

REGULATION OF BUD GROWTH IN KENTUCKY BLUEGRASS (POA PRATENSIS L.)
AS INFLUENCED BY TEMPERATURE, ETHYLENE AND KINETIN

By

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ABSTRACT

REGULATION OF BUD GROWTH IN KENTUCKY BLUEGRASS (POA PRATENSIS L.) AS
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High midsummer temperatures inhibit bud growth in many cool season grasses. Experiments were conducted, both under field conditions and controlled environments (growth chambers), on the regulation of bud growth in Kentucky bluegrass (Poa pratensis L.) cv. Merion and Nugget. Bud growth was schematically illustrated by stages: 1) initiation of bud activity to first primordial leaf; 2) second primordial leaf to leaf unfold, and; 3) ligule formation to leaf emergence above the subtending leaf sheath. The increase in the number of active buds (bud activity) never ceased but was reduced when the grasses were grown at 33C. Temperatures of 22C were found to significantly increase bud length in both cultivars compared to 33C. The change in temperature influenced the number of active buds in Merion to a much greater extent than in Nugget. The number of active buds at the stem base and nodes were also reduced by supraoptimal temperatures compared to cooler temperatures in both cultivars.

To evaluate the effect of ethylene concentration on bud activity,

ethylene was introduced for 24 hr in two temperature treatments of 22 and 33C. Following the treatment, the grasses were grown for 10 days at either temperature. Results showed that only a 24 hr exposure at 33C was needed to inhibit bud activity. Inhibition was extended when both cultivars were subsequently exposed to 10 days of supraoptimal temperatures. Significant increases in the number of active buds at 22/22C were evident when comparing treatments of 10 and 100 $\mu\text{l/L}$ ethylene in Nugget and 1 and 10 $\mu\text{l/L}$ ethylene in Merion with respective controls. Both cultivars exhibited lowered numbers of active buds when both the initial exposure and postinitial temperatures were 33C, irrespective of ethylene concentration. The number of active buds increased when cultivars exposed to 33C were returned to cooler temperatures.

When the grasses were placed under hypobaric ventilation to reduce ethylene and other gases to subnormal levels, the number of active buds were reduced at 22C. Bud activity returned to normal when ethylene was reintroduced. Under higher temperatures the number of active buds could not be restored by the reintroduction of ethylene. Ethylene production, measured at 5C increments from 15C to 40C, peaked at 27C in Merion and 34C in Nugget. High ethylene levels were considered a contributing factor in bud activity inhibition at high temperatures.

Kinetin was applied as a foliar spray to both cultivars grown at 22 and 33C to evaluate its effect on bud activity and ethylene production. Ethylene and kinetin, when applied alone, significantly increased the number of active buds at 22C. When the cultivars were grown at

33C, neither ethylene, kinetin nor their combination had a significant effect on bud activity. Results from hypobaric conditions suggest that bud activity may be influenced by kinetin stimulated ethylene. Kinetin was found to enhance bud activity in Nugget grown at 22C apparently through stimulation of ethylene. Inhibition of bud activity resulted from increased ethylene production generated endogenously or by kinetin application at 33C.

Rates of Ethepon (2-chloroethylphosphonic acid), less than 1000 $\mu\text{l/L}$ applied as drenches, were ineffective in increasing shoot numbers under summer field conditions. Monthly nitrogen drenches of 0.48 kg N/100m², were more effective in improving shoot density and quality in both cultivars compared to combinations of nitrogen and Ethepon.

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TABLE OF CONTENTS

	Page
LIST OF TABLES	v
LIST OF FIGURES	vii
INTRODUCTION	1
CHAPTER 1: TEMPERATURE INFLUENCES ON BUD MORPHOGENESIS IN KENTUCKY BLUEGRASS	
Abstract	3
Introduction	4
Materials and Methods	5
Results and Discussion	7
Literature Cited	20
CHAPTER 2: HYPOBARIC AND TEMPERATURE EFFECTS ON BUD GROWTH AND ETHYLENE PRODUCTION IN KENTUCKY BLUEGRASS	
Abstract	22
Introduction	23
Materials and Methods	25
Results and Discussion	27
Literature Cited	39
CHAPTER 3: REGULATION OF BUD GROWTH IN KENTUCKY BLUEGRASS. EFFECT OF KINETIN AND TEMPERATURE ON ETHYLENE PRODUCTION	
Abstract	42

Introduction	43
Materials and Methods	44
Results and Discussion	48
Literature Cited	55
CHAPTER 4: INFLUENCE OF ETHYLENE, KINETIN AND NITROGEN DRENCHES ON SHOOT DENSITY IN KENTUCKY BLUEGRASS UNDER SUMMER FIELD CONDITIONS	
Abstract	57
Introduction	58
Materials and Methods	60
Results	61
Discussion	71
Literature Cited	77
CONCLUSIONS	80
LIST OF REFERENCES	82

LIST OF TABLES

Table	Page
CHAPTER 1	
1. Schematic presentation of the influence of temperature on bud growth in Merion and Nugget Kentucky bluegrass	11
2. Effect of sampling date, temperature and position on bud length of Merion Kentucky bluegrass expressed as the percent of total bud numbers at each position	14
3. Effect of sampling date, temperature and position on bud length of Nugget Kentucky bluegrass expressed as the percent of total bud numbers at each position	15
4. Influence of time and temperature on length of subtending leaf in Merion and Nugget Kentucky bluegrass	16
CHAPTER 2	
1. Effect of ethylene and temperature on bud activity in Merion and Nugget Kentucky bluegrass	28
2. Effect of temperature and gas mixture on rhizome/tiller ratio in Merion and Nugget Kentucky bluegrass	34
3. Effect of ethylene concentration and temperature exposure on the number of active buds in Merion Kentucky bluegrass . .	35
4. Effect of ethylene concentration and temperature exposure on the number of active buds in Nugget Kentucky bluegrass . .	36
CHAPTER 3	
1. Effect of temperature on the number of active buds in Merion and Nugget Kentucky bluegrass as influenced by ethylene and Kinetin concentration	49
2. Effect of kinetin concentration on the number of active buds in Nugget Kentucky bluegrass as influenced by temperature . .	52
3. Effect of kinetin and temperature on Kentucky bluegrass bud activity in response to hypobaric ventilation with or without supplemental ethylene	53

Table		Page
CHAPTER 4		
1.	Effect of Ethephon concentration and nitrogen level on turfgrass quality rating and shoot density in Merion Kentucky bluegrass during the months June to September .	62
2.	Effect of Ethephon concentration and nitrogen level on turfgrass quality rating and shoot density in Nugget Kentucky bluegrass during the months June to September .	64
3.	Effect of Ethephon and kinetin concentration on turfgrass shoot density and quality in Merion Kentucky bluegrass during the months June to September	66
4.	Effect of Ethephon and kinetin concentration on turfgrass shoot density and quality in Nugget Kentucky bluegrass during the months of June to September	67
5.	Effect of Ethephon and silver nitrate concentration on turfgrass shoot density and quality in Merion Kentucky bluegrass during the months June to September	68
6.	Effect of Ethephon and silver nitrate concentration on turfgrass shoot density and quality in Nugget Kentucky bluegrass during the months June to September	70

LIST OF FIGURES

Figure		Page
CHAPTER 1		
1.	Schematic presentation of tiller bud growth and development in Kentucky bluegrass	8
2.1	Photomicrograph illustrating bud swell, Stage I of initiation of bud activity to first primordial leaf in Merion bluegrass x 25	10
2.2	Photomicrograph illustrating second primordial leaf, Stage II of second primordial leaf to leaf unfold in Merion bluegrass x 25	10
2.3	Section through Merion bluegrass tiller bud illustrating the dome shaped growing point overarched by leaf primordia x 1000	
3.	Effect of temperature and time on bud length in Merion and Nugget bluegrass	13
4.	Effect of temperature and time on the s/t ratio (tiller bud length/length of subtending leaf) in Merion and Nugget bluegrass	17
CHAPTER 2		
1.	Method of gas sampling from turfgrass under conditions of controlled temperature	30
2.	Effect of temperature on ethylene production in Nugget and Merion bluegrass	32
CHAPTER 3		
1.	Method for ethylene detection of turfgrass sample	46
2.	Effect of kinetin concentration and time on ethylene production in Nugget bluegrass grown at optimal (22C) and supraoptimal (33C) temperatures	50

Figure	Page
CHAPTER 4	
1. Daily minimum and maximum temperatures from May to September 1977, recorded at the Crop and Soil Science Barns, Michigan State University, 300m trial area	74

INTRODUCTION

Bud activity in many cool season turfgrasses is inhibited by supraoptimal temperatures, or those temperatures higher than the optimum for growth. Although the potential buds are present, their inhibition results in poor shoot density and lowered turfgrass quality. Lack of shoot density is also compounded by excessive wear during the summer period.

The fact that repression or inhibition of bud activity occurs in grasses suggests control of bud growth by endogenous growth regulators, particularly at an early stage of bud development. Recent theories on bud development in cool season grasses have credited Indole-3-acetic acid (IAA) with a major role, but its mode of action is still not clear. Recent research has implicated ethylene, which can be induced by auxin, in the improvement of tillering and stem elongation in Kentucky bluegrass. Ethephon (2-chloroethylphosphonic acid), which breaks down to ethylene, has also been reported to induce both tiller and rhizome bud activity in other graminaceous plants. These studies suggest that bud activity in Kentucky bluegrass may be controlled by ethylene levels.

Cytokinins have also been credited with the release of lateral buds from apical dominance, tiller bud elongation and leaf recovery from supraoptimal temperatures. It was proposed that application of a foliarly applied kinetin would increase bud activity when grown under supraoptimal temperatures.

The objective of the dissertation was to evaluate the influence of endogenous and exogenous ethylene levels and kinetin on bud activity in Kentucky bluegrass when grown under optimal (22C) and supraoptimal (33C) temperatures. Lack of information on tiller bud activity of Kentucky bluegrass necessitated a preliminary study to document bud development by illustration, and to evaluate the influence of temperature on morphogenesis. The technique of hypobaric ventilation, which reduced endogenous ethylene and other gases to subnormal levels, was used to determine the influence of ethylene on bud activity.

CHAPTER 1

TEMPERATURE INFLUENCES ON BUD MORPHOGENESIS IN KENTUCKY BLUEGRASS

Abstract

Poa pratensis L. cv. Merion and Nugget were studied to evaluate the influence of temperature on bud morphogenesis. Turfgrass buds were schematically illustrated by stages for description: 1) initiation of bud activity to first primordial leaf; 2) second primordial leaf to leaf unfold and; 3) ligule formation to leaf emergence above the subtending leaf sheath. The increase in the number of active buds (bud activity) never ceased but was reduced when the grasses were grown at 33C. Temperatures of 22C were found to significantly increase bud length in both cultivars compared to 33C. The change in temperature influenced the number of active buds in Merion to a much greater extent than in Nugget. The number of active buds at the stem base and nodes were also reduced by supraoptimal temperatures compared to cooler temperatures in both cultivars. The establishment of s/t ratio, which is the ratio of the tiller bud length to subtending leaf, suggests a direct relationship between tiller bud growth and maturation of the subtending leaf sheath.

Introduction

An important component of turfgrass quality is density or the number of shoots per unit area. In cool season grasses, two types of buds contribute to shoot density, those developing into rhizomes, or into intra or extravaginal tillers (3, 4). Buds can also be found in the axils of scale leaves on rhizomes (13).

Reviews on tillering have largely centered on the effect of environmental factors on shoot and inflorescence morphology (2, 5, 6, 8) or on tiller number after emerging above the subtending leaf sheath (9, 11). Little is known about the growth of tillers before they become visible externally. In 1975, Williams and co-workers examined the growth and form of the wheat tiller bud and its response to two levels of light intensity and nitrogen supply grown at 20/15C day night temperatures. They found that axillary buds never cease growing from initiation but may vary in their rate of development.

Tiller buds develop both in the axils of the coleoptile and the first one or two foliage leaves in graminaceous seeds (8). Following seed germination, the bud is organized from intercalary meristematic tissue at the base of the phytomer, or grass shoot unit (5, 12). These buds have an outer skin, the dermatogen, and an inner hypodermis, both of which are derived from the main shoot. Deeper tissues such as the subhypodermis and core are derived from subhypodermal tissue of the main axis (17). These buds are initiated at the same rate as the leaf

primordia and arise in acropetal succession from the base upwards (9). The developed bud can often be recognized by the time the leaf primordium has arched over the stem apex (6). Buds are dormant in the sense that its potentially active subapical meristem is arrested; hence, little internode elongation occurs. Bud break and shoot elongation are the result of leaf elongation and subapical meristematic activity (14).

The objective of this study was to illustrate the bud growth and development of Kentucky bluegrass and to evaluate the influence of temperature on the stages of morphogenesis.

