grouping the data gathered from the gas experiments will be discussed in each of the following sections.

CA statistical comparison I.--A summary of gas mixtures whose effects were compared in this statistical analysis are presented in Table 40.

The main effect means for root production in relation to carbon dioxide, oxygen, and ethylene levels after storage under controlled atmospheres are presented in Table 41. The mean root production in relation to storage

Table 40. Gas mixtures whose effects were compared by factorial AOV in "CA statistical comparison I"

CO_2 - O_2 - C_2H_4 (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)
0 - 2 - 0	0 - 2 - 2	0 - 2 - 4	0 - 2 - 8
0 - 4 - 0	0 - 4 - 2	0 - 4 - 4	0 - 4 - 8
18 - 2 - 0	18 - 2 - 2	18 - 2 - 4	18 - 2 - 8
18 - 4 - 0	18 - 4 - 2	18 - 4 - 4	18 - 4 - 8

time was relatively constant. When comparing the response of sod stored under 0 and 18% CO_2, more root production occurred in response to the 18% CO_2 level after 24 hours of storage while the 0% CO_2 level resulted in more root production after 96 hours of storage. The 4% O_2 level resulted in greater root production after 24, 48, and 72 hours of CA storage, but more root production resulted from the 2% O_2 level after 120 hours of CA treatment. Ethylene levels of 4 and 8 ppm depressed root production as compared to 0 and 2 ppm of ethylene. These results for ethylene levels were significant after 24, 48, and 120 hours of CA storage. It was clear that ethylene levels of 4 ppm were harmful to sod rooting, but apparently the 8 ppm level of ethylene did not result in greater damage. No leaf injury or differences in percent leaf cover occurred.

Table 41. Main effect means for root production data from Merion Kentucky bluegrass sod stored under the controlled atmospheres listed in Table 40 for 5 days

		Root Organic Matter Production (mg/pot)							
Hours of Storage	Mean	% CO_2		% O_2		ppm C_2H_4			
		0	18	2	4	0	2	4	8
24	79	52	107***	45	114***	99a	105a	55b	59b*
48	66	62	69	52	80***	77a	93a	45b	48b***
72	75	71	79	62	88**	81ab	100a	62bc	56c**
96	68	84	51***	65	70	71ab	87a	48c	64bc**
120	81	79	82	92	69*	92a	107a	64b	60b**

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the .05 level.

Significant carbon dioxide x oxygen interactions for root production occurred after 24, 72, and 120 hours of CA storage (Table 42). The treatment combinations of 18% CO_2 and 4% O_2 stimulated root production significantly after 24 hours of CA storage. In the presence of 2% O_2, the 18% CO_2 level significantly decreased root production while 18% CO_2 increased root production after 72 hours at the 4% O_2 level. Also, 4% O_2 stimulated root production when 18% CO_2 was present after 72 hours. In the presence of 18% CO_2, exposure to 4% O_2 for 120 hours of storage decreased root production. These results suggest that the combination of 18% CO_2 and 4% O_2 stimulates root production for up to 72 hours

Table 42. Significant carbon dioxide x oxygen concentration interactions for root production (mg/pot) of Merion Kentucky bluegrass sod stored under the controlled atmospheres listed in Table 40 for 5 days

Hours of Storage	% CO_2	% O_2 2	% O_2 4	Simple Effects
24	0	49	55	6
	18	41	173	132**
	Simple Effects	-8	118**	
72	0	77	65	-12
	18	46	112	66**
	Simple Effects	-31**	47**	
120	0	81	77	-4
	18	104	61	-43**
	Simple Effects	23	-16	

*, **Differences are greater than LSD at the .05 and .01 level, respectively.

of CA storage, but that the presence of 4% O_2 resulted in more rapid depletion of carbohydrate reserves and decreased root production after 120 hours of CA storage.

A significant oxygen x ethylene interaction for root production occurred after 48 hours of CA storage (Table 43). In the presence of 0 and 2 ppm ethylene, the 4% O_2 level increased root production significantly. The 4 and 8 ppm ethylene levels decreased root production in the presence of 4% O_2. Oxygen simulated root production at low ethylene levels while high ethylene levels decreased root production when adequate oxygen was available. The trend in the oxygen x ethylene interaction was similar to the above after 24, 72, and 96 hours of CA storage.

CA statistical comparison II.--A list of gas mixtures whose effects were compared in this statistical analysis are presented in Table 44.

The main effect means for root production in relation to 2, 4, and 8% O_2 and 0 and 4 ppm ethylene after storage in controlled atmospheres are presented in Table 45. More root production occurred in response to 4 and 8% O_2 after 24 hours of storage. However, the 4 and 8% O_2 levels resulted in decreased root production after 120 hours of storage. Four ppm ethylene depressed root production significantly after 24 and 120 hours of storage. No leaf injury resulted from these treatments.

Table 43. Significant oxygen x ethylene concentration interaction for root production of Merion Kentucky bluegrass sod stored under the controlled atmospheres listed in Table 40

			ppm Ethylene				Simple Effects					
	Hours of	%	0	2	4	8						
Measurement	Storage	O_2	a_1	a_2	a_3	a_4	a_2-a_1	a_3-a_1	a_4-a_1	a_3-a_2	a_4-a_2	a_4-a_3
Root organic matter (mg/pot)	48	2	49	67	38	53	18	-11	4	-29*	-14	15
		4	105	119	52	43	14	-53**	-62**	-67**	-76**	-9
Simple Effects			56**	52**	14	-10						

*, **Differences are greater than LSD at the .05 and .01 level, respectively.

Table 44. Gas mixtures whose effects were compared by factorial AOV in "CA statistical comparison II"

CO_2 - O_2 - C_2H_4 (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)
18 - 2 - 0	18 - 2 - 4
18 - 4 - 0	18 - 4 - 4
18 - 8 - 0	18 - 8 - 4

Table 45. Main effect means for root production (mg/pot) for Merion Kentucky bluegrass sod stored in the controlled atmospheres listed in Table 44 for 5 days

Hours of Storage	Mean	% O_2			ppm C_2H_4	
		2	4	8	0	4
24	129	41	181	165**	169	89*
48	78	59	86	90	84	72
72	97	46	110	134	98	95
96	57	56	55	61	66	48
120	77	108	66	58*	92	62*

*, **Differences between main effect means are significant at the .05 and .01 level of probability, respectively, for designated hours of storage.

<u>CA statistical comparison III</u>.--Gas mixtures whose effects were compared in this statistical analysis are presented in Table 46.

