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

presented by

JOHN WILLIAM KING

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Ph.D. degree in Crop Science

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Major professor

Date ____________________

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.

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

By

John William King

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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

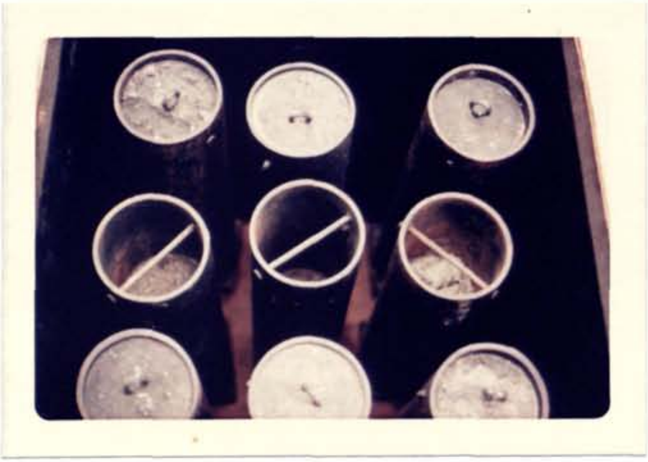

Figure 2. Weights (255 lb) in sod heating box.

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 ±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° 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.

1969 Season

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.

<u>Sod harvesting</u>.--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.

<u>Temperature measurement</u>.--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.

<u>Atmospheric measurements</u>.--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.

<u>Other supporting experiments</u>.--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

Measurement	Hours of Storage	Mean	Nitrogen (lb/A)		Irrigation (in)		Clipping Removal		Cutting Ht. (in)		N^6BA (lb/A)	
			0	130	0	2	-	+	2	0.75	0	0.0055
% Moisture	0	57	57	57	54	59***	57	57	59	55***	57	56
Temp. (°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.