Materials and Methods

Plugs of Kentucky bluegrass cv. Merion and Nugget were taken from the field and broken into tillers having the same leaf number. Following preliminary observations, the axillary bud of the fourth leaf from the top was selected for description. This was also in agreement with previous work (10, 15) in that tiller expansion is limited only to sites in the axils of mature leaves. Seven tillers were equally spaced and planted near the circumference of 200ml styrofoam cups containing a soil admendment¹ and acclimated in the greenhouse for 10 days. Prior to the temperature treatment, the fourth leaf was identified by a felt pencil mark. The cups were then transferred to two growth chambers which were maintained at 22 or 33C. Both chambers were set on a 16 hr

¹Turfex., Wyandotte Chemicals of Canada, Scarborough, Ontario.

photoperiod with a photosynthetic radiation rate of 30 Wm^2 . Every second day at 1300 hr, until the tiller was exposed, twenty-eight plants were harvested and wrapped in moist towelling. Harvesting was in accordance to a predetermined randomized plan. The buds were separated carefully from their stem under a stereoscope with bud length being determined with an ocular micrometer. Measurement of bud length was from their tip to the point of disappearance of the buttress bulge (19). Both length of the tiller bud and its subtending leaf were expressed in mm.

Bud growth in Kentucky bluegrass was described in three separate stages, each being subcategorized into A, B, and C to provide greater description (Figure 1). The designation of stages and subcategories was determined by the number of buds having the highest common description on any particular harvest day. Photomicrographs were also taken to provide detail of the stages in bud development.

In another study, plants were grown under similar environmental conditions as previously described, the position and length of buds were recorded as to their location on the stem base and nodes. Data was taken every 5th day with nonactive buds classed as those less than 1.0 mm in length and elongated buds as those exceeding 1.0 mm in length.

Values stated in the tables or shown in figures are the mean of four replications repeated twice with the mean separation carried out using Duncan's Multiple Range Test.

Results and Discussion

A schematic presentation of bud growth and development was generated and described by stages which were as follows:

State I. Initiation of bud activity to first primordial leaf

State II. Second primordial leaf to leaf unfold;

State III. Ligule formation to leaf emergence (Figure 1)

Prior to their increase in length, the buds initiated a basal swelling (Figure 2-1) which occurred within two days from earliest observation. This was represented by Stage I(b) in Figure 1. Elongation followed, in which up to three leaf primordia were developed (Figure 2-2). This was designated as the conclusion of Stage II(c). These morphological events occurred within 6 days in Merion, but were delayed to the tenth day in Nugget (Table 1). A basipetal unfolding of the leaf followed demarcation of the ligule region, which occurred within the enclosed leaf sheath. Ligule formation in Merion, as represented by Stage III(a) in Figure 1, was present on the eighth day when the leaf was approximately 1.2 to 1.8 cm in length. By the tenth day the leaf blade protruded above the subtending leaf in Merion Kentucky bluegrass. Bud development followed similar pattern in both cultivars. Bud morphogenesis in Nugget Kentucky bluegrass did not proceed past Stage II(a) over the ten day study. Table 1 shows that leaf emergence (Stage III(b)) was attained by Merion in ten days, irrespective of temperature. Bud length in Nugget Kentucky bluegrass was not influenced

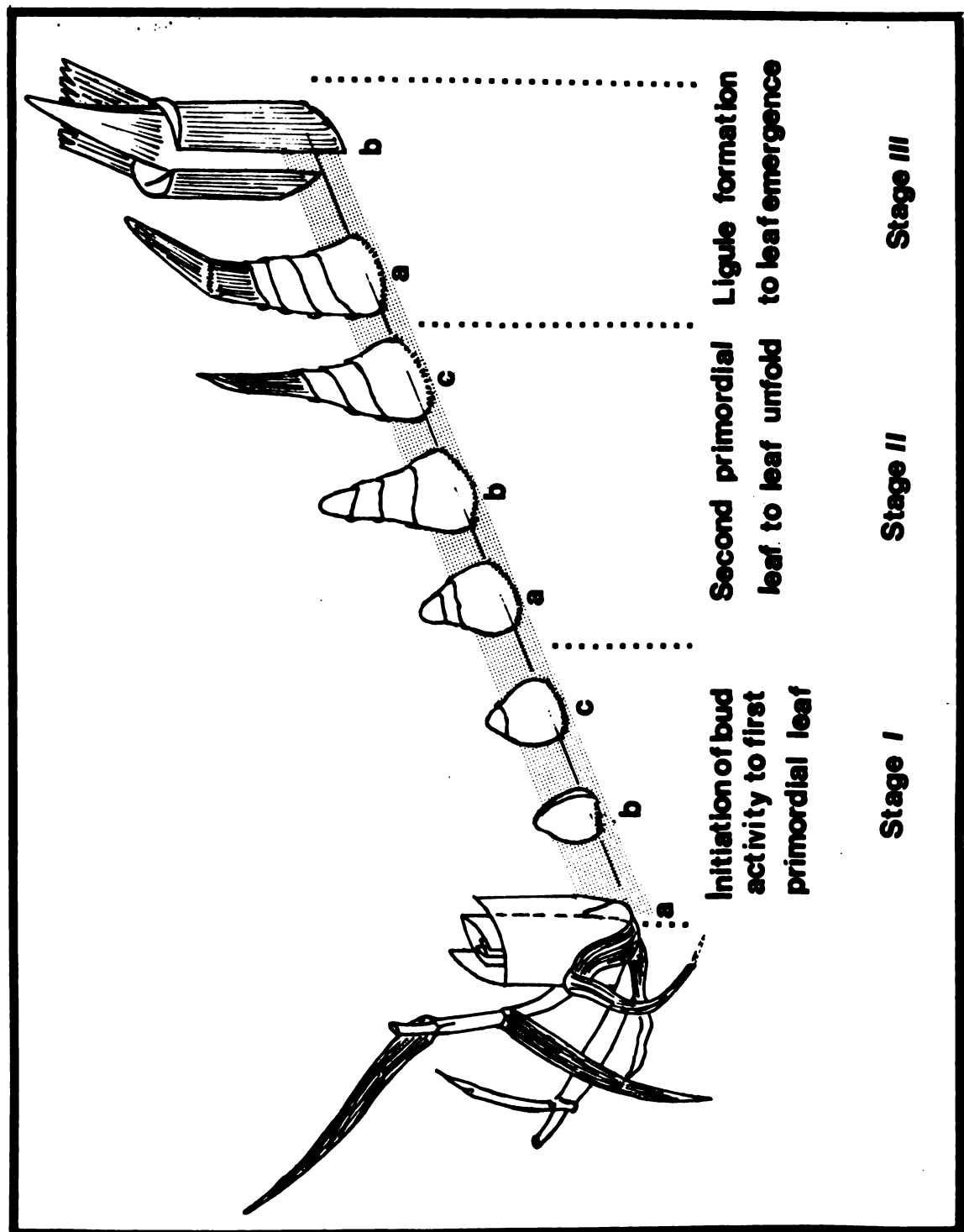


Figure 1. Schematic presentation of tiller bud growth and development in Kentucky bluegrass.

Figure 2.1. Photomicrograph illustrating bud swell, Stage 1 from initiation of bud activity to first primordial leaf in Merion bluegrass X 25.

Figure 2.2. Photomicrograph illustrating second primordial leaf, Stage 11 from second primordial leaf to leaf unfold in Merion bluegrass X 25.

Figure 2.3. Section through Merion bluegrass tiller bud illustrating the dome shaped growing point overarched by leaf primordia X 1000.

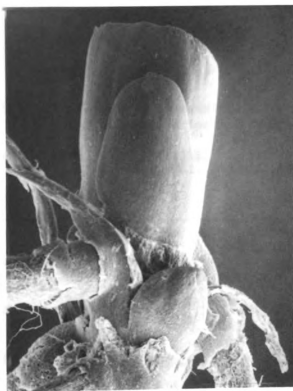


Figure 2.1

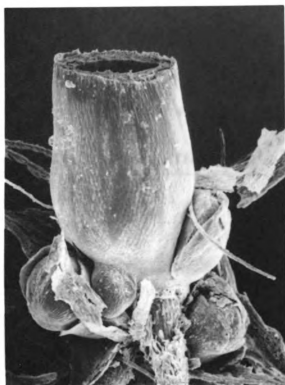


Figure 2.2

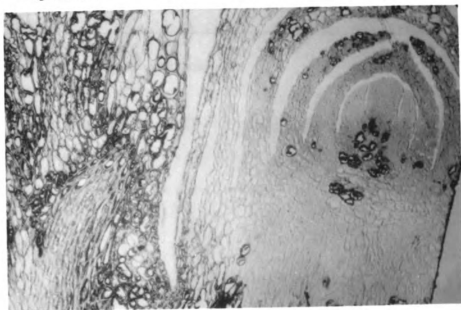


Figure 2.3

Table 1. Schematic presentation of the influence of temperature on bud growth in Merion and Nugget Kentucky bluegrass.

CULTIVAR	TEMPERATURE (C°)	DAYS FROM TEMPERATURE TREATMENT				
		2	4	6	8	10
Nugget	22	bud initiate	third break	>		leaf unfold
Merion	22	bud initiate	leaf unfold	>	ligule formation	leaf emergence
Nugget	33	bud initiate	second break	>		third break
Merion	33	bud initiate	third break	>	ligule formation	leaf emergence

¹ Mean of twenty-eight observations

by temperature and was always significantly less than Merion (Figure 3). Supraoptimal temperatures slowed bud elongation after the sixth day in Merion bluegrass. Elongation did occur in Nugget at both temperatures but at a much reduced rate.

The significance of temperature on bud elongation is shown in Tables 2 and 3. The first sampling of Merion Kentucky bluegrass at 22C revealed that a large percentage of buds had not elongated further than 10 mm, a major portion of which had not exceeded 1 mm. Bud expansion had occurred at the stem base and the first nodal region at this temperature. Shifts were detected 15 days after the temperature treatment as indicated by the large percentage of buds in the higher bud length categories. This indicates that buds were elongating into potential tillers and that growth was not inhibited. New bud development was evident in the 0-10 mm range at the termination of the study. Growing temperature of 33C reduced bud length and the rate of new tiller development. Bud elongation did not occur in Nugget Kentucky bluegrass, irrespective of temperature, over the study period. At the lower growing temperature, a small shift occurred at the stem base on the last three sampling dates, but buds at nodes above this did not elongate.

The (s/t) ratio, which is the ratio of the tiller bud length to the length of the subtending leaf (Table 4) was established and presented in Figure 4. The ratio suggests that between the second and fourth day after the temperature treatment, leaf elongation

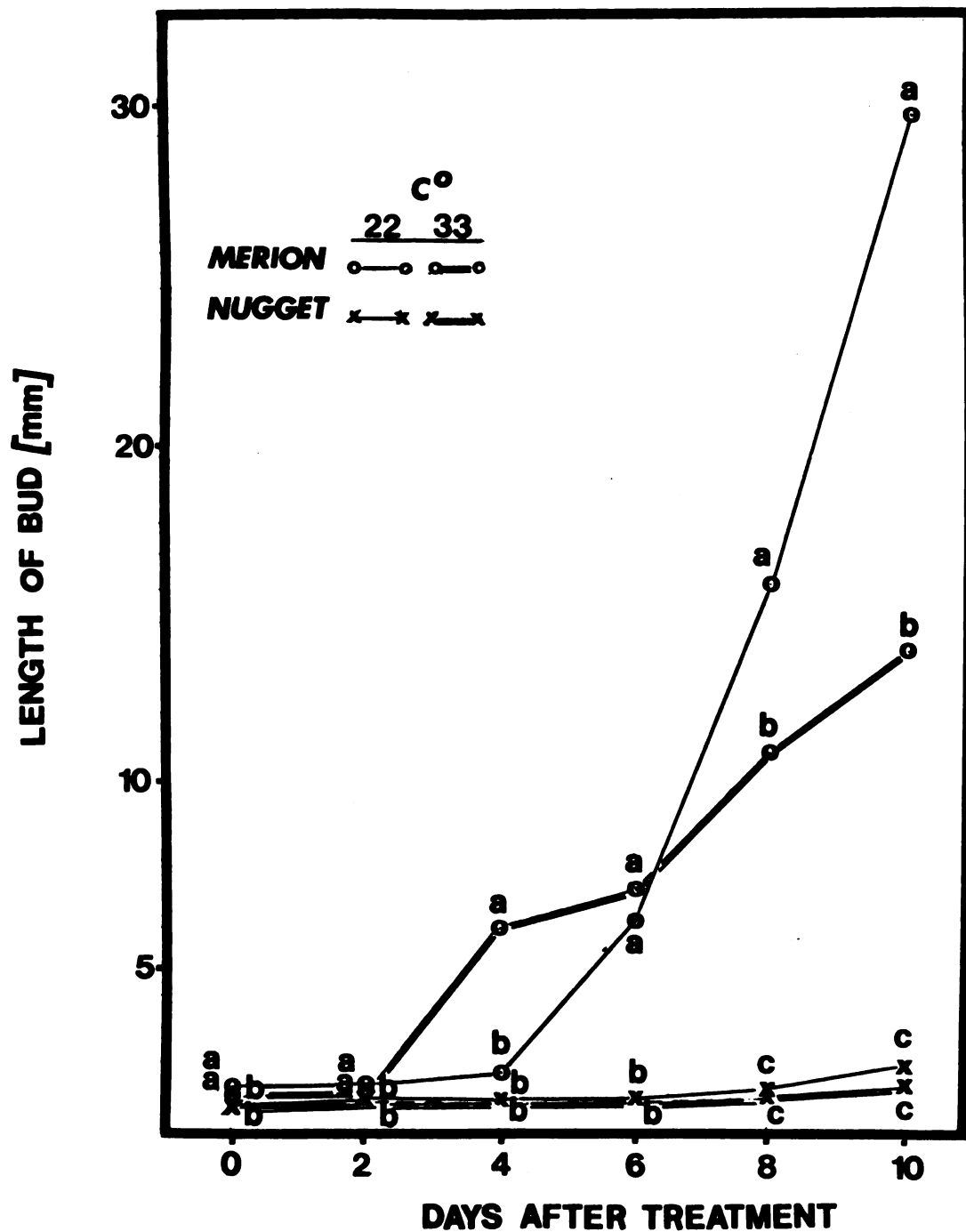


Figure 3. Effect of temperature and time on bud length in Merion and Nugget bluegrass. Means within days having the same letter are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

Table 2. Effect of sampling date, temperature and position on bud length of Merion Kentucky bluegrass expressed as the percent of total bud numbers at each position.