The main effect means for root production in relation to oxygen and ethylene levels are presented in Table 47. More root production occurred at 0% O_2 than at the 2% O_2 level after 24 hours of storage. This was unexpected since the 0% O_2 treatment caused 17% leaf kill after 24 hours of storage. The 0% O_2 level resulted in significantly less root production than 4% O_2 after 48 hours. The 2 and 4% O_2 levels gave more root production than 0% O_2 after 72, 96 and 120 hours of storage. In the absence of oxygen, the turfgrass plants died rapidly, but the presence of only 2% O_2 was sufficient to sustain the metabolism of the plants for 120 hours. The 4 ppm ethylene level depressed root production significantly after 48, 72, and 96 hours.

For the zero O_2 level the leaf kill over time was as follows:

24	48	72	96	120	Hours
17	93	98	100	100	% leaf kill

No leaf kill occurred when oxygen was present until after 120 hours. Then 10% leaf kill occurred in response to the 4% O_2 level. This suggests that, in the presence of 4% O_2, the respiration rate was great enough to deplete carbohydrate reserves and resulted in some leaf injury after 120 hours of storage.

Table 46. Gas mixtures whose effects were compared by factorial AOV in "CA statistical comparison III"

CO_2 (%)		O_2 (%)		C_2H_4 (ppm)	CO_2 (%)		O_2 (%)		C_2H_4 (ppm)
0	-	0	-	0	0	-	0	-	4
0	-	2	-	0	0	-	2	-	4
0	-	4	-	0	0	-	4	-	4

Table 47. Main effect means for root production (mg/pot) for Merion Kentucky bluegrass sod stored in the controlled atmospheres listed in Table 46 for 5 days

Hours of Storage	Mean	% O_2			ppm C_2H_4	
		0	2	4	0	4
24	50	66a	39b	48ab*	55	46
48	43	17b	41ab	72a**	56	31*
72	48	12b	72a	59a***	63	32***
96	45	3b	60a	72a***	56	35**
120	50	3b	80a	67a***	57	43

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

<u>CA statistical comparison IV</u>.--A summary of the gas mixtures whose effects were compared in this statistical analysis are presented in Table 48.

Table 48. Gas mixtures whose effects were compared by factorial AOV in "CA statistical comparison IV"

CO_2 (%)	-	O_2 (%)	-	C_2H_4 (ppm)	CO_2 (%)	-	O_2 (%)	-	C_2H_4 (ppm)
0	-	0	-	0	18	-	0	-	0
0	-	2	-	0	18	-	2	-	0
0	-	4	-	0	18	-	4	-	0
0	-	8	-	0	18	-	8	-	0
0	-	16	-	0	18	-	16	-	0

The main effect means for root production and percent leaf kill in relation to carbon dioxide and oxygen levels are presented in Table 49. The 18% CO_2 level resulted in significantly greater root production after 24 hours of storage and significantly less after 96 hours. When oxygen was absent, low root production occurred after 24 hours and no root production occurred after 48, 72, 96, and 120 hours of CA storage. The highest numerical values for root production occurred at the 4, 4, 8, 4, and 2% O_2 levels for 24, 48, 72, 96, and 120 hours, respectively.

Table 49. Main effect means for root production and percent leaf kill for Merion Kentucky bluegrass sod stored in the controlled atmospheres listed in Table 48 for 5 days

Measurement	Hours of Storage	Mean	% CO_2		% O_2				
			0	18	0	2	4	8	16
Root organic matter (mg/pot)	24	92	55	128**	37c	57bc	158a	137ab	68abc**
	48	68	59	77	0c	55b	105a	92ab	88ab***
	72	59	55	64	0c	71ab	94ab	102a	30bc***
	96	54	64	45*	0b	65a	83a	75a	49a***
	120	62	62	62	0c	107a	83ab	75ab	47b***
% Leaf kill	24	8	8	8	40	0	0	0	0***
	48	20	20	20	100	0	0	0	0***
	72	20	20	20	100	0	0	0	0***
	96	23	24	22	100	0	0	5	10***
	120	26	31	21	100	0	5	8	18***

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

Oxygen levels of 4 to 8% gave the best root production results for sod storage time of up to 96 hours. A 2% O_2 level was best when the sod was stored 120 hours.

Forty percent leaf kill occurred after 24 hours of CA storage without oxygen. The leaf kill was 100% for longer periods of storage without oxygen. No leaf kill occurred in the presence of oxygen until after 96 hours of storage. The leaf kill was 5 and 10% for 8 and 16% O_2, respectively, after 96 hours. Leaf kill was 5, 8, and 18% for 4, 8, and 16% O_2, respectively, after 120 hours. Carbon dioxide levels did not affect leaf kill.

Significant carbon dioxide x oxygen concentration interactions for root production occurred after 24, 48, 72, and 120 hours of CA storage (Table 50). The pattern of response shows increased root production in response to 4 and 8% O_2 in the presence of 18% CO_2 for 24, 48, and 72 hours (except 16% O_2 after 48 hours). The 18% CO_2 and 2% O_2 treatment combinations gave the most root production after 120 hours. These interactions also indicate a shift in optimum oxygen levels for sod storage from 4 to 8% O_2 to a 2% O_2 level when the length of CA storage increases beyond 72 hours.

Table 50. Significant (.05 level) carbon dioxide x oxygen interactions for root production (mg/pot) of Merion Kentucky bluegrass sod stored in the controlled atmospheres listed in Table 48 for 5 days

Hours of Storage	% CO_2	% O_2 0	2	4	8	16
24	0	41	51	57	90	38
	18	33	63	258	184	99
48	0	0	46	97	107	44
	18	0	64	113	76	133
72	0	0	84	87	69	34
	18	0	59	101	135	26
120	0	0	88	79	86	59
	18	0	127	87	63	36

CA statistical comparison V.--A summary of gas mixtures whose effects were compared in this statistical analysis are presented in Table 51.

Table 51. Gas mixtures whose effects were compared by factorial AOV in "CA statistical comparison V"

CO_2 - O_2 - C_2H_4 (%) (%) (ppm)	CO_2 - O_2 - C_2H_4 (%) (%) (ppm)
0 - 2 - 0	0 - 8 - 0
9 - 2 - 0	9 - 8 - 0
18 - 2 - 0	18 - 8 - 0
27 - 2 - 0	27 - 8 - 0

The main effect means for root production in relation to carbon dioxide and oxygen levels are presented in Table 52. Significant differences in response to carbon dioxide levels occurred after 24, 72, and 120 hours of CA storage. More root production occurred in response to 18% CO_2 than to the other levels after 24 hours. The 27% CO_2 level resulted in less root production than the 0 and 18% CO_2 levels after 72 hours. The root production for 27% CO_2 was significantly less than for the other carbon dioxide levels after 120 hours of storage. The 8% O_2 level resulted in significantly more root production than 2% O_2 after 24 and 48 hours. The 2% O_2 level resulted in significantly more root production after 120 hours of CA storage.

