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.

Experiment I (May 16, 1969)

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^{6}benzyladenine 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^{6}benzyladenine 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^{6}benzyladenine (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) 0 a_1	.0055 a_2	.0275 a_3	.0550 a_4	Simple Effects 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^{6}benzyladenine 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	$N^{6}BA$ (lb/A) 0	$N^{6}BA$ (lb/A) .055	Cutting Ht. (in) and Time (days) 2	0.75 10	0.75 5	0.75 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

Measurement	Hours of Storage	N^6BA (lb/A)	Cutting Ht. (in) & Time (days) 2 / 2	0.75 / 10	0.75 / 5	0.75 / 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

Measurement	Hours of Storage	Mean	N^6BA (lb/A)		Cutting Ht. (in) & Time (day)			
			0	.055	2	0.75	0.75	0.75
					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^{6}benzyladenine 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^{6}benzyladenine 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^{6}BA (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. (^oF)	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	^{o}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 4	215 8	215 lb/A 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)		Nitrogen Treatments			
			0	.055	0	215 4	215 8	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.

Results and discussion.--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	^{o}F

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	^{o}F

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 (°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

Data	Hours of Storage	Mean	Cutting Height (in) and Time (days) 0.50 0	0.75 0	0.75 5	0.75 10	2 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	0.75 0	0.75 5	0.75 10	2 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	^{o}F

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	^{o}F

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

Measurement	Hours of Storage	Harvest Time	Nitrogen (lb/A) 0 a_1	130 a_2	215 a_3	Simple Effects 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	^{o}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 stepwise 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^{o} 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.

$$\% \text{ TAC} = \left[\frac{(\text{Std}_2 - \text{Std}_1)\ A_s}{A_{\text{Std}_2} - A_{\text{Std}_1}} + b \right] \left(\frac{\text{dilution} \times 100}{\text{Wt}_s} \right)$$

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)

$$b = \text{correction for slope} = \left[\frac{(\text{Std}_2 - \text{Std}_1)\ A_{\text{Std}_2}}{A_{\text{Std}_2} - A_{\text{Std}_2}} \right]$$

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. (^{o}F)	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

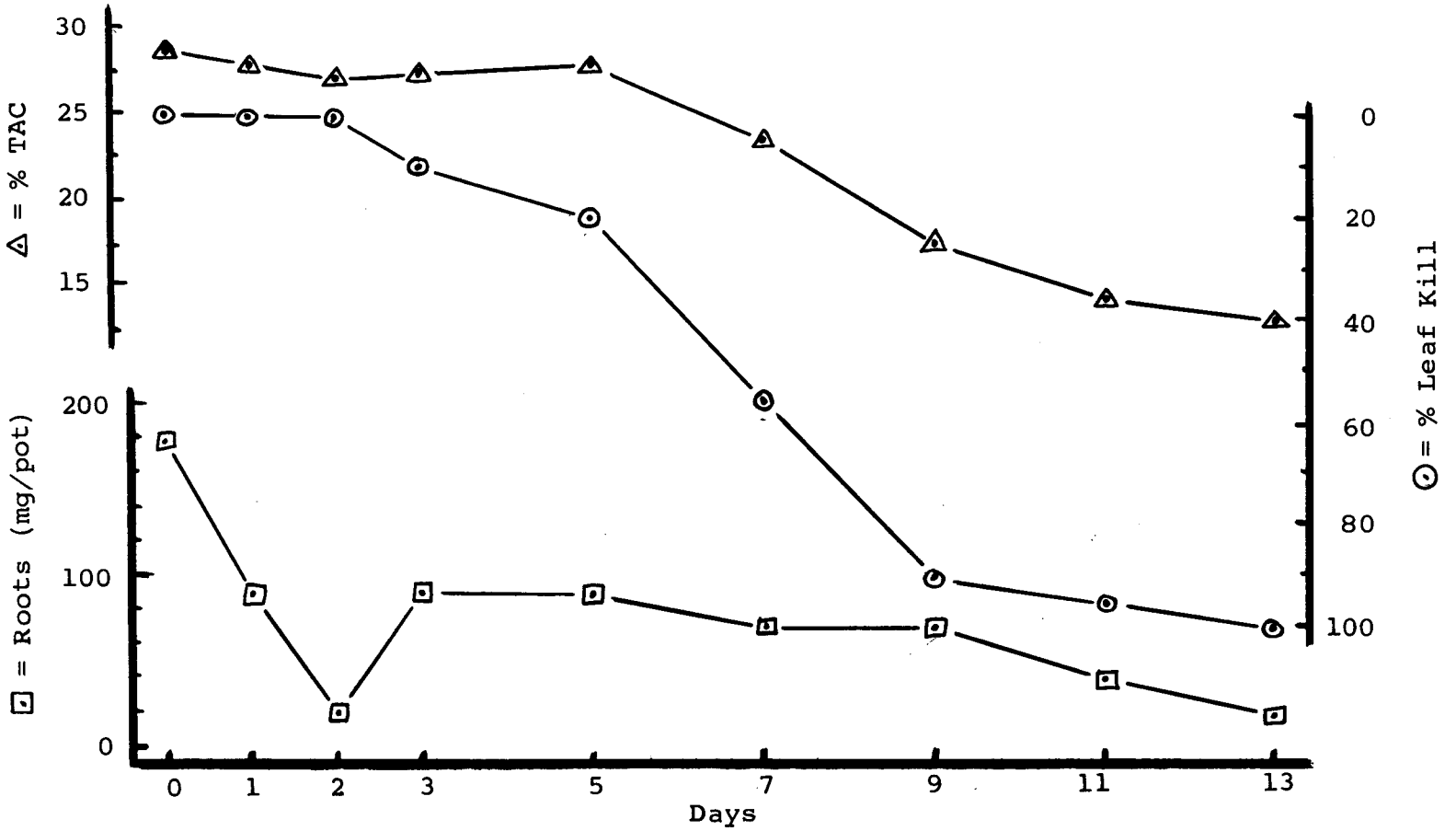

Figure 7. Percent total available carbohydrates, root production, and percent leaf cover in relation to storage under simulated shipping condition for 13 days for commercial sod harvested on October 24, 1969.

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.