Sampling Date	TREATMENT		BUD LENGTH (mm)				
	Temperature (C)	Position of bud*	0-1	1-10	11-20 Percent of Buds	21-30	30+
9/9	22	Stem base	11	37	32	16	4
		1st node	33	44	12	-	11
		2nd node	17	83	-	-	-
		3rd node	83	17	-	-	-
		4th node	100	-	-	-	-
	33	Stem Base	43	36	14	-	7
		1st node	28	28	-	16	28
		2nd node	33	50	-	-	17
		3rd node	33	33	33	-	-
		4th node	-	100	-	-	-
9/14	22	Stem base	33	25	-	33	9
		1st node	33	67	-	-	-
		2nd node	80	20	-	-	-
		3rd node	33	33	33	-	-
		4th node	33	-	66	-	-
	33	Stem base	42	33	25	-	-
		1st node	67	33	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-
		4th node	100	-	-	-	-
9/19	22	Stem base	-	20	30	30	20
		1st node	-	40	40	20	-
		2nd node	-	60	-	20	20
		3rd node	-	80	-	20	-
		4th node	20	60	-	-	20
	33	Stem base	50	25	8	17	-
		1st node	40	60	-	-	-
		2nd node	80	-	20	-	-
		3rd node	100	-	-	-	-
		4th node	100	-	-	-	-
9/24	22	Stem base	-	42	17	17	24
		1st node	-	83	-	-	17
		2nd node	33	67	-	-	-
		3rd node	80	20	-	-	-
		4th node	100	-	-	-	-
	33	Stem base	90	10	-	-	-
		1st node	100	-	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-
		4th node	100	-	-	-	-

* The 1st, 2nd, 3rd and 4th node of the phytomer unit commencing above the stem base

Table 3. Effect of sampling date, temperature and position on bud length of Nugget Kentucky bluegrass expressed as the percent of total bud numbers at each position.

Sampling Date	TREATMENT		BUD LENGTH (mm)				
	Temperature (C)	Position of bud*	0-1	1-10	11-20	21-30	30+
9/9	22	Stem base	100	-	-	-	-
		1st node	100	-	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-
	33	Stem base	100	-	-	-	-
		1st node	100	-	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-
9/14	22	Stem base	83	17	-	-	-
		1st node	100	-	-	-	-
		2nd node	80	20	-	-	-
		3rd node	100	-	-	-	-
	33	Stem base	80	20	-	-	-
		1st node	83	17	-	-	-
		2nd node	80	20	-	-	-
		3rd node	100	-	-	-	-
9/19	22	Stem base	80	20	-	-	-
		1st node	100	-	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-
	33	Stem base	100	-	-	-	-
		1st node	100	-	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-
9/24	22	Stem base	60	20	-	20	-
		1st node	100	-	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-
	33	Stem base	100	-	-	-	-
		1st node	100	-	-	-	-
		2nd node	100	-	-	-	-
		3rd node	100	-	-	-	-

* The 1st, 2nd and 3rd node of the phytomer unit commencing above the stem base

Table 4. Influence of time and temperature on length of subtending leaf in Merion and Nugget bluegrass

TIME	TEMPERATURE	LENGTH OF SUBTENDING LEAF (mm) ¹	
(DAYS)	(C°)	MERION	NUGGET
2	22	53.0 b	62.0 d
	33	62.5 ab	62.2 d
4	22	74.1 a	63.8 cd
	33	68.2 a	76.0 ab
6	22	74.3 a	69.6 bcd
	33	75.3 a	71.7 bc
8	22	73.5 a	72.9 b
	33	73.5 a	80.4 a
10	22	70.4 a	72.1 b
	33	68.1 a	84.3 a

¹Mean values followed by the same letter within cultivars are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

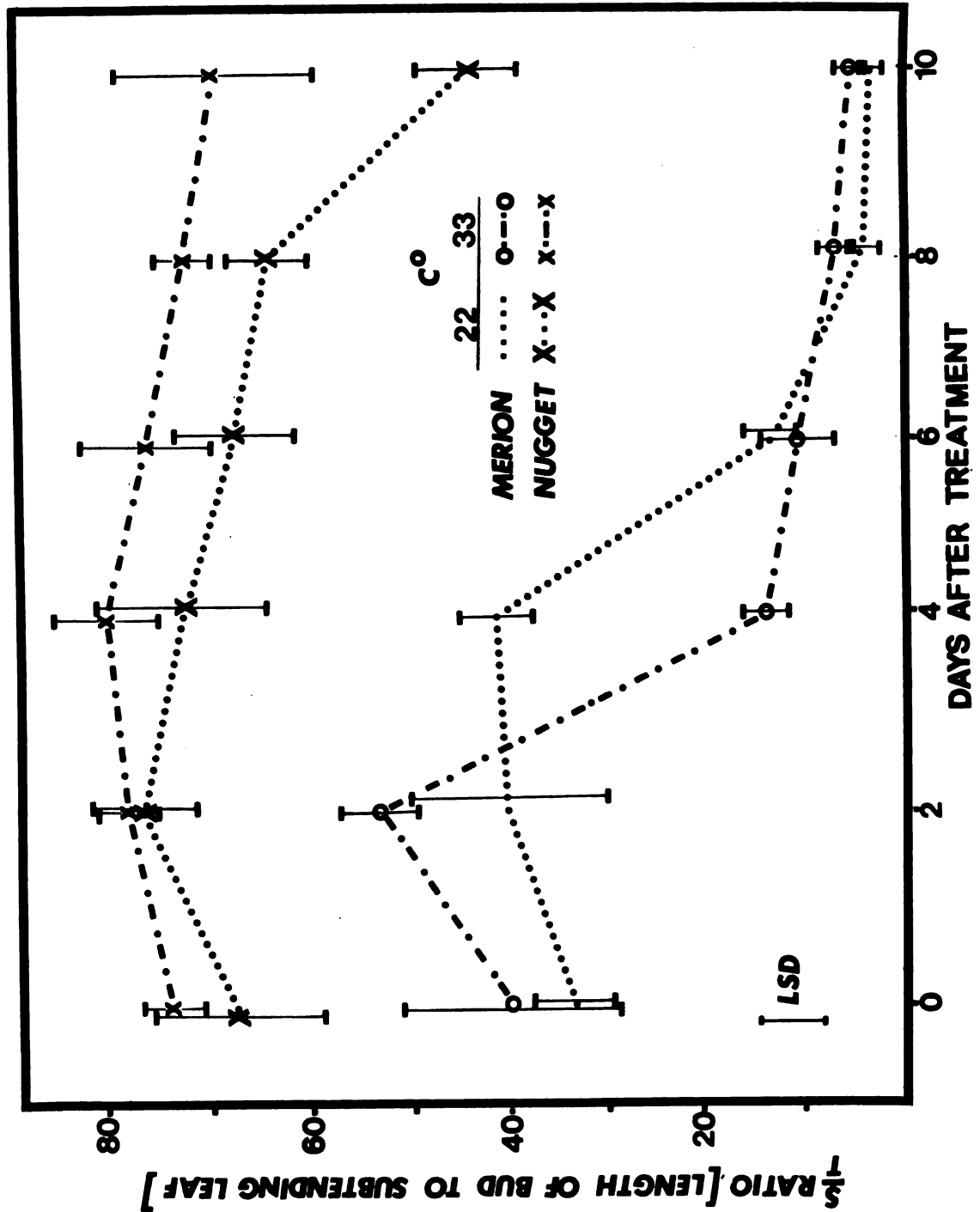


Figure 4. Effect of temperature and time on the s/t ratio (tiller bud length/length of subtending leaf) in Merion and Nugget bluegrass.

proceeded at the expense of tiller bud development in both cultivars. This occurred although the ligule was exposed, indicating that leaf lamina elongation had ceased (16). However, as the leaf matures basipetally (18), sheath elongation may not have ceased by the fourth day, thus providing additional overall length to the leaf. This is substantiated in Table 4, in which leaf length is shown to increase significantly between the second and fourth days, but does not increase further over the remaining time in Merion. The change of the s/t ratio in favor of tiller bud growth over leaf length after the fourth day suggests a direct relationship between initiation and development of tiller bud growth and maturation of the subtending leaf. In Nugget bluegrass, no significant differences were noted in leaf length until the sixth day when grown at 22C. Under supraoptimal temperatures leaf length increased throughout the study (Table 4). The slower elongation and maturation in Nugget may result in slower tiller bud development, as illustrated by the higher s/t ratio in Figure 4. Both the significant decline in this ratio and the lack of significance in leaf length on the last three days may be taken as a sign of sheath maturation. Nugget is known to be less responsive to temperature change than Merion bluegrass (1) and to have a poor spring green-up rate (4).

The significance of this ratio early in bud development may also be related to Williams and Metcalf's concept of bud escape (20). The authors suggest that physical constraint of the surrounding tissues restrict tiller bud development. The bud needs to 'escape' from its

cavity in which it develops to grow and become an independent tiller. The 'escape' time in Merion, at both temperatures, could be the fourth day as tiller bud growth exceeded the length of the leaf. This time period also corresponds to Stages I(b) to II(b) in Figure 1, which involves bud swell and development of the leaf primordia. Bud activity in Nugget did not exhibit a definite 'escape' over the period of study possibly because the bud was contained by the tight immature sheath.

The difference in tiller bud growth of the two cultivars may be due to their climatic origin. Merion Kentucky bluegrass is an apomictic selection from Ardmore, Pa., with an excellent vertical growth rate and good sod strength. Nugget Kentucky bluegrass is an Alaskan selection demonstrating a low growth habit but excellent sod strength. This view is in agreement with other research which reported pronounced differences in tillering at various temperatures among Poa pratensis L. strains of dissimilar climatic origin (21).

This study illustrated the observable morphological changes in bud growth and development in Kentucky bluegrass when grown under optimal and supraoptimal temperatures. Bud development was schematically presented and described in stages. Cooler growing temperatures were found to significantly improve bud length and the rate of bud elongation into potential tillers. Based on the s/t ratio, it was speculated that the rate of sheath maturation may influence the degree of bud elongation.

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CHAPTER 2

HYPOBARIC AND TEMPERATURE EFFECTS ON BUD GROWTH AND ETHYLENE PRODUCTION IN KENTUCKY BLUEGRASS

Abstract

High midsummer temperatures inhibit bud growth in many cool season grasses. Recent research has indicated that ethylene can increase tillering in Kentucky bluegrass (Poa pratensis L.). The objective of this study was to determine the role of ethylene in bud growth in Kentucky bluegrass at different temperatures, using the hypobaric ventilation technique to reduce endogenous ethylene to sub-normal levels. In addition the effect of ethylene concentration and the length of temperature exposure on bud activity of grasses was evaluated when grown at optimal (22C) and supraoptimal (33C) temperatures.

Results indicate that the number of active buds in Poa pratensis L. cv. Merion and Nugget, grown for 10 days at 22, 30 and 35C, were significantly reduced at higher temperatures. Under hypobaric conditions of 0.2 atm the number of active buds was significantly reduced at all temperatures compared to the air treatment without ethylene. Reintroducing ethylene to plants growing at the reduced pressures resulted in the same number of active buds found for the air treatment. Natural ethylene production peaked at 34C for Nugget and

27C for Merion. It is proposed that endogenous ethylene increases the number of active buds at 22C, but may be a contributing factor in bud activity inhibition at supraoptimal temperatures.