Table 52. Main effect means for root production (mg/pot) of Merion Kentucky bluegrass sod stored in the controlled atmospheres listed in Table 51 for 5 days

Hours of Storage	Mean	% CO_2				% O_2	
		0	9	18	27	2	8
24	12	71b	61bc	123a	35c***	39	106***
48	71	77	68	70	71	50	93**
72	64	76bc	45bc	97a	38c	59	69
96	62	74	47	66	59	67	56
120	84	87a	92a	95a	60b*	101	66***

*, **, ***Differences between main effect means are significant at the .05, .01, and .001 level of probability, respectively, for designated hours of storage. Main effect means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 5% level.

Significant oxygen x carbon dioxide concentration interactions for root production occurred after 24, 72, 96, and 120 hours of CA storage (Table 53). The 8% O_2 and 18% CO_2 treatment combination resulted in the greatest root production after 24 and 72 hours. The 27% CO_2 and 2% O_2 treatment combination increased root production while the 27% CO_2 and 8% O_2 treatment combination decreased root production after 96 hours. The 9 and 18% CO_2 with 2% O_2 increased root production after 120 hours.

Table 53. Significant (.05 level) oxygen x carbon dioxide concentration interactions for root production (mg/pot) of Merion Kentucky bluegrass sod stored in the controlled atmospheres listed in Table 51 for 5 days

Hours of Storage	% O_2	% CO_2			
		0	9	18	27
24	2	51	28	63	14
	8	90	93	184	56
72	2	84	54	58	38
	8	69	35	135	38
96	2	66	50	64	89
	8	82	44	68	30
120	2	88	113	126	72
	8	86	72	63	43

<u>CA temperature experiment</u>.--The response of sod to 8 days of CA storage at 104 and 83° F was studied in this experiment. Two CA chambers were placed in the growth chamber (104° F) and 2 were set on the floor (83 ± 1° F) for each gas mixture used. Temperatures were measured twice a day. The 4 chambers were connected in series. The gas flow rate was set at 0.3 cu ft per hour. The general methods were the same as described in the Methods and Materials for Controlled Atmosphere (CA) Studies section.

The averages for percent leaf kill and root production data in relation to temperature and the gas mixtures used are presented in Table 54. The duration of leaf survival and amount of root production was surprisingly high for sod stored in pure nitrogen gas (0-0-0) at 83° F. Storage in the 18-16-0 gas mixture resulted in the lowest percent leaf kill and the highest root production, especially after 6 and 8 days at 83° F. The results for the sod stored at 83° F were similar to those obtained in the previous CA studies. Very high levels of leaf kill occurred after only 2 days of storage at 104° F. The sod was completely killed after 4 or more days of 104° F storage. These results show a definite positive relationship between sod temperature and injury.

<u>Total available carbohydrates (TAC) for the CA temperature experiment</u>.--The TAC levels for the sod used in the CA temperature experiment were determined initially and after 8 days of storage. The final determination was made on grass stems collected from 1 chamber for each gas

Table 54. Percent leaf kill and root production in relation to temperature of Merion Kentucky bluegrass sod stored in the gas mixtures listed for 8 days

Gas Mixture		Percent Leaf Kill				Root Production (mg/pot)			
		Days of Storage				Days of Storage			
CO_2-O_2-C_2H_4 (%) (%) (ppm)	Temp. (^oF)	2	4	6	8	2	4	6	8
0 - 0 - 0	104	100	100	100	100	0	0	0	0
	83	0	45	92	80	95	53	38	0
18 - 2 - 8	104	98	100	100	100	0	0	0	0
	83	0	20	55	65	106	112	78	46
27 - 2 - 0	104	92	100	100	100	6	0	0	0
	83	0	12	75	90	82	68	49	11
18 -16 - 0	104	70	95	100	100	22	8	0	0
	83	0	0	30	20	78	147	164	154

mixture and temperature. The TAC determinations were made using the methods described in the October 24, 1969, sod heating box experiment section.

The TAC data in relation to temperature, leaf kill, and root production are presented in Table 55. The TAC of the sod was 32.9% at the beginning of the experiment.

The sod stored in nitrogen gas (0-0-0) had 18.1 and 17.6% TAC for 104 and 83° F storage temperatures, respectively. The sod stored at 104° F was dead after 2 days while 8% of the plants for sod stored at 83° F survived 6 days of storage (see Table 54). Nevertheless, the TAC levels were about the same for sod stored under the two temperature regimes.

The sod stored in the 18-2-8 atmosphere had 16.9 and 18.6% TAC for 104 and 83° F storage temperatures, respectively. The sod stored at 104° F was dead after 2 days. The sod stored at 83° F had 60% leaf kill and a moderate level of root production after 8 days of storage.

Initially, the sod stored in the 27-2-0 atmosphere had 23.2 and 18.4% TAC for 104 and 83° F temperatures, respectively. The sod stored at 104° F was dead after 4 days of storage and still retained 23.2% TAC. The sod stored at 83° F had 90% leaf kill and a low level of root production after 8 days of storage.

The sod stored in the 18-16-0 atmosphere had 28.8 and 24.0% TAC for 104 and 83° F storage temperatures, respectively. The sod stored in this atmosphere had survived

Table 55. Percent total available carbohydrate (TAC) in relation to temperature, percent leaf kill, and root production of Merion Kentucky bluegrass sod harvested on October 29, 1969, and stored for 8 days in the gas mixtures listed

Gas Mixtures CO_2-O_2-C_2H_4 (%) (%) (ppm)	Temp. (^oF)	% TAC[a]	% Leaf Kill	Root Production (mg/pot)
0 - 0 - 0	104	18.1	100	0
	83	17.6	70	0
18 - 2 - 8	104	16.9	100	0
	83	18.6	60	73
27 - 2 - 0	104	23.2	100	0
	83	18.4	90	8
18 - 16 - 0	104	28.8	100	0
	83	24.0	20	180

[a]The sod had 32.9% TAC at the beginning of the experiment.

the 104° F temperature better than sod stored in the other atmospheres. The sod at 83° F had only 20% leaf kill and high root production after 8 days of storage. A higher respiration rate and more rapid depletion of TAC was expected in the presence of 16% O_2, but this did not occur. The sod retained more than 75% of its original TAC level and had the best survival.

Apparently the high temperature (104° F) resulted in direct injury to the sod. No evidence for the depletion of carbohydrates to some critically low level before sod injury occurred was found in this experiment.

COMMERCIAL SOD LOAD MEASUREMENTS

Measurements of temperature were obtained during the shipment of 3 commercial sod loads from Emerald Valley Sod Nurseries near Gregory, Michigan, to the Cleveland, Ohio area. Measurements of carbon dioxide, oxygen, and ethylene levels were obtained for 2 of these sod loads. These measurements of changes within the commercial sod load were used to assess the effectiveness of the sod heating boxes in simulating sod load conditions.

First Commercial Sod Load

The Merion Kentucky bluegrass sod was cut and rolled from 7:30 to 8:30 a.m. and loaded on a flat-bed, semi-trailer from 8:45 to 10:00 a.m. on July 10, 1968. The effectiveness of ventilator tubes in reducing the rate of temperature increase in the load was investigated. Also, the temperature profile in relation to distance from the bottom of the load was measured.

The load contained 1300 yards of sod. The sod was cut into pieces 2 feet wide by 4.5 feet long at a depth of 0.7 inch. These pieces were rolled and ranked into place on the semi-trailer. Individual sod rolls were about 11 inches in diameter and crushed to an elliptical shape in the load. The major part of the load was 4 rolls wide and 6 rolls or tiers high (35 inches). This was held in place by topping the load with a section that was 3 rolls wide and 3 rolls deep. Finally, a canvas tarp was tied in place over the top of the load.

Ventilation tubes and thermocouple wires were inserted into the load while the sod was being loaded. The ventilation tubes consisted of 4 inch diameter by 8 feet long sections of polyvinylchloride drain tile, which had 0.5 inch diameter holes drilled on 1.2 inch centers. An elbow, attached to each tube, pointed forward to catch air during transport. Four ventilation tubes were placed on top of the bottom tier of sod rolls. The tubes were spaced at 5 foot intervals in the load. Thermocouples were inserted into the center of the 2 sod rolls located in the central 2 rows and immediately behind the ventilation tubes in the second tier. Thermocouples were similarly placed in sod rolls located 1 roll further away from the ventilation tube. Thermocouples were also placed in sod rolls in the central 2 rows of the first through the sixth tiers from the bottom of the load. Temperature was measured with a Leeds and Northrup portable potentiometer and 18 gauge copper-constantan thermocouples.

Results and discussion.--The main effect means for temperature changes in relation to distance from the ventilation tubes are presented in Table 56. The initial temperature was 66° F; this was low for July 10. June of 1968 was cool with very high rainfall. One inch of rain fell on

Table 56. Temperature (^{o}F) changes in relation to distance from ventilation tubes inserted across a semi-trailer load of commercial sod during 20 hours of storage on the load for Merion Kentucky bluegrass sod harvested on July 10, 1968

Hours on Load	Mean	Distance Behind Ventilator (in)		Air Temperature
		6	18	
0	66.2	66.2	66.1	60
6	69.3	70.0	68.6	76
12	70.6	70.5	70.6	67
20	72.0	71.9	72.2	63

July 9. These two facts contributed to the low initial temperature. The temperature increased about 6^{o} F during the 20 hours that sod was in the load. The initial temperature measurements were taken immediately after the sod loading was completed. The 12 hour temperature measurements were taken just after the sod load arrived in Cleveland after 4 hours of highway travel. The temperature within sod rolls adjacent (6 inches) to the ventilation tubes was the same as that 18 inches away. This clearly shows that the ventilation tubes were not effective in reducing temperature.

The main effect means for temperature changes in relation to distance from the bottom of the load are presented in Table 57. The distance from the bottom of the sod load did not affect temperature. The sod was not injured during shipment.

Table 57. Temperature (^{o}F) changes in relation to distance from the bottom of a commercial sod load during 20 hours of storage on the load for Merion Kentucky bluegrass sod harvested on July 10, 1968

Hours on Load	Mean	Distance from Bottom (in)					
		5	10	15	20	25	30
0	67.2	67.5	66.5	68.0	67.5	67.0	67.0
6	69.3	68.5	69.0	69.0	69.5	70.0	70.0
12	70.4	71.0	71.0	70.0	70.0	70.0	70.5
20	73.0	73.0	73.0	73.0	73.0	73.0	73.0

Second Commercial Sod Load

The Merion Kentucky bluegrass sod used in this study was cut between 7 and 8 a.m. and stacked on pallets between 8 and 10 a.m. on May 26, 1969. The effectiveness of ventilation tubes in reducing the rate of temperature increase in the sod stack was investigated. Also, the temperature in relation to distance from the bottom of the palleted sod was measured.

The pallets were 4 by 5 feet in size. One hundred yards of sod were stacked on each pallet. The sod was stacked in alternating layers of flat and rolled pieces of sod. Alternating layers were positioned at right angles to each other. Ventilation tubes were placed on top of the first layer of rolled sod on 2 pallets as the sod was being stacked. The ventilation tubes and elbows were as described for the first sod load, except for being cut to 4 feet in length. Thermocouples and gas sampling tubes were placed in the center of the sod stack at 6, 12, 24, and 36 inches from the bottom of the stack. The thermocouples and gas sampling tube placed at 6 inches from the bottom were 2 sod layers (about 1.6 in) below the ventilation tube. The thermocouple and gas sampling tube placed at 12 inches were one sod layer above the ventilation tube. Two more pallets had thermocouples and gas sampling tubes, but not ventilation tubes, inserted at the same heights. Temperature was measured with a Leeds and Northrup portable potentiometer. The procedure for collection and analysis of gas samples was as described in the Development of Methods section. The temperature and atmosphere within the sod stack were measured at 10 a.m. on May 26 and 6 a.m. on May 27th. The sod load was transported to Cleveland during the late afternoon of May 26, 1969.