Twenty-four hour exposures of 33C can inhibit bud growth. Significant increases in active buds were found at 22/22C comparing 10 and 100 $\mu\text{l/L}$ in Merion with their respective controls. Both cultivars exhibited a lowered number of active buds when both the initial and post-initial temperatures were 33C, irrespective of ethylene concentration. The number of active buds increased as did their response to ethylene when plants first exposed to 33C were then returned to cooler temperatures.

Introduction

Reviews on tillering have largely centered on effects of environmental factors (14, 18, 30) on which data is taken on tillers already emerged above the subtending leaf sheath. However, relatively little is known about the mechanism of bud activity and growth of the tiller before its emergence. In many cool season grasses tiller bud initiation (11) and growth (12, 19) are inhibited by supraoptimal summer temperatures. Under these high temperatures the low tillering rates are considered a consequence of the failure of tiller buds to break and emerge, although the potential buds are present (22). Optimum temperatures for tillering in many cool season grasses are 15-24C which are slightly lower than those required for shoot growth. (23, 29).

This repression or inhibition of bud activity suggests control by endogenous growth regulators, particularly at the early stages of development. Early research (20) suggested that tiller development, although not necessary tiller bud initiation, was partially under auxin control. This theory of auxin inhibition has recently been revised to include theories of auxin stimulated inhibitors, or where auxin acts by "blocking" transport to the active bud (32). Auxin (Indole-3-acetic acid) inhibitor relationships have been described for perennial ryegrass (Lolium perenne) (28) and tall fescue (Festuca arundinacea) (33).

Auxin induced ethylene production has been reported to inhibit the action of IAA (8). It therefore may be speculated that ethylene acts as an intermediate initiating molecule in bud growth. Recently the ethylene generating chemical Ethephon has been found to promote tillering in cool season grasses (6, 26, 30). Ethylene has also been responsible for the breaking of dormancy in quackgrass (Agropyron repens) (1) and johnsongrass (Sorghum halpense) rhizomes (3). This suggests that the number of tiller buds that could exhibit growth in cool season grasses may be controlled by ethylene.

Temperature stress affecting the growth of grasses has often been associated with seasonal changes. However, but growth cessation has been recorded for shorter time intervals. In 1970 researchers (31) compared both a 35 and 22C preconditioning temperature for 8 days on Kentucky bluegrass and found cultivars tolerant to high temperatures

had higher foliage yields and lower nitrate uptake than heat intolerant cultivars. In another bluegrass study (13) plants exposed to 38C for 11 weeks did not show an improvement in rhizomatous bud development until returned to cooler growing temperatures. Field research (21) demonstrated that a single day reaching 35C for a few hours could reduce the percentage of Kentucky bluegrass tillers after vernalization.

The objective of this study was to determine the role of ethylene in bud growth of Kentucky bluegrass grown under optimal (22C) and supraoptimal (33C) temperatures. In addition, the effect of ethylene concentration and the length of temperature exposure on bud activity was evaluated in Kentucky bluegrass grown under the same temperatures.

Methods and Materials

Plugs of Poa pratensis L. cv. Merion and Nugget were taken with a 7.5 cm cutter from established turf at the Michigan State University turf research plots. The plugs were separated into tillers and senescent leaves were removed to produce a tiller with 6 leaves. Fifteen tillers were planted into 200 ml styrofoam cups containing Turface soil amendment and acclimated for 14 days under greenhouse conditions. This constituted the plant material used in the ethylene evacuation and length of exposure studies.

Ethylene Evacuation.

The hypobaric ventilation technique was used to reduce endogenous

tissue ethylene to subnormal levels (7, 10). To enhance gas diffusion from the tissue, atmospheric pressure within the desiccator was reduced to 0.2 atm. Thus, the partial pressure of ethylene at equilibrium in the tissue is reduced 5-fold, even though the rate of ethylene production of O_2 to CO_2 , an oxygen source enriched with 0.15% was passed through the desiccator rather than air.

In this way the turf plant was exposed to gas mixtures and pressure treatments described in Table 1. Three cups, of two cultivars were randomized in each of two desiccators. Temperatures of 22, 30 and 35C were run at a 16 hr. photoperiod and with a photosynthetic radiation rate of 30 Wm^2 . The desiccators were continuously evacuated over a 10 day period. Reduced pressure and flow rate was regulated by manipulation of the vacuum regulator and a metering valve at the desiccator outlet. Water stress was minimized by placing each cup in a circular stage containing holes and maintaining a 2.0 cm level of water within the cup. The water was administered into the desiccators at reduced pressure, with tubing from a reservoir at atmospheric pressure. The number of active buds were counted at the termination of each study. This included intravaginal buds where tillers protruded above the subtending leaf sheath and rhizome buds (5).

The data recorded as the number of active buds per plant in Table 1,

is the mean of three experiments and two replications.

Ethylene Production. Turfgrass plants were placed in an insulated hollow cylinder as illustrated in Figure 1. Temperatures were maintained by circulating glycol, from a controlled temperature water bath, around the cylinder. Temperatures were monitored by a thermometer inserted through a stopper into the cylinder. Temperatures ranged from 15 to 40C taken up in 5C increments over three 2.5 hr studies for each cultivar. Four ml gas samples were taken every 30 seconds with a gas-tight syringe. The samples were injected into a gas chromatograph equipped with a 2 mm by 1 mm column of activated alumina and a flame ionization detector. Nitrogen at 60C was used as the carrier gas.

The data represented is the mean of three replications of each cultivar with ethylene production expresses in nMoles gm hr⁻¹. A ratio of the number of rhizome to tiller buds was calculated and expressed as an r/t ratio.

Length of Temperature Exposure. Six cups of each cultivar, were placed in two 10 L desiccators and treated with 0, 1, 10, 100 and 1000 µl/L ethylene. Ethylene levels were analyzed with a gas chromatograph equipped with an activated alumina column and flame ionization detector as previously described. Three replications of the treated plants were exposed in the sealed desiccators for 24 hr, and then placed in growth chambers at either 22 or 33C. Chamber conditions were previously described. Following ethylene exposure the plants were removed and

grown for 10 days under post initial temperatures of 22 and 33C to give four treatments designated at 22C/22C, 22C/33C, 33C/22C and 33C/33C. This study was repeated with bud activity expressed as the number of active buds per plant.

All data was statistically analyzed with the analysis of variance. Mean separation was by Duncan's Multiple Range Test.

Results and Discussion

Ethylene Evacuation. The number of active buds in both cultivars decreased with increasing temperature (Table 1). In Merion the decrease was 41% between the 22C and 35C temperatures and for Nugget a 74% decline was observed over the same temperatures. Ethylene at a concentration of 1.34 ppm stimulated additional numbers of active buds compared to its control when grown at 22C. However, with supplemental ethylene there was a decline in the number of active buds per plant with increasing temperature. Turfgrass plants subjected to 0.2 atm in which ethylene was removed showed a significant decline in bud activity in both cultivars compared to their air controls. By maintaining a 0.2 atm, and introducing 6.7 ppm ethylene into the ventilating stream, the number of active buds were returned to the level of the control plants maintained at 1 atm. Under hypobaric conditions the decline in the number of active buds per plant at a reduced pressure, followed by restoration of their numbers with ethylene, strongly suggests that ethylene is an agent in bud activity. Merion Kentucky bluegrass

Table 1. Effect of ethylene and temperature on the number of active buds in Merion and Nugget bluegrass.

Temperature (C°)	Treatment		Number of active buds per plant ¹	
	Pressure (atm)	Gas Mixture	Merion	Nugget
22	1	Air	3.73 b	2.62 bc
	1	Air + 1.34 ppm ethylene	4.14 a	3.00 a
	0.2	99.85% O ₂ /0.15% CO ₂	3.14 c	1.81 g
	0.2	99.85% O ₂ /0.15% CO ₂	3.63 b	2.67 b
		+ 6.70 ppm ethylene		
30	1	Air	1.77 de	2.41 d
	1	Air + 1.34 ppm ethylene	1.84 d	2.55 c
	0.2	99.85% O ₂ /0.15% CO ₂	1.48 f	1.67 h
	0.2	99.85% O ₂ /0.15% CO ₂	1.55 ef	2.39 d
		+ 6.70 ppm ethylene		
35	1	Air	1.54 ef	1.93 f
	1	Air + 1.34 ppm ethylene	1.66 def	2.08 ef
	0.2	99.85% O ₂ /0.15% CO ₂	1.13 g	1.54 i
	0.2	99.85% O ₂ /0.15% CO ₂	1.57 ef	1.96 f
		+ 6.70 ppm ethylene		

¹Means within columns followed by the same letter are not significantly different at the 5% level of probability by Duncan's Multiple Range Test.

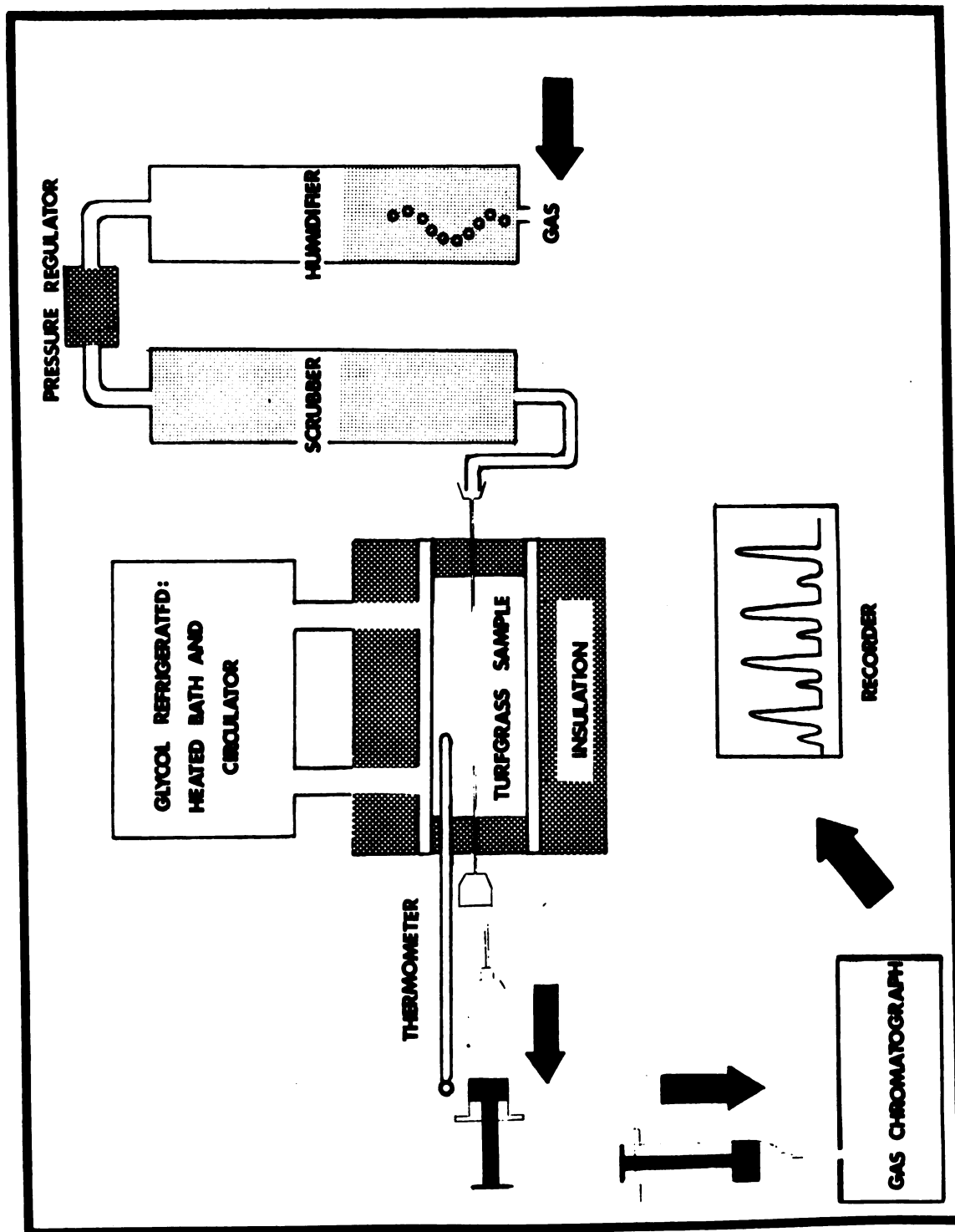


Figure 1. Method of gas sampling from turfgrass under conditions of controlled temperature.

demonstrates bud activity inhibition at both 30 and 35C temperatures. This is shown by the lack of significance in the number of active buds between the air control and where ethylene was supplemented at 1 atm. Therefore, possible interrelationships between ethylene and another hormone(s) is hypothesized when Kentucky bluegrass is grown under supraoptimal temperatures. If ethylene alone was suspected as the bud dormancy releasing agent, the number of active buds per plant under supraoptimal temperatures should be similar to those at the optimum temperature of 22C. This was not the case in this study.

Ethylene Production. Ethylene production in both cultivars was influenced by temperature as illustrated in Figure 2. The rate of ethylene production differed between the two grasses with Merion showing peak production at 27C and Nugget at 34C. The decline in peak ethylene production was sharper in Nugget than for Merion Kentucky bluegrass. Under the higher temperatures the increase in ethylene production may be considered as one of a number of changes contributing to bud inhibition.