Results and discussion.--The main effect means for temperature, percent carbon dioxide and oxygen, and ppm ethylene in relation to distance from the bottom of the sod on pallets with ventilation tubes are presented in Table 58. The ventilation tubes significantly reduced the rate of temperature increase for a distance of 2 inches. Gas levels were not affected by the ventilation tubes. The carbon dioxide and oxygen levels did not change as fast in the palleted sod as in the sod heating boxes. The ethylene level was higher initially than after 20 hours. These facts

Table 58. Temperature and gas levels in relation to distance from the bottom of the sod on pallets with ventilation tubes after 20 hours of storage for Merion Kentucky bluegrass sod harvested on May 26, 1969

Measurement	Initial Mean (0 hr)	Mean (20 hr)	Position of Thermocouples and Gas Sampling Tubes (inches from bottom of sod)			
			6	12	24	36
Temp. (^{o}F)	54	60	57	56	64	64*
% CO_2	2.2	2.0	2.4	2.0	2.2	1.6
% O_2	7.2	18.4	17.8	18.2	18.8	18.7
ppm C_2H_4	2.8	1.3	1.5	1.0	1.4	1.2

*Differences between main effect means are significant at the .05 level of probability.

indicate that the gas diffusion rate was greater in the sod load than in the sod heating boxes. The 10^{o} F temperature increase during 20 hours of storage was similar to rates of temperature increase in sod heating boxes.

The main effect means for temperature and gas levels in relation to distance from the bottom of the sod on pallets without ventilation tubes are presented in Table 59. The initial temperature of this sod was higher because it was stacked about an hour later. The rate of temperature increase was slow. Carbon dioxide accumulated significantly faster near the bottom of the sod stack. Oxygen percentages were lower and temperatures were higher near the bottom of the sod stack, but not significantly different from values

Table 59. Temperature and gas levels in relation to distance from the bottom of the sod on pallets after 20 hours of storage for Merion Kentucky bluegrass sod harvested on May 26, 1969

Measurement	Initial Mean (0 hr)	Mean (20 hr)	Position of Thermocouples and Gas Sampling Tubes (inches from bottom of sod)			
			6	12	24	104
Temp. (^oF)	61	64	65	65	62	64
% CO_2	2.6	3.3	4.3	4.8	2.0	2.0**
% O_2	16.1	16.2	15.4	14.7	17.3	17.6
ppm C_2H_4	2.7	1.4	1.5	1.6	1.0	1.6

**Differences between main effect means are significant at the .01 level of probability.

found at the 24 and 36 inch positions of measurement. The carbon dioxide and oxygen levels did not change as rapidly in the palleted sod as in the sod heating boxes. The ethylene level was lower after 20 hours of storage than initially. The gas diffusion rate was greater in the sod load than in the sod heating boxes. The sod survived shipment without injury.

Third Commercial Sod Load

The Merion Kentucky bluegrass sod used in this study was cut and rolled between 11 and 12 a.m. and stacked on pallets between 3 and 4 p.m. on June 9, 1969. The temperature increase in relation to distance from the bottom of 4 pallets was measured. Thermocouples and gas sampling tubes were placed at 6, 12, and 24 inches from the bottom of the sod stacks. Temperature and atmosphere within the sod stack were measured at 4:30 p.m. June 9th and at 4:30 a.m. on June 10, 1969. The sod load was transported to Cleveland during that night.

Results and discussion.--The main effect means for temperature, percent carbon dioxide and oxygen, and ppm ethylene are presented in Table 60. The temperature and gas measurements did not differ in relation to the distance from the bottom of the pallets. The temperature increased 9° F during 12 hours on the load. This rate of temperature increase was similar to that occurring in sod heating boxes. The rate of change in carbon dioxide and oxygen levels was faster in this load than in previous sod loads, but not as rapid as in the sod heating boxes. Ethylene levels were very low. The sod survived shipment without any injury.

Table 60. Temperature and gas levels in relation to distance from the bottom of the sod on pallets after 12 hours of storage for sod harvested on June 9, 1969

Measurement	Initial Mean (0 hr)	Mean (12 hr)	Position of Thermocouples and Gas Sampling Tubes (inches from bottom of sod)		
			6	12	24
Temp. (°F)	77	86	86	87	86
% CO_2	2.9	10.1	10.6	10.4	9.3
% O_2	17.1	7.8	6.7	7.9	8.8
ppm C_2H_4	0.30	0.20	0.18	0.25	0.18

Comparison of Sod Load and Sod Heating Box Conditions

The rate of temperature increase was nearly identical for the third sod load and Experiment I (May 16, 1969). The initial sod temperature was 77° F compared to 86° F after 12 hours in the third sod load. The initial temperature was 73.5° F compared to 82.1° F after 12 hours in Experiment I. The initial sod temperature was 69° F compared to 77° F after 12 hours in Experiment IV (June 4, 1969). The initial sod temperatures and the rates of temperature increase varied among sod heating box experiments. The initial sod temperature and rate of temperature increase was lower in the first 2 commercial sod loads than for sod heating box experiments. Nevertheless, the data clearly shows that the sod heating boxes simulated commercial sod load conditions quite well in terms of heat exchange.

The carbon dioxide level was 10% after 12 hours in the third sod load compared to 16% after 12 hours in Experiment IV. The rate of increase of carbon dioxide level was slower in the second sod load. The oxygen levels were higher after 12 hours in the sod loads than in sod heating box experiments. Therefore, the sod heating boxes were tighter in terms of gas exchange than the palleted sod.

MEASUREMENT OF RESPIRATION RATES

Respiration rates of sod were measured on the Automatic Photosynthetic and Respiration Integrating Laboratory (APRIL) in the Department of Horticulture (Dilley, 1969). Three 6 inch diameter sod pieces were spaced in a triangular pattern in the bottom of bucket chambers similar to those described for the controlled atmosphere experiments. The chambers were placed in a constant temperature room at 27^{o} C. The respirometer chambers were connected through a system of tubing and valves to a Beckman IR-115 analyzer. A continuous flow of air at 300 ml/hr was maintained in the system. The ppm carbon dioxide in the airstream from each chamber of the series was measured at 7 minute intervals in a 12 hour cycle. The respiration rate was calculated with the following equation:

$$\text{ml } CO_2/\text{kg/hr} = \frac{(\text{Flow in ml/hr})\,(273)\,(P)}{(\text{Weight in kg})\,(T)\,(760)}\,(\%\ CO_2 \text{ in sample} - \%\ CO_2 \text{ in air blanks})$$

The respiration rate in terms of oxygen use was not obtained because the Beckman G-2 Oxygen Analyzer was not working properly.

Respiration Rate of the Sod Used in Experiment IV

The respiration rate was measured on sod that had received the following cultural treatments: (a) 2 versus 0.75 inch cutting heights, (b) 0 versus 215 lb/A of nitrogen, and (c) 0 versus 0.0550 lb/A of N^6benzyladenine. The low cutting and nitrogen fertilization was done 5 days before harvest. N^6benzyladenine was applied just before harvest. The sod cut at 2 inches had many seedheads present. The sod pieces were harvested in the forenoon and kept covered in the shade until they were placed in respirometer chambers in the late afternoon of June 4, 1969. Respiration measurements were obtained at 10 p.m. June 4, and at 10 a.m. and 10 p.m. June 5.

Results and discussion.--The respiration rates in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments are presented in Table 61. The mean rate of respiration decreased slowly over time, possibly as a result of slow depletion of available carbohydrates. The low cutting resulted in a decreased respiration rate. This was expected since the relative proportion of living tissue to weight of sod pieces was lower after low cutting. The reduced respiration rate with low cutting corresponds to the decreased temperature, carbon dioxide, and injury levels found in the sod heating box experiment. The high nitrogen rate resulted in higher numerical values for respiration rate, but the differences were not statistically significant. N^6benzyladenine did not affect respiration rate significantly.

Table 61. Respiration rate in relation to cutting height, nitrogen rate, and N^6benzyladenine treatments of Merion Kentucky bluegrass sod harvested on June 4, 1969 (Experiment IV)

Date and Time of Measurements	Mean	Respiration Rate (ml CO_2/kg/hr)					
		Cutting Ht. (in)		Nitrogen (in)		N^6BA (lb/A)	
		2	0.75	0	215	0	.055
June 4, 10 p.m.	108	121	97†	104	113	113	104
June 5, 10 a.m.	103	114	93†	97	109	106	100
June 5, 10 p.m.	98	106	89	92	103	101	96

†Differences between main effect means are significant at the .10 level of probability at designated times of measurement.

Components of Respiration

The respiration rate of complete sod pieces and organic soil was measured for Merion Kentucky bluegrass sod and soil harvested on June 7 and 14, 1969. The sod was from Green Acres Sod Farm; the same sod source as for the first seven 1969 sod heating box experiments. Only a few seed-heads were present in the sod during these experiments. The cutting height of the sod was 2 inches. The sod was cut at a 0.7 inch depth and then into 6 inch diameter pieces. Three of the sod pieces were placed in each chamber. The organic soil was obtained by scraping sod pieces over screen having 0.25 sq inch openings. These sod pieces were discarded. A 0.6 inch layer of this soil was spread over the bottom of the respirometer chambers. Four replications were used.

Air pump failure in APRIL prevented measurement of respiration of sod and soil collected on June 7 until June 9 at 10 a.m. and 10 p.m. The chambers were left open in the 27^{o} C room until the air pump was replaced.

The respiration rate of the sod and soil collected on June 14 was measured at 10 a.m. and 10 p.m. on June 15.

Results and discussion.--The respiration rates for sod and organic soil harvested on June 7 and 14 are presented in Table 62. The respiration rate of the sod was about 8 times greater than that of the organic soil in which sod had been growing. One of the implications of this data

Table 62. Respiration rates for Merion Kentucky bluegrass sod cut at 2 inches and organic soil harvested on June 7 and 14, 1969

Date and Time of Measurements	Respiration Rate (ml CO_2/kg/hr)	
	Sod	Soil
June 9, 10 a.m.	80	13***
June 9, 10 p.m.	87	12***
June 15, 10 a.m.	69	4***
June 15, 10 p.m.	62	10***
Overall Mean	75	10

***Differences between main effect means are significant at the .001 level of probability for designated times of development.

is that lower cutting of the turf just before harvest will be more effective in reducing respiration rate (and therefore temperature increase) in the load than thinner cutting of the sod. This is due to the fact that the respiration rate of the turfgrass plants is about 6.5 times that of the soil microorganisms.

SUMMARY AND DISCUSSION

Commercial sod is composed of living turfgrass plants whose roots and rhizomes are tightly intertwined in a thin layer of soil. The plants continue to respire during shipment. Respiration uses oxygen and reserve carbohydrates and releases carbon dioxide and heat. If these changes occur rapidly in the load injury or death of the turfgrass plants may occur before the sod is unloaded and transplanted. Usually sod will survive in the load 24 hours or sometimes longer without injury, but incidents of sod damage in 12 hours or less have occurred.

Dissipation of heat and diffusion of oxygen and carbon dioxide are severely limited within the confined space of the sod load. Information on the changes in temperature, gas levels, and carbohydrate reserves during storage under simulated shipping conditions was obtained from the sod heating box experiments. Sod response to carbon dioxide, oxygen, and ethylene levels in controlled atmospheres was investigated. The major implications of these results will be discussed in the following sections.

Effects of Cultural Treatments on Sod During Storage

The effects of height of cut, nitrogen fertilization, respiration inhibitors, and time of day of harvest were investigated in a series of sod heating box experiments. The sod heating boxes simulated commercial sod load conditions well in terms of temperature, but were more restrictive of gas diffusion. The following sections summarize the results of the experiments.

Height of cut.--The 2 inches versus 0.75 inch height of cut treatment was included in 7 of the 1969 sod heating box experiments. The 0.75 inch height of cut resulted in lower temperatures. The 0.75 inch height of cut reduced carbon dioxide levels by 1 to 4% in most experiments. The oxygen levels were higher during the early hours of storage where the sod was cut at 0.75 inch. The ppm ethylene was lower for sod cut at 0.75 inches. The 0.75 inch height of cut treatment never increased temperature, carbon dioxide or ethylene levels. Low cutting greatly reduced the amount of respiring leaf tissue and this provides a satisfactory explanation for these results.

The mean respiration rate was about 115 ml CO_2/kg/hr for sod cut at a 2 inch height in Experiment IV where abundant seedheads were present. The mean respiration rate was 93 ml CO_2/kg/hr where most of the seedheads were removed by the 0.75 inch cutting treatment for sod used in Experiment IV. The mean respiration rate was 75 ml CO_2/kg/hr for sod cut at a 2 inch height (no seedheads present) and used in the components of respiration studies. The respiration rate of sod is greater when seedheads are present and reduced by lowering the height of cut.

The 0.75 inch height of cut treatments were initiated 10, 5, and 1 day before harvest and 10 and 5 days before harvest and on the day of harvest for Experiment III and VII, respectively. The respiration rate and temperature was slightly lower for sod cut at 0.75 inch 10 days before harvest, but slightly less injury and more leaf cover and root production occurred for sod cut at 0.75 inch on the day of harvest or 1 day before harvest.

The effects of the 0.75 height of cut on percent leaf kill and cover and root production appear to be more closely related to temperature than to height of cut _per se_. In general, when the mean temperatures for an experiment were above 92° F the 0.75 inch height of cut resulted in lower temperatures which reduced injury and increased root production.