Rhizome/Tiller Ratio. In Kentucky bluegrass, tillers develop from axillary buds and rhizomes from nodal buds (25). Tillering is most frequent in spring and fall and is favored by temperatures slightly lower than the optimum for growth (2, 12). A major portion of rhizome bud initiation and elongation occurs during summer (29) and is favored by long days (24). The change in the r/t ratio

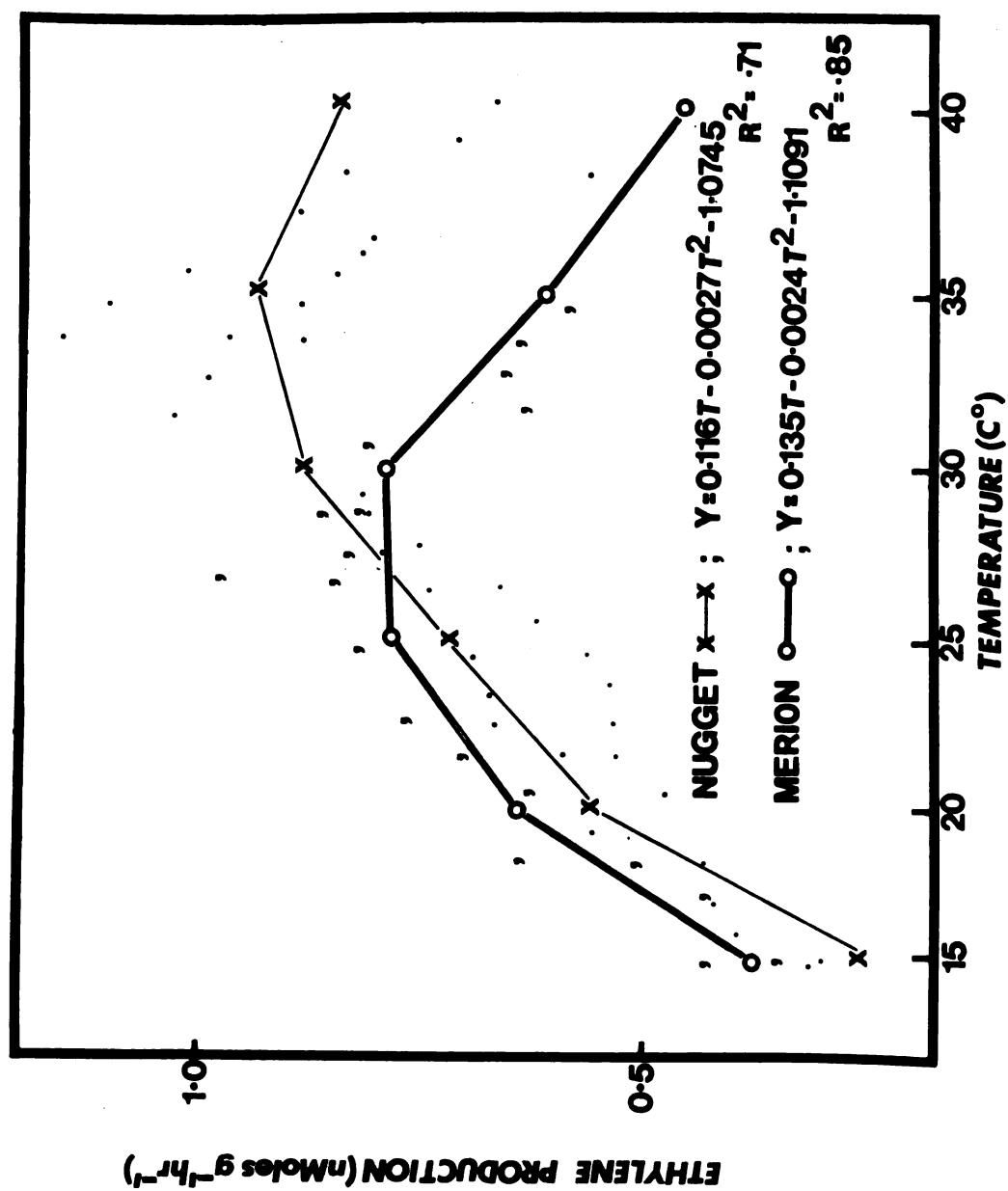


Figure 2. Effect of temperature on ethylene production in Merion and Nugget bluegrass.

of the air treatments at 22 and 35C favors rhizome growth in Merion Kentucky bluegrass (Table 2). The addition of supplemental ethylene to Merion, irrespective of temperature, also shows strong rhizome development. Stimulation of stem elongation with ethylene generating chemicals have been previously demonstrated in Kentucky bluegrass (14, 27). Nugget maintained a high r/t ratio irrespective of ethylene or temperature treatment. According to Beard (4), Nugget also has exhibited a superior sod strength in summer plantings compared to Merion. In addition, the summer rooting performance of Merion was poor, suggestive of a lower r/t compared to Nugget.

Length of Temperature Exposure. Merion Kentucky bluegrass, grown under optimum conditions of 22C/22C, had a significant increase in the number of active buds per plant at 10 and 100 μ l/L ethylene treatment (Table 3). Nugget gave a similar response at the 1 to 10 μ l/L ethylene level (Table 4). The number of active buds was not significantly altered by 10 days of supraoptimal temperatures following the 24 hr. exposure at 22C. Both cultivars had fewer active buds when both the exposure temperature and the post initial temperatures were 33C compared to treatments of 22C/22C. This agrees with the earlier study which suggests that high levels of ethylene in the tissue may contribute to bud inhibition at supraoptimal temperatures. Twenty-four hours were sufficient to reduce the number of active buds at the 33C exposure temperature, as bud activity did improve when the cultivars were

Table 2. Effect of temperature and gas mixture on rhizome/tiller bud ratio in Merion and Nugget bluegrass.

Temperature (C°)	Gas Mixture	Rhizome: Tiller bud ratio (r/t) ¹	
		Merion	Nugget
22	Air	1.8 b	19.3 a
	Air + 1.34 ppm ethylene	5.8 ab	17.5 a
30	Air	4.7 ab	21.7 a
	Air + 1.34 ppm ethylene	5.3 ab	24.0 a
35	Air	7.3 a	19.7 a
	Air + 1.34 ppm ethylene	8.1 a	20.2 a

¹ Means within columns followed by the same letter are not significantly different at the 5% level of probability by Duncan's Multiple Range Test.

Table 3. Effect of ethylene concentration and temperature exposure on the number of active buds in Merion Kentucky bluegrass.

Treatment Ethylene Concentration (μ l/L)	Number of active buds per plant ¹			
	22/22 ²	22/33	33/22	33/33
0	1.31 c	0.15 f	0.28 ef	0.81 d
1	1.56 bc	0.28 def	1.31 c	0.81 d
10	1.79 b	0.51 def	1.54 bc	0.62 def
100	2.21 a	0.13 f	2.54 a	0.64 de
1000	0.59 def	0.17 f	1.59 bc	0.48 def

¹ Mean values followed by the same letter are not significantly different at the 5% confidence level (Duncan's Multiple Range Test)

² 22/22: 22C for 24 hr undergoing ethylene exposure, followed by a 22C growing temperature for 10 days.

Table 4. Effect of ethylene concentration and temperature exposure on the number of active buds in Nugget Kentucky bluegrass.

Treatment Ethylene Concentration (μ l/L)	Number of active buds per plant ¹			
	22/22 ²	22/33	33/22	33/33
0	0.60 de	0.27 ghi	0.25 hi	0.36 fgh
1	1.46 b	0.21 hi	0.55 def	0.37 fgh
10	1.81 a	0.33 fghi	0.76 c	0.63 de
100	1.02 c	0.24 hi	0.98 c	0.28 ghi
1000	0.61 de	0.12 i	0.30 ghi	0.50 efg

¹ Mean values followed by the same letter are not significantly different at the 5% confidence level (Duncan's Multiple Range Test)

² 22/22: 22C for 24 hr undergoing ethylene exposure, followed by a 22C growing temperature for 10 days.

subsequently transferred to a favorable temperature of 22C (Tables 3 and 4).

The effectiveness of temperature exposure on the number of active buds was found to be significant for both cultivars. At 33C/33C, both Merion and Nugget lacked significance in response to ethylene concentration. When the cultivars were grown at 22C/22C a significant increase in the number of buds exhibiting activity was observed between 10 and 100 $\mu\text{l/L}$ in Merion and 1 and 10 $\mu\text{l/L}$ in Nugget. Under similar post initial conditions, but different exposure temperatures, a single day at 33C significantly reduced the number of active buds per plant. The effect of ethylene on bud activity was still measurable at the cooler post growing temperature. A single day at 22C, followed by a 33C post growing temperature, did not significantly increase bud breaks in Merion Kentucky bluegrass.

These results indicate that 24 hr. at an exposure temperature of 33C can induce bud inhibition. Inhibition was extended when the grasses were kept at supraoptimal temperatures for 10 days. The number of active buds were increased when cultivars exposed to 33C were returned to cooler temperatures of 22C. The knowledge that ethylene production is influenced by temperature, and can be translocated rapidly (17, 34) suggests that high ethylene levels produced at supraoptimal temperatures may inhibit bud activity. Such inhibition may also be influenced by the marked diurnal variation in endogeneous ethylene recently reported (16).

The results of this study support the auxin concept of apical dominance as it has been shown that auxin-induced ethylene production could account for the inhibitory action of applied IAA (8). This concept fits well into recent tillering research (33) in that high summer temperatures, favored the accumulation of endogenous auxin in the stem bases of tall fescue, which appeared to be related to inhibition of tiller initiation. Therefore, endogenous auxin concentrations may, in fact, determine ethylene concentrations which could act as the intermediate initiating molecules in bud break.

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CHAPTER 3

REGULATION OF BUD GROWTH IN KENTUCKY BLUEGRASS.

EFFECT OF KINETIN AND TEMPERATURE ON ETHYLENE PRODUCTION.

Abstract

Kinetin was applied as a foliar spray to Poa pratensis L. cv. Merion and Nugget to evaluate its effect on bud growth and ethylene production grown at optimal (22C) and supraoptimal (33C) temperatures. Ethylene and kinetin, when applied alone, both significantly increased the number of active buds at 22C. When both cultivars were grown at 33C, neither ethylene, kinetin nor their combinations had a significant effect on the number of active buds compared to their controls.

Studies using hypobaric ventilation conditions, which reduced ethylene and other gases to subnormal levels, suggested that bud growth may be influenced by kinetin stimulated ethylene production. Kinetin was found to enhance the number of active buds in Nugget Kentucky bluegrass grown at 22C, apparently through stimulation of ethylene. Increased ethylene production, generated endogenously or by kinetin application, resulted in a decrease in the number of active buds grown under supraoptimal temperatures.

Introduction

Both tiller bud and shoot growth of cool season grasses are often inhibited by supraoptimal temperatures, or those temperatures higher than the optima for growth. Under these high summer temperatures, tiller bud growth is inhibited (7) although buds are present (15). Often turfgrass quality deteriorates because of excessive wear and loss of density.

Although the control of lateral bud development has been recently reviewed (19), relatively little research has been done on regulation aspects of bud growth in Kentucky bluegrass under supraoptimal temperatures. Auxin inhibition of bud development was first proposed in 1949 (14) and revised to include theories of indirect inhibitor production as reported for perennial ryegrass (Lolium perenne) (20) and tall fescue (Festuca arundinacea) (23).

Ethylene inhibits growth by reducing cell division and elongation (5). Recently, the ethylene generating compound Ethephon (2-chloro-ethylphosphonic acid) was found to increase tillering (3, 22) promote stem length and reduce growth of leaf blades (18) of Kentucky bluegrass. Ethylene has also been shown to trigger bud activity in Kentucky bluegrass grown at optimal temperatures (1). However, an interrelationship between ethylene and other hormones is hypothesized under supraoptimal temperatures. Under these conditions ethylene is considered as one of several factors contributing to bud inhibition.

Cytokinins have been shown to release lateral buds from apical dominance and auxin inhibition (19), to improve tiller bud elongation (10, 11) and assist leaf tissue recovery from supraoptimal temperatures (9).

This investigation was designed to evaluate the effect of foliarly applied kinetin on ethylene production and bud growth in Kentucky bluegrass grown at optimal (22C) and supraoptimal (33C) temperatures. A second study was initiated to evaluate a possible kinetin/ethylene interaction on bud growth using the method of hypobaric ventilation which reduced ethylene concentration to subnormal levels.