Nitrogen fertilization.--The effects of nitrogen fertilization on sod heating and damage were studied in 6 of the sod heating box experiments. The effects of applying 215 lb/A of nitrogen a few days before harvest were investigated in five experiments. The application of 215 lb/A of nitrogen is 2 to 5 times more than a commercial sod producer should apply at one time. The "zero" nitrogen rate was the amount applied in the normal sod production fertilization program; that is, 100 to 150 lb/A/year depending on the sod source.

Significantly higher temperatures resulted from the 215 lb/A nitrogen application for the June 4, 1969 experiment. Abundant seedheads were present. No differences in temperature in relation to nitrogen level were found for other experiments which compared the "zero" and 215 lb/A nitrogen level.

Generally, the carbon dioxide level was increased and the oxygen was decreased somewhat during the early hours of storage as a result of the 215 lb/A nitrogen treatment.

The 215 lb/A nitrogen treatment resulted in higher levels of ethylene in all 5 experiments where "zero" versus 215 lb/A nitrogen levels were compared.

The percent leaf kill was greater and the percent leaf cover and root production were lower where the 215 lb/A nitrogen was applied. This general conclusion is valid although the results for individual experiments after given times of storage were neither perfectly consistent nor always significant.

Temperature, carbon dioxide, and leaf kill increased progressively with nitrogen rate while leaf cover and root production decreased progressively in relation to nitrogen rate in Experiment X. Sod which had been produced with 0, 90, 180, 360, and 340 lb/A of nitrogen was compared. The commercial sod (340 lb/A of N) had the best appearance and seemed to be growing the fastest. The other four sods were

produced on a low fertility organic soil. The sod grown with 0 or 90 lb/A of nitrogen had better root production after storage than the other sods.

Respiration inhibitors.--A respiration inhibitor which could be sprayed onto sod shortly before harvest to reduce injury during shipment would be an ideal solution to the sod heating problem. N^6benzyladenine, a respiration inhibitor capable of prolonging storage life of green leafy vegetables (Dedolph, Wittwer, Tuli, and Gilbert, 1962) showed some promise in preliminary investigations. Alar*85 (succinic acid* 2,2-dimethyl hydrazide, 85% by weight) and Cycocel (CCC) (2-(chloroethyl)trimethylammonium chloride) did not show any effect in preliminary trials.

N^6benzyladenine, applied at a rate of 0.055 lb/A in 65 gal of water per acre, was included in 6 of the 1969 experiments. N^6benzyladenine at 0.0055, 0.0275, and 0.0550 lb/A rates was sprayed onto sod just prior to harvest for Experiment I. The 0.055 lb/A rate resulted in a decrease in temperature after 96 hours of storage. The 0.055 lb/A rate of N^6 benzyladenine in combination with a 0.75 inch height of cut also reduced temperature significantly after 48, 72, and 96 hours of storage. Because of these results the 0.055 lb/A of N^6benzyladenine was used in subsequent experiments.

Generally, N^6benzyladenine did not affect the results of the experiments. Thirteen scattered instances of significant differences between main effect means for 0 and 0.055 lb/A of N^6benzyladenine occurred as follows: temperature and carbon dioxide were decreased once each, oxygen was increased twice, ethylene was increased once and decreased once, percent leaf cover was decreased once, and root production was decreased twice. The N^6benzyladenine was applied just prior to harvest and 5 and 10 days before harvest in Experiment VI and none of the main effect means for N^6benzyladenine treatments were different. In several instances N^6benzyladenine interacted significantly with height of cut or nitrogen level to affect temperature, oxygen or ethylene levels, but these trends were not consistent either. One must conclude that N^6benzyladenine was not shown to be of practical value for reducing sod injury during shipment.

Time of harvest.--The effects of 9 a.m. versus 2 p.m. harvest were investigated in Experiment IX. The initial temperatures were 73.5 and 83.1° F. The sod harvested in the morning was cooler during the entire 72 hours of storage, but its rate of heating was faster than for sod harvested in the afternoon. Percent leaf kill and cover and root production were not affected by the temperature differences probably because of the unusually rapid rate of injury (61% leaf kill after 24 hours). Nevertheless, early morning harvest should normally prolong the safe storage of sod.

Physiological Mechanisms Involved in Sod Injury

Physiological processes that might have caused or contributed to sod injury during storage under simulated shipping conditions include suffocation, ethylene toxicity, carbohydrate starvation, and high temperature injury. The following sections discuss these possibilities.

Suffocation.--No evidence for suffocation under the conditions in the sod heating boxes was found. The carbon dioxide in the sod heating boxes increased rapidly to 13 to 19%. The oxygen decreased concurrently to 2 to 5%. These changes in carbon dioxide and oxygen levels occurred within 24 hours. The carbon dioxide and oxygen levels remained relatively constant for longer periods of storage. The controlled atmosphere studies showed that root production was highest after 120 hours of storage for the 18% CO_2 and 2% O_2 treatments. The 4 and 8% O_2 levels resulted in better root production for shorter periods of storage. The 16% O_2 level reduced root production. The 0, 9, and 27% CO_2 levels resulted in less root production than for 18% CO_2. Leaf injury was not observed after CA treatment with any gas mixture that contained 2% or more of oxygen. Percent leaf kill was not affected by the carbon dioxide and oxygen levels that occurred in the sod heating boxes. Root production may have been decreased somewhat as a result of low oxygen levels in some experiments (especially likely in Experiment V). Actually, the carbon dioxide and oxygen levels that occurred in the sod heating boxes were near optimum for the longest survival of sod in storage.

However, the carbon dioxide levels were lower and the oxygen levels remained higher under commercial sod load conditions than in the sod heating boxes. The higher oxygen level may be beneficial for up to normal length of storage time, but it will probably result in greater injury during adverse conditions or longer than usual times of storage on commercial sod loads.

Ethylene toxicity.--Ethylene toxicity undoubtedly contributed to sod injury in some of the sod heating box experiments, but it would rarely cause injury in commercial sod loads.

The controlled atmosphere studies showed that 0 and 2 ppm of ethylene did not reduce root production but that 4 and 8 ppm did. A definite threshold level for ethylene injury exists between 2 and 4 ppm of ethylene.

High ethylene levels in the sod heating box experiments were generally associated with the high (215 lb/A) nitrogen treatments. The ethylene levels exceeded 3 ppm (highest was 5.35 ppm) for the 215 lb/A nitrogen treatments after 12, 24, and 48 hours of storage in Experiment V. Root production was quite low for the high nitrogen treatments after 48 hours and zero after 72 hours in Experiment V. Ethylene production above 2 ppm was associated with high nitrogen treatments in Experiments IV and IX. Ethylene production may result from a minor anaerobic respiration pathway accentuated by high concentrations of ammonium ion in the grass plant. Apparently more ethylene was produced when the oxygen level was slightly below 2% as occurred in Experiment V. Ethylene production was independent of temperature. The highest ethylene levels were found after 24 or 48 hours of storage in the sod heating box experiments.