Materials and Methods

Effect of Kinetin and Ethylene. Plugs of Poa pratensis L. cv. Merion and Nugget were broken into tillers having the same leaf number. Senescent leaves were removed resulting in a plant with six leaves. The tillers were planted near the circumference of 200 ml styrofoam cups containing a soil admendment (Wyandotte Turface Soil Admendment, Wyandotte Chemicals of Canada, Scarborough, Ontario). Following 10 days of acclimation in a greenhouse, the plants were placed into sealed desiccators at temperatures of either 22 or 33C and exposed to either 0 or 10 $\mu\text{L/L}$ ethylene for 24 hrs. They were then grown in chambers having the same temperatures. The chambers were maintained at a 16 hr. photoperiod and at a photosynthetic radiation rate of 30 Wm^2 . A kinetin solution (23 μM of 6-furfurylaminopurine) was atomized on to leaves

daily to drip point. Equal volumes of distilled water were applied to the control treatments.

Buds were counted after 10 days and expressed as the number of active buds per plants (Table 1).

Ethylene Production. Plugs of the same cultivars were taken from the field and categorized as previously described. Forty tillers were planted in styrofoam cups containing Turface soil amendment and acclimated in a greenhouse for 10 days. One cup was then placed in an inverted 1000 ml glass jar fitted with a closure as illustrated in Figure 1. Each jar and contents represented a treatment which was replicated three times. Inserted in each lid were three ports, a gas inlet leading from a filter and flow regulator, a gas outlet for ventilation and a serum stopper for gas sampling. One milliliter gas samples were taken every 24 hrs. Ethylene production was measured with a Varian aerograph model 1700 gas chromatograph equipped with a 2 mm by 1mm activated alumina column and a flame ionization detector. The carrier gas was nitrogen at 60C. Following each gas sampling the plants received a spray application of either 5, 14 or 23 μ M kinetin (6-furfurylaminopurine) (Sigma Chemical Co., St. Louis, MO) applied to the drip point. Control plants were sprayed with equal volumes of distilled water. Each jar and contents was then ventilated with air at 500 ml/min. for 5 minutes. This procedure was repeated daily over the duration of the study. Approximately 10 pMoles of ethylene

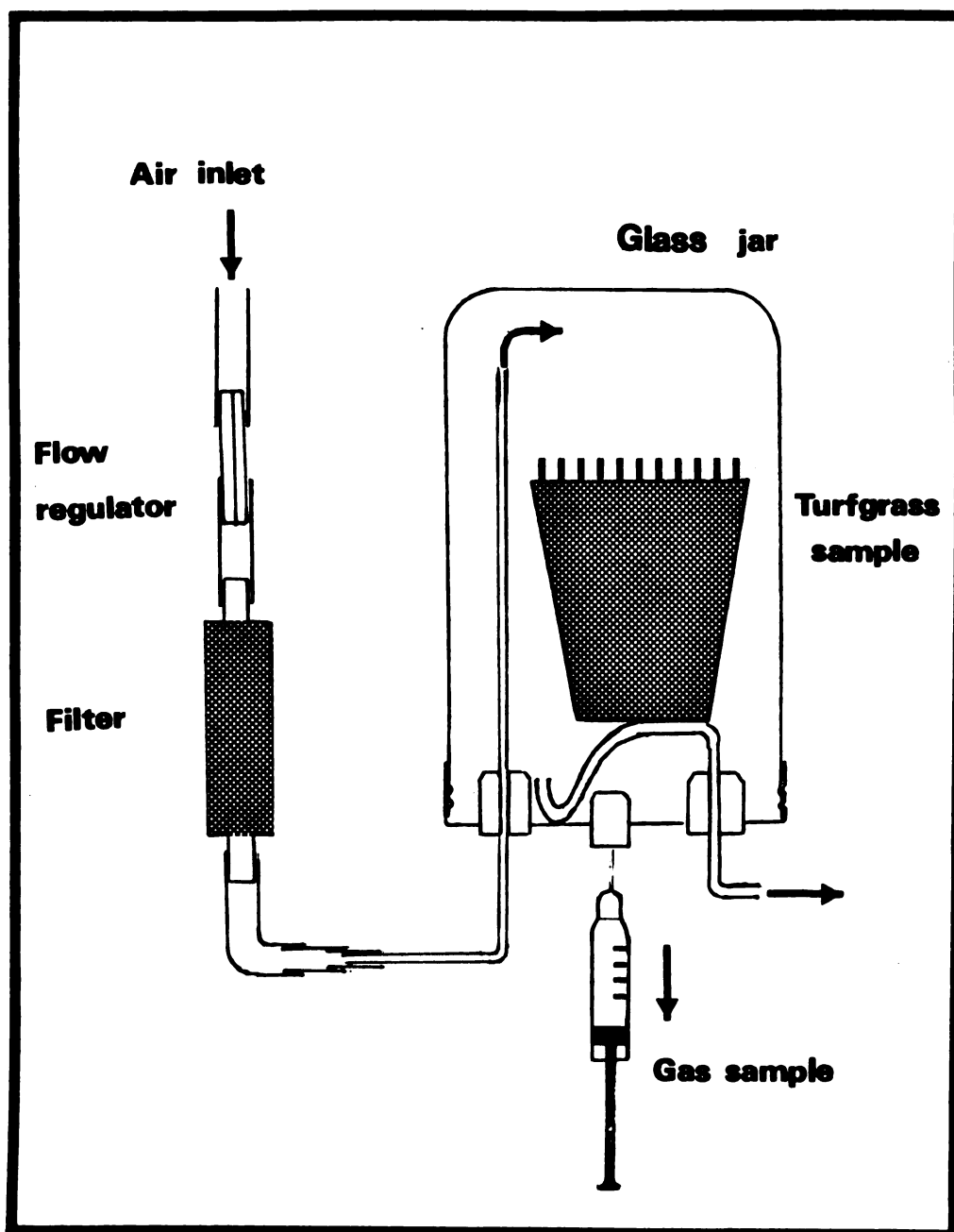


Figure 1. Method for ethylene detection of turfgrass sample.

accumulated over the 24 hr period at both temperatures in glass jars without plant tissue, and such production was attributed to the rubber seals.

The cultivar Nugget was selected for this study because it was shown to generate more ethylene than Merion (1) and therefore thought to be more definitive in demonstrating bud regulation when using the hypobaric technique. This grass has also shown improved heat tolerance when grown under supraoptimal temperatures (2).

Ethylene production was expressed as $\text{nMoles gm}^{-1} \text{ hr}^{-1}$ (Figure 2) and buds as the number of active buds after 6 days (Table 2). Environmental conditions during the investigation were temperatures of 22 or $32 \pm 2^\circ\text{C}$, photoperiod of 16 hr and a photosynthetic radiation rate of 30 Wm^2 as measured within the jar.

Effect of Ethylene Evacuation. Turfgrass plants were acclimated as described in the first study. The hypobaric technique, used to reduce endogenous ethylene to subnormal levels by evacuation at 0.2 atm, has been previously described (4, 6, 16). Three replications of cups containing each cultivar were placed into holes made in a stage located within 10 L desiccators. Desiccators were maintained for 10 days under the conditions outlined in Table 3. Dilute ethylene concentrations were premixed in compressed gas cylinders (21) and the composition verified by gas chromatography. The desiccators were opened daily at 1300 hrs. to apply an aerosol spray of $23 \mu\text{M}$ kinetin or distilled water

to the respective grass treatments.

Values stated in the tables or shown in figures are the mean of three replications repeated twice with the mean separation carried out according to Duncan's Multiple Range Test.

Results and Discussion

Effect of Kinetin and Ethylene. At the 22C growing temperature, both ethylene and kinetin applied alone, significantly increased the number of active buds per plant in Merion Kentucky bluegrass (Table 1). When kinetin was applied following an ethylene treatment, bud activity was not significantly increased over the control. Neither separate nor combined applications of ethylene or kinetin treatments had a significant effect on the number of active buds of either cultivar when grown at 33C. As kinetin is known to increase lateral bud outgrowth (10, 11), it was speculated the material would improve bud growth in Kentucky bluegrass, especially when grown under supraoptimal temperatures. The results of the first study suggested that ethylene, either exogenously applied or influenced by kinetin may inhibit bud growth at such temperatures. The effect of temperature and kinetin level on ethylene production was substantiated by later studies.

Ethylene Production. At 22C kinetin stimulated ethylene production for the first 3 days compared to the distilled water control (Figure 2). Kinetin applications have been previously reported to increase ethylene production in sorghum (Sorghum vulgare) (8, 17) and mung bean

Table 1. Effect of temperature on the number of active buds in Merion and Nugget bluegrass as influenced by ethylene and kinetin concentration.

TREATMENTS			CULTIVAR	
Temperature (C)	Ethylene (μ l/L)	Kinetin (μ M)	Number of active buds per plant ¹	
			Merion	Nugget
22	0	0	0.38 c	0.14 c
		23	1.65 a	0.71 a
	10	0	0.72 b	0.29 bc
		23	0.48 c	0.27 bc
33	0	0	0.48 c	0.24 bc
		23	0.40 c	0.39 b
	10	0	0.47 c	0.32 bc
		23	0.41 c	0.23 bc

¹Mean values followed by the same letter within cultivars are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

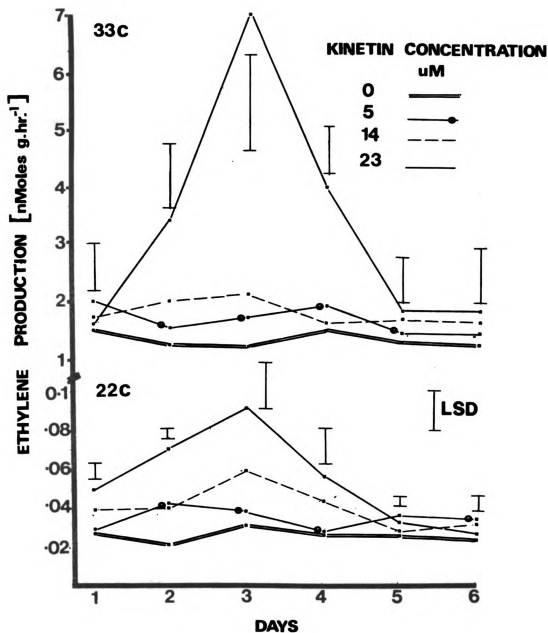


Figure 2. Effect of kinetin concentration and time on ethylene production in Nugget bluegrass grown at optimal (22 C) and supraoptimal (33 C) temperatures.

(Phaseolus aureus) hypocotyls (12, 13). The data in Table 2 shows that kinetin may enhance bud growth in Nugget bluegrass by stimulating ethylene production. When grown at 22C, foliarly applied kinetin was shown to significantly stimulate plants to produce more ethylene than the control (Figure 2), which in turn induced additional bud activity. At 33C kinetin increased ethylene production above the control. Under these supraoptimal temperatures high endogenous ethylene production inhibited bud growth in Nugget Kentucky bluegrass as shown by the lower number of active buds (Table 2). Inhibition of bud growth at supraoptimal temperatures may be due to the three fold increase in ethylene production either produced by turfgrass tissue or influenced by kinetin application. However, as kinetin activity is lower under supraoptimal temperatures (9), kinetin appears secondary to temperature.

Effect of Ethylene Evacuation. Foliarly applied kinetin increased the number of active buds in both cultivars at 22C compared to the control (Table 3). Hypobaric conditions, which enhanced diffusion of ethylene and other gases from turfgrass tissue were significantly lower compared to their control. At 33C only Nugget bluegrass showed a decline in the number of active buds compared to the control following kinetin application. The decline in the number of active buds also occurred at both temperatures when similar treatments were under hypobaric conditions (Table 3). Similarly, plants not receiving the kinetin application showed an increase in the number of active buds compared

Table 2. Effect of kinetin concentration on the number of active buds in Nugget bluegrass as influenced by temperature.

Kinetin (μ M)	Number of active buds per plant ¹	
	22C	33C
0	0.41 a	0.19 a
5	0.77 b	0.38 a
14	0.76 b	0.31 a
23	0.86 b	0.32 a

¹Mean values followed by the same letter within temperatures are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

Table 3. Effect of kinetin and temperature on Kentucky bluegrass bud activity in response to hypobaric ventilation with or without supplemental ethylene.

TREATMENT	MERION			NUGGET ¹	
	22C	33C	22C	22C	33C
Control	1.68 b	1.90 a	0.86 c	0.40 a	
Kinetin (23µM)	2.52 a	1.73 ab	1.78 a	0.27 b	
Control plus hypobaric ventilation ²	1.15 c	1.05 c	0.76 c	0.60 a	
Kinetin "	2.30 a	1.62 b	1.03 b	0.26 b	
Control "	" plus ethylene	1.54 b	0.70 d	0.55 c	0.13 c
Kinetin "	" "	1.39 b	0.92 cd	0.80 bc	0.14 c

¹ Mean values followed by the same letter within cultivar growing temperatures are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

² 0.2 atm of 99.85% + 0.15% CO₂ + µl/L ethylene

to their counterparts under hypobaric ventilation. In the presence of kinetin, ethylene had no effect on the number of active buds in either cultivar when grown at 22 or 33C under hypobaric ventilation. These conditions suggest that bud activity may be influenced by kinetin stimulated ethylene production. Such ethylene production promoted bud growth in Kentucky bluegrass under optimal temperatures. Previous research has implicated high rates of ethylene production in bud inhibition (1). Under supraoptimal temperatures such inhibition may result from increased ethylene production, either produced endogenously or induced by kinetin application.

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Chapter 4

INFLUENCE OF ETHYLENE, KINETIN AND NITROGEN DRENCHES ON SHOOT DENSITY IN KENTUCKY BLUEGRASS UNDER SUMMER FIELD CONDITIONS

Abstract

Ethephon (2-chloroethylphosphonic acid), kinetin (6-furfurylamino-purine), silver nitrate, and ammonium nitrate drenches were applied to Poa pratensis L. cv. Merion and Nugget to evaluate their effects on shoot density and turfgrass quality under summer field conditions. Rates of Ethephon less than 1000 $\mu\text{l/L}$ did not increase shoot density in either cultivar. Monthly nitrogen drenches of 0.48 kg N/100m² increased both shoot density and quality in both cultivars compared to combinations of nitrogen and Ethephon. No strong trend developed to support field applications of silver nitrate for suppression of ethylene synthesis and/or action to enhance tiller bud numbers. Kinetin drenches increased turfgrass quality, as measured by greenness and density, in Nugget only under supraoptimal temperatures in July but the effect could not be sustained through the season.

Introduction

Both shoot growth (10) and tiller bud initiation (8) are inhibited by temperatures higher than the optimum for growth. Stress on turfgrass is increased due to excessive wear resulting in a decline in shoot density (tillers per unit area).

According to a recent review (20) of research on lateral bud development, relatively little field work has been attempted on bud activity under summer field conditions. Lateral buds are present but fail to become active and elongate into tillers (15). It has been suggested that growth regulators influence the tillering rate, particularly at bud initiation (12). Recent theories on bud development in cool season grasses have credited IAA with a major role (14), with revised theories including indirect inhibitor production (21, 29).

Recently, ethylene generating chemicals have increased tillering (6, 24), promoted stem elongation and shortened the leaf blade in Kentucky bluegrass (19). Ethylene has also been reported to affect bud growth of Kentucky bluegrass under optimum growing temperatures (1).

Nitrogen applications are also known to improve tillering (13, 28). One of the main effects of nitrogen is to extend the duration of tillering. Withholding nitrogen causes plants to stop producing new tillers at an early date (25). Both the limitation on soil moisture and soil nitrogen influenced grass growth in midsummer (3). As high rates frequently injure plants and reduce stand density (16),

only low nitrogen rates are practical during summer. Turf grown under low nitrogen levels has been found to be more tolerant to high temperatures (18, 27). Watschke and co-workers (1970) suggest that the inherent ability of certain bluegrasses to absorb lower amounts of nitrate-nitrogen under high temperatures, may influence growth and rooting ability.

The decline in shoot growth is predisposed by an increase in root maturation and death (5) brought on by the high summer temperatures. Cytokinins, thought to be of root origin, can extend regulatory control over the metabolism of aerial parts (4). Cytokinins have also been shown to release lateral buds from apical dominance and also inhibition by auxin (20). In addition cytokinins are known to improve root growth (23) and tiller bud elongation (12) in graminaceous plants as well as assisting in recovery of plant tissue from supraoptimal temperatures (11).

Recently Ag (I), applied as AgNO_3 , effectively blocked the ability of exogenously applied ethylene to elicit responses in the etiolated pea, cotton and orchid (7). This material has also found to inhibit both ethylene synthesis and action in postclimacteric apple and banana tissue (22). Since endogenous ethylene levels influence changes in shoot density (1) silver nitrate treatments could also alter turfgrass shoot density via inhibition of ethylene action.

The objective of this field study was to compare the influence of Ethephon, kinetin and nitrogen alone and in combination on shoot density

and turfgrass quality in Kentucky bluegrass.

Materials and Methods

Studies were carried out on a 111 m² block of Merion and an equal size block of Nugget at the M.S.U. turfgrass research plots. Ethephon rates of 0, 10, 100 and 1000 µl/L were applied alone and in combination with either of two rates of ammonium nitrate (0.30 and 0.48 kg N/100m²), two rates of silver nitrate (10 and 100 µl/L) and a single rate of 5 µl/L kinetin. All treatments were applied as drenches to 1.67 m² plots at approximately monthly intervals from May to September. Dates of both evaluation and treatment applications were 5/29, 6/22, 7/20 and 8/22 for Nugget Kentucky bluegrass and 5/23, 6/13, 7/14 and 8/16 for Merion Kentucky bluegrass. The silver nitrate was sprayed late in the afternoon to avoid photodecomposition. Application was with a hand held sprayer pressurized with CO₂ at 2.0 atmospheres. This was followed by 2 cm of irrigation. The cultivars were mowed to 4 cm two times per week and regularly irrigated. One month after application, 3 by 10 cm diameter plugs were removed per treatment with a cup cutter and the shoots counted. Data, expressed as shoots per dm², was used as a measure of the bud activity, influenced by the different treatments. Ratings were also taken on turfgrass quality, (1=high; 9=low) throughout the study.

Each value stated in the tables or shown in figures are the mean of a single study comprising three replications, with mean separation

by Duncan's Multiple Range Test.

Results

Ethylene and Nitrogen combinations. An interaction between nitrogen and ethylene levels occurred in shoot numbers of Merion Kentucky bluegrass recorded for June (Table 1). At 0 nitrogen, ethylene application stimulated shoot density while at 0.48 nitrogen, ethylene levels reduced shoot density. High nitrogen levels stimulated Merion shoot density at 0 ethylene, but had no effect on reduced shoot density if ethylene was applied. In the July rating, no differences occurred among treatments. The densities of Merion Kentucky bluegrass, increased by ethylene and nitrogen in June, were reduced significantly to the levels of the check by the July rating. A significant increase in Merion shoot density occurred when comparing August and September with June and July. This increase appeared to occur independent of treatments. At the highest nitrogen rate, ethylene applications resulted in a lower density of Merion Kentucky bluegrass in August and September similar to the response found in June. Reverse shifts in shoot density of Merion bluegrass in June and September, irrespective of ethephon or nitrogen rate, may be under the influence of day-length. In the June rating, applications of nitrogen significantly improved turfgrass quality compared to 0 nitrogen. However, continued applications did not result in improved quality over the 0 nitrogen treatment at the July, August and September rating. While higher

Table 1. Effect of Ethephon concentration and nitrogen level on shoot density and turfgrass quality in Merion Kentucky bluegrass during the months June to September.

MONTH	ETHEPHON CONCENTRATION ($\mu\text{l/L}$)	DENSITY (Shoots/dm ²)		NITROGEN LEVEL (kg N/100m ² /month)		QUALITY RATING (1=high; 9=low)	
		0 ¹	0.30	0.48	0	0.30	0.48
June	0	63 l	91 i-l	111 g-i	4.0 f-i	3.3 h-j	2.8 j
	10	88 i-l	87 i-l	80 j-l	4.3 fg	3.3 h-j	3.2 ij
	100	104 h-k	89 i-l	81 j-l	4.3 fg	3.2 ij	3.5 g-j
	1000	117 f-i	77 kl	86 i-l	4.7 ef	3.9 f-i	3.8 f-i
July	0	72 kl	84 j-l	71 kl	6.7 ab	7.0 a	6.5 a-c
	10	71 kl	76 kl	70 kl	6.0 b-d	6.5 a-c	5.5 de
	100	80 j-l	65 l	70 kl	5.7 cd	5.7 cd	6.8 ab
	1000	80 j-l	72 kl	65 l	6.0 b-d	6.6 a-c	6.7 ab
August	0	133 b-h	151 b-e	165 ab	3.3 h-j	2.8 j	3.5 g-j
	10	144 b-g	130 c-h	122 e-h	4.0 f-i	3.5 g-j	4.5 f
	100	163 a-c	158 b-d	149 b-f	4.3 fg	4.3 fg	3.2 ij
	1000	141 b-g	136 b-g	125 d-h	4.7 ef	3.1 ij	3.3 h-j
September	0	162 a-c	143 b-g	192 a	3.5 g-j	4.3 fg	4.2 f-h
	10	140 b-g	153 b-e	150 b-f	3.3 h-j	4.2 g-h	4.7 ef
	100	159 b-d	122 e-h	150 b-f	3.5 g-j	4.4 fg	4.3 fg
	1000	153 b-e	145 b-f	131 c-h	4.2 f-h	4.0 f-i	4.3 fg

¹Mean values followed by the same letter within quality rating and density are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

turfgrass quality ratings were found for 1000 $\mu\text{l/L}$ Ethephon compared to 0, 10 and 100 $\mu\text{l/L}$ at all fertility levels in June, this reduction in quality could not be documented statistically. Furthermore, Ethephon concentration had no effect on turfgrass quality at the July, August, and September rating in Merion Kentucky bluegrass. Turfgrass quality was significantly less at the July rating compared to June, August and September. This reduction and subsequent increase in quality appeared to occur independent of the treatments.

Nugget Kentucky bluegrass exhibited a significant increase in shoot density in June and August when Ethephon was applied at 1000 $\mu\text{l/L}$ compared to their controls (Table 2). Density remained high in September. Significantly high densities were demonstrated in July and August at 100 $\mu\text{l/L}$ Ethephon resulted in increased shoot density in all months. However, the shoot density on the plots receiving 0.48 kg N/100m² was significantly higher than its control only in June and July.

In the absence of both Ethephon and nitrogen, the quality of Nugget Kentucky bluegrass decreased progressively from June to September (Table 2). Ethephon concentration did not significantly effect rating. A significantly lower rating was recorded in August and September compared to June and July, irrespective of Ethephon concentration. Both nitrogen rates, when applied alone, produced a better rating when compared to the control in June and July. Only higher nitrogen rates were successful in maintaining better quality turf in August and

Table 2. Effect of Ethephon concentration and nitrogen level on shoot density and turfgrass quality in Nugget Kentucky bluegrass during the months June to September

MONTH	ETHEPHON CONCENTRATION (μ l/L)	DENSITY (Shoots/dm ²)		NITROGEN LEVEL (kg N/100m ² /month)		QUALITY RATING (1=high; 9=low)	
		0 ¹	0.30	0.48	0	0.30	0.48
June	0	194 k-q	202 g-o	218 c-g	4.0 g-j	3.2 j	3.2 j
	10	219 c-g	222 b-f	201 g-q	4.1 g-j	4.1 g-j	3.5 i-j
	100	195 j-q	190 l-r	195 k-q	4.4 f-j	4.3 f-j	4.2 f-j
	1000	249 a	213 c-k	215 c-h	4.2 f-j	4.8 e-h	4.5 f-h
July	0	184 n-r	183 o-r	216 c-h	4.7 e-h	3.9 h-j	3.8 h-j
	10	173 r	182 p-r	216 c-h	3.3 i-j	4.4 f-i	4.0 q-j
	100	211 c-k	208 d-l	201 g-p	4.3 f-j	5.0 e-g	4.2 f-j
	1000	155 s	196 j-q	205 e-m	4.2 f-j	4.6 e-h	5.1 d-f
August	0	189 l-r	181 qr	196 l-q	6.0 b-d	7.3 a	5.2 d-f
	10	203 f-n	197 h-q	204 e-m	6.5 ab	4.3 f-j	3.8 h-j
	100	216 c-h	209 c-l	190 l-r	6.0 b-d	5.5 c-e	4.7 e-h
	1000	223 b-e	219 c-g	211 c-k	6.2 bc	4.7 e-h	4.3 f-j
September	0	219 c-g	215 c-l	228 bc	6.0 b-d	7.2 a	5.0 d-f
	10	187 m-r	227 b-d	214 c-j	6.5 ab	4.3 f-j	3.8 h-j
	100	182 p-r	238 ab	254 a	6.0 b-d	5.5 c-e	4.7 e-h
	1000	227 b-d	214 c-j	222 b-f	6.2 bc	4.2 f-j	4.7 e-h

¹Mean values followed by the same letter within quality rating and nitrogen level are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

September. However, both fertilizer rates did interact with Ethephon concentration during these months to produce significantly better ratings than their controls.

Ethylene and Kinetin Combinations. Table 3 shows that Merion bluegrass density was not influenced by either kinetin or kinetin/ethephon drenches throughout the study. A significant increase in shoot density occurred between July and August which was independent of these treatments. Generally, Ethephon and kinetin combinations did not alter turfgrass quality ratings in Merion Kentucky bluegrass. An exception was in August where Ethephon at 1000 $\mu\text{l/L}$ plus kinetin resulted in a significantly higher quality rating. Combinations of Ethephon and kinetin on Nugget Kentucky bluegrass did not increase shoot density either within or between months (Table 4). Shoot density did decline when the higher Ethephon rates were combined with kinetin, a trend also observed in Merion Kentucky bluegrass.