Factors other than excessive nitrogen fertilization can result in high ethylene levels. A 3.22 ppm ethylene level was associated with the 2 inch height of cut after 24 hours of storage during Experiment VIII. A mean of 2.66 ppm of ethylene occurred with the "zero" nitrogen rate after 24 hours of storage during Experiment III.

The ethylene levels remained below 2 ppm in the other experiments. The nitrogen level was equal to or below that commonly applied in producing commercial sod in most of these experiments. Therefore, it is concluded that ethylene toxicity would not generally be a cause of sod injury in commercial sod loads.

Carbohydrate starvation.--The decrease in percent total available carbohydrates (TAC) correlated closely with the increases in percent leaf kill during 13 days of storage in the sod heating boxes during Experiment XI. The TAC decreased from 28.6 to 12.8% while the leaf kill increased from 0 to 100%. The fructosan content of the stems was 5.3, 5.3, and 6.9% after 9, 11, and 13 days of storage, respectively. Sullivan and Sprague (1949) clipped perennial ryegrass plants to 1.5 inches and then grew the plants at 90/80° F and 525 ft-c in growth chambers for 40 days. The fructosan content in the stubble decreased from 28 to 7% during the first 21 days. Even though the plants were stunted and spindly, they survived for 19 more days with the 7% level of fructosan.

The percent TAC in relation to percent leaf kill and root production for sod stored in controlled atmospheres at 104 and 83° F was measured. This data did not show a correlation between percent TAC and percent leaf kill or temperature.

The data show that TAC was depleted during sod storage, but TAC was not exhausted or depleted to a consistent low level before death of the sod occurred. Carbohydrate starvation was not a direct cause of sod death. Whether or not carbohydrate depletion contributed to sod injury can not be determined from the limited data gathered.

High temperature injury.--The growth and development of turfgrasses is usually confined to a 40 to 105° F temperature range (Beard, in press). The optimum temperature range for sustained root growth for Kentucky bluegrass is 50 to 65° F (Brown, 1943). Kentucky bluegrass root and rhizome growth is restricted at soil temperature above 90° F (Beard, in press). Mitchell (1956) found that growth of cool season grasses ceased above 95° F. Fischer (1967) found that temperatures above 105° F killed *Poa annua*.

Soil temperatures are more important than air temperatures in plant survival (Carroll, 1943). The lethal temperature varies with the time of exposure; the lower the temperature the longer the time required to produce tissue kill (Fischer, 1967).

A summarization of mean temperatures, percent leaf kill, and root production for the 1969 sod heating box experiments is presented in Table 63. In general, the higher the temperature the greater the percent of leaf kill. Root production was greater and temperatures were lower in Experiments I and II. The root production was lower and less consistent in the later experiments. High nitrogen treatments seemed to result in somewhat more injury for a given temperature level. Pellett and Roberts (1963) found that high nitrogen reduced the ability of Kentucky bluegrass to resist high temperature injury. The presence of seed-heads increased the injury in relation to temperature in Experiment IV. The high initial soil temperature resulted in more rapid increases in leaf kill in Experiment VIII; probably because of the longer exposure to high temperature. The controlled atmosphere temperature study showed very clearly that the 104° F temperature resulted in more leaf kill and less root production than for 83° F. One must conclude that sod injury is closely related to temperature level. The higher the temperature the more sod injury occurred.

Table 63. Summarization of mean temperatures, percent leaf kill, and root production for the 1969 sod heating box experiments

Experiments and Treatments	Hours of Storage	Mean Temp. (°F)	Mean % Leaf Kill	Mean Root Production (mg/pot)
	0	74		
I	24	91	0	46
2 vs 0.75 inch cut	48	91	0	102
N^6BA	72	88	0	82
	96	86	0	40
II	6	71		
2 vs 0.75 inch cut	24	82	0	90
0 vs 215 lb N	48	86	0	82
N^6BA	72	86	0	92
	96	86	6	49
	0	85		
III	24	94	0	49
2 vs 0.75 inch cut	48	95	0	47
10, 5, 1 days	72	95	9	35
N^6BA	96	93	45	18
	120	87	91	20
IV	0	69		
2 vs 0.75 inch cut	24	81	0	34
0 vs 215 lb N	48	87	6	31
N^6BA	72	88	41	32
(seedheads)	96	89	86	6
V	0	74		
0 vs 215 lb N	24	88	9	60
4, 8, 18 days	48	93	8	9
N^6BA	72	90	90	14
	00	68		
VI	24	82	0	43
2 vs 0.75 inch cut	48	88	1	93
0, 5, 10 days	72	91	3	110
N^6BA	96	90	30	79
	0	69		
VII	24	78		
2, 0.75, 0.50 inch cut	48	88	10	40
0.75--0, 5, 10 days	72	93	23	75
	96	94	51	38
VIII	0	87		
2 vs 0.75 inch cut	24	95	29	8
0 vs 215 lb N	48	95	84	20
N^6BA	72	95	94	8
	0	78		
IX	24	90	61	135
9 a.m. to 2 p.m.	48	94	98	8
0, 130, 215 lb N	72	96	100	0
	0	82		
X	24	90	2	64
0, 90, 180,	48	93	7	47
360, 340 lb N	72	93	16	54
during production	96	95	48	34
	120	94	69	33

CONCLUSIONS

The following conclusions may be drawn from these experiments.

1. Sod injury increased progressively in relation to increased temperature levels occurring during storage of Merion Kentucky bluegrass sod under simulated shipping conditions.
2. Sod cut at a 0.75 inch height within a few days before harvest survived storage longer than sod cut at 2 inches.
3. Sod injury during storage increased progressively with increasing rates of nitrogen fertilization.
4. Inhibition of respiration from oxygen starvation or from high carbon dioxide levels was not a cause of sod injury.
5. Early morning harvest increases the length of time that sod may be stored in the load.
6. N^6benzyladenine, a respiration inhibitor, did not affect carbon dioxide and oxygen levels, temperature, or injury of sod during storage.
7. The amount of ethylene released in commercial sod loads during shipment is too small to cause injury of sod.

8. The rate of respiration was higher and the amount of sod injury was greater relative to temperature when seedheads were present.
9. Root production decreased as temperature and nitrogen levels increased.

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