Ethylene and Silver Nitrate Combinations. Ethephon rates of 100 and 1000 $\mu\text{l/L}$, either applied alone or in association with 100 $\mu\text{l/L}$ silver nitrate, significantly increased the shoot density of Merion Kentucky bluegrass in June (Table 5). However, when the same Ethephon levels were combined with 100 $\mu\text{l/L}$ silver nitrate, density was significantly depressed. The shoot density of Merion was not influenced by Ethephon/silver nitrate combinations in July. In August, both rates of silver nitrate when combined with 100 and 1000 $\mu\text{l/L}$ Ethephon significantly increase shoot density compared to the control and the

Table 3. Effect of Ethephon and kinetin concentration on shoot density and turfgrass quality in Merion Kentucky bluegrass during the months June to September.

MONTH	ETHEPHON CONCENTRATION ($\mu\text{l/L}$)	DENSITY (Shoots/dm ²)		QUALITY RATING (1=high; 9=low)	
		Kinetin concentration ($\mu\text{l/L/month}$)			
		0 ¹	5	0	5
June	0	63 gh	87 e-h	4.0 e-g	3.3 g
	10	88 e-h	82 e-h	4.3 d-g	3.2 g
	100	104 c-f	63 gh	4.3 d-g	3.5 fg
	1000	117 b-e	99 c-g	4.7 c-e	4.5 d-f
July	0	72 f-h	86 e-h	6.7 a	6.7 a
	10	71 f-h	53 h	6.0 ab	5.2 b-d
	100	80 e-h	57 h	5.7 a-c	5.2 b-d
	1000	80 e-h	90 d-h	6.0 ab	6.8 a
August	0	133 a-c	156 a	3.3 g	3.2 g
	10	144 ab	143 ab	4.0 e-g	4.8 c-e
	100	163 a	128 a-c	4.3 d-g	5.2 b-d
	1000	141 ab	141 ab	4.7 c-e	3.2 g
September	0	162 a	152 a	3.5 fg	3.3 g
	10	140 ab	92 d-h	3.3 g	4.0 e-g
	100	159 a	125 a-d	3.5 fg	4.3 d-g
	1000	153 a	150 ab	4.2 d-g	4.6 c-e

¹Mean values followed by the same letter within quality rating and density are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

Table 4. Effect of Ethephon and kinetin concentration on shoot density and turfgrass quality in Nugget Kentucky bluegrass during the months June to September.

MONTH	ETHEPHON CONCENTRATION (μ l/L)	DENSITY (Shoots/dm ²)		QUALITY RATING (1=high; 9=low)	
		Kinetin concentration (μ l/L/month)			
		0 ¹	5	0	5
June	0	194 b-f	212 a-e	4.0 d-g	4.5 c-e
	10	219 a-d	179 c-f	4.1 d-g	3.2 g
	100	196 b-f	173 d-f	4.4 c-e	3.3 fg
	1000	250 a	169 ef	4.2 c-f	4.3 c-e
July	0	184 b-f	183 b-f	4.7 cd	3.5 e-g
	10	174 d-f	183 b-f	3.3 fg	4.3 c-e
	100	211 a-e	179 c-f	4.3 c-e	5.0 cd
	1000	156 f	202 b-f	4.2 c-f	4.9 cd
August	0	190 b-f	191 b-f	6.0 ab	6.5 a
	10	204 b-e	183 b-f	6.5 a	6.7 a
	100	216 a-d	204 b-e	6.0 ab	5.3 bc
	1000	224 a-c	197 b-f	6.2 a	6.7 a
September	0	219 a-d	177 c-f	6.0 ab	6.2 a
	10	188 b-f	213 a-e	6.5 a	6.7 a
	100	182 b-f	202 b-f	6.0 ab	5.2 bc
	1000	228 ab	193 b-f	6.2 a	6.7 a

¹Mean values followed by the same letter within quality rating and density are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

Table 5. Effect of Ethephon and silver nitrate concentration on shoot density and turfgrass quality in Merion Kentucky bluegrass during the months June to September.

MONTH	ETHEPHON CONCENTRATION ($\mu\text{L/L}$)	DENSITY (Shoots/dm ²)		QUALITY RATING (1=high; 9=low)			
		AgNO ₃ concentration ($\mu\text{L/L/month}$)		0	10	100	1000
		0 ¹	10				
June	0	63 v	84 r-v	109 m-q	4.0 kl	6.0 b-d	6.7 a
	10	88 q-u	82 4-v	111 l-p	4.3 i-k	6.5 a	6.2 a-c
	100	104 o-r	107 n-q	75 s-v	4.3 i-k	5.4 ef	5.8 cd
	1000	117 k-o	108 n-q	83 r-v	4.7 hi	6.2 a-c	6.3 ab
July	0	72 t-v	74 t-v	86 r-u	6.7 a	6.5 a	6.5 a
	10	71 uv	67 uv	71 uv	6.0 b-d	5.7 de	6.2 a-c
	100	80 s-v	82 r-v	73 t-v	5.7 de	6.7 a	6.0 b-d
	1000	80 s-v	94 p-t	72 t-v	6.0 b-d	6.5 a	5.8 cd
August	0	133 h-k	130 i-m	126 j-n	3.3 m	3.5 lm	3.5 lm
	10	144 e-j	150 c-i	135 h-k	4.0 kl	4.3 i-k	3.8 l
	100	163 b-f	164 b-e	165 a-e	4.3 i-k	3.3 m	4.0 kl
	1000	141 f-j	164 b-e	167 a-d	4.7 hi	3.5 lm	4.2 j1
September	0	162 b-f	172 a-c	160 b-g	3.5 lm	4.3 i-k	4.7 hi
	10	140 g-j	147 d-j	131 h-l	3.3 m	4.2 j1	4.3 i-k
	100	159 b-g	173 ab	97 o-s	3.5 lm	4.3 i-k	4.8 gh
	1000	153 b-h	185 a	142 e-j	4.2 j1	4.5 h-j	5.2 fg

¹Mean values followed by the same letter within quality rating and density are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

density counts of June and July. This interaction also occurred at 100 $\mu\text{l/L}$ Ethephon when combined with the 100 $\mu\text{l/L}$ silver nitrate rate. The addition of silver nitrate to Merion Kentucky bluegrass, either applied alone or with Ethephon, caused a significant decline in the quality rating in June. In July, quality dropped which could not be explained by silver nitrate or Ethephon treatment.

Turfgrass shoot density was increased significantly in June when Nugget Kentucky bluegrass was drenched with Ethephon applications of 1000 $\mu\text{l/L}$ alone or combined with 10 $\mu\text{l/L}$ silver nitrate (Table 6). This trend was also significant in July. Density did not vary greatly in August and September due to any Ethephon or silver nitrate treatments. A decline in density however, was observed when 10 $\mu\text{l/L}$ was combined with 10 $\mu\text{l/L}$ silver nitrate when compared to the controls. The quality rating changed little in June, although quality was poorer when Ethephon was combined with 100 $\mu\text{l/L}$ silver nitrate compared to the controls. Quality fell significantly in August and September when compared to the June and July ratings, apparently independently of Ethrel or silver nitrate concentration. A significant improvement in quality, compared to the control, was observed when 10 $\mu\text{l/L}$ Ethephon was combined with 10 $\mu\text{l/L}$ silver nitrate in August and September. However, this was reversed at the higher silver nitrate level.

Table 6. Effect of Ethephon and silver nitrate concentration on shoot density and turfgrass quality in Nugget Kentucky bluegrass during the months June to September

MONTH	ETHEPHON CONCENTRATION ($\mu\text{l/L}$)	DENSITY (Shoots/ dm^2)				QUALITY RATING (1=high; 9=low)			
		AgNO ₃ concentration ($\mu\text{l/L/month}$)							
		0 ¹	10	100	0	10	100		
June	0	194 c-j	218 a-f	176 h-m	4.0 j-1	3.2 m	4.7 hi		
	10	219 a-f	227 a-c	176 h-m	4.1 j-1	4.4 h-k	4.5 h-j		
	100	196 c-j	194 c-j	189 f-1	4.4 h-k	4.5 h-j	4.3 h-1		
	1000	250 a	232 ab	200 b-1	4.2 i-1	3.9 kl	4.8 gh		
July	0	184 f-1	174 h-m	182 g-1	4.7 hi	4.1 j-1	3.8 l		
	10	173 h-m	184 g-1	187 f-1	3.3 m	3.3 m	4.7 hi		
	100	211 b-g	165 i-m	186 f-1	4.3 h-1	4.4 h-k	3.9 kl		
	1000	156 k-m	230 ab	191 d-j	4.2 i-1	4.1 j-1	4.3 h-1		
August	0	190 e-k	189 f-1	198 b-1	6.0 b-e	5.8 c-e	5.8 c-e		
	10	204 b-h	149 m	190 d-k	6.5 b	5.3 ef	5.2 fg		
	100	216 a-g	193 c-j	153 lm	6.0 b-e	6.3 bc	6.3 bc		
	1000	224 a-e	212 b-g	188 f-1	6.2 b-d	5.7 d-f	5.7 d-f		
September	0	219 a-f	217 a-g	206 b-h	6.0 b-e	5.8 c-e	6.2 b-d		
	10	188 f-1	164 j-m	192 d-k	6.5 b	5.2 fg	7.0 a		
	100	182 g-1	213 b-g	215 b-g	6.0 b-e	6.3 bc	6.3 bc		
	1000	228 a-c	225 a-d	212 b-g	6.2 b-d	5.5 ef	5.7 d-f		

¹Mean values followed by the same letter within quality rating and density are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

Discussion

Under hypobaric conditions, ethylene has been shown to be the agent to stimulate bud break in Kentucky bluegrass when grown at 22C (1). However, under supraoptimal temperatures of 33C, the increase in endogenous ethylene is considered a contributing factor in bud inhibition. Both an increase in tillering and stem length have been reported using rates of Ethephon ranging from 1.4 to 8.6 kg a.i./ha (16). Ethephon sprays at rates of 0.5 to 2.2 kg a.i./ha have generally stimulated tillering in Kentucky bluegrass, tall fescue and annual ryegrass (2). However, the present price of \$12.2/L (9) which represents \$211.1/kg active, prevents the widespread usage on extensive turfgrass areas. It was speculated that monthly Ethephon drenches at low concentrations during summer would increase bud activity by supplementing endogenous ethylene. The stimulation of tillering would be of significant value over summer in cool season grasses.

Field results showed that only in June for Merion Kentucky bluegrass and July and August for Nugget was there a significant improvement in shoot density. Ethephon rates of less than 1000 µl/L were not considered practical in promoting bud activity. Generally, quality was not increased following Ethephon application and research indicated that it may increase Dollar spot (Sclerotinia homeocarpa) activity in Nugget Kentucky bluegrass.

Summer nitrogen application should be practiced judiciously, as

shoot growth is often minimal. The use of light frequent applications of readily available nitrogen fertilizer are often preferred to heavy infrequent applications (26). The use of light (0.30 and 0.48 kg N/100m²) and frequent (monthly) rates applied in combination were expected to improve the longevity of tillering by providing nutrition to the new buds.

In Merion Kentucky bluegrass, neither 1000 µl/L Ethephon nor 0.48 kg N/100m², applied alone, provided an increased June density. The latter treatment also offered an improvement in quality over the Ethephon treatment. This trend was also apparent in Nugget. In July, neither the application of Ethephon or nitrogen produced any dramatic differences in density or quality. Therefore the decision to either forego nitrogen application in July or apply it at the lower rate will rest on the proposed use of the turf. In Nugget Kentucky bluegrass the higher nitrogen rates were considered desirable to obtain higher density, but quality was not altered, when nitrogen was applied in July.

In August and September there was a significant increase in the shoot density of Merion but not Nugget Kentucky bluegrass compared to earlier months. The 0.48 kg N/100m² applied alone, continued to be the best drench to increase density in Merion and Nugget Kentucky bluegrass over the months of August and September. The results showed that the higher nitrogen rate should be used in these months as it gave both

a higher quality, a greater density, and reduced Dollar spot activity. However, a combination of drenches incorporating nitrogen with 10 $\mu\text{l/L}$ Ethephon was also found to reduce disease activity. Ethephon applications, applied alone to Nugget should be avoided during August and September as quality is reduced and Dollar spot activity increased.

Little information is available on the effects of kinetin drenches on shoot density and quality of Kentucky bluegrass. Earlier work with cytokinins has shown this material to release lateral buds from dormancy (20) promote tiller bud elongation (12) and to prevent loss of leaf chlorophyll content (11). Kinetin drenches could not be recommended for Merion Kentucky bluegrass as little effect was observed in shoot density or quality over the study. Both density and quality were improved in August and September, compared to the July figures, but this was independent of any kinetin Ethephon combination. The addition of kinetin did not alter the quality differences between June and July and those of August and September as found in Table 2. In Nugget Kentucky bluegrass, a kinetin drench, applied on its own, was shown to improve quality in July, the month having both the highest average maximum and minimum temperatures (Figure 1), but the effect could not be sustained by succeeding monthly applications.

A silver nitrate drench was included in the field study to evaluate its effect on ethylene produced by turf. Silver nitrate was found to be a potent anti-ethylene agent in several plant processes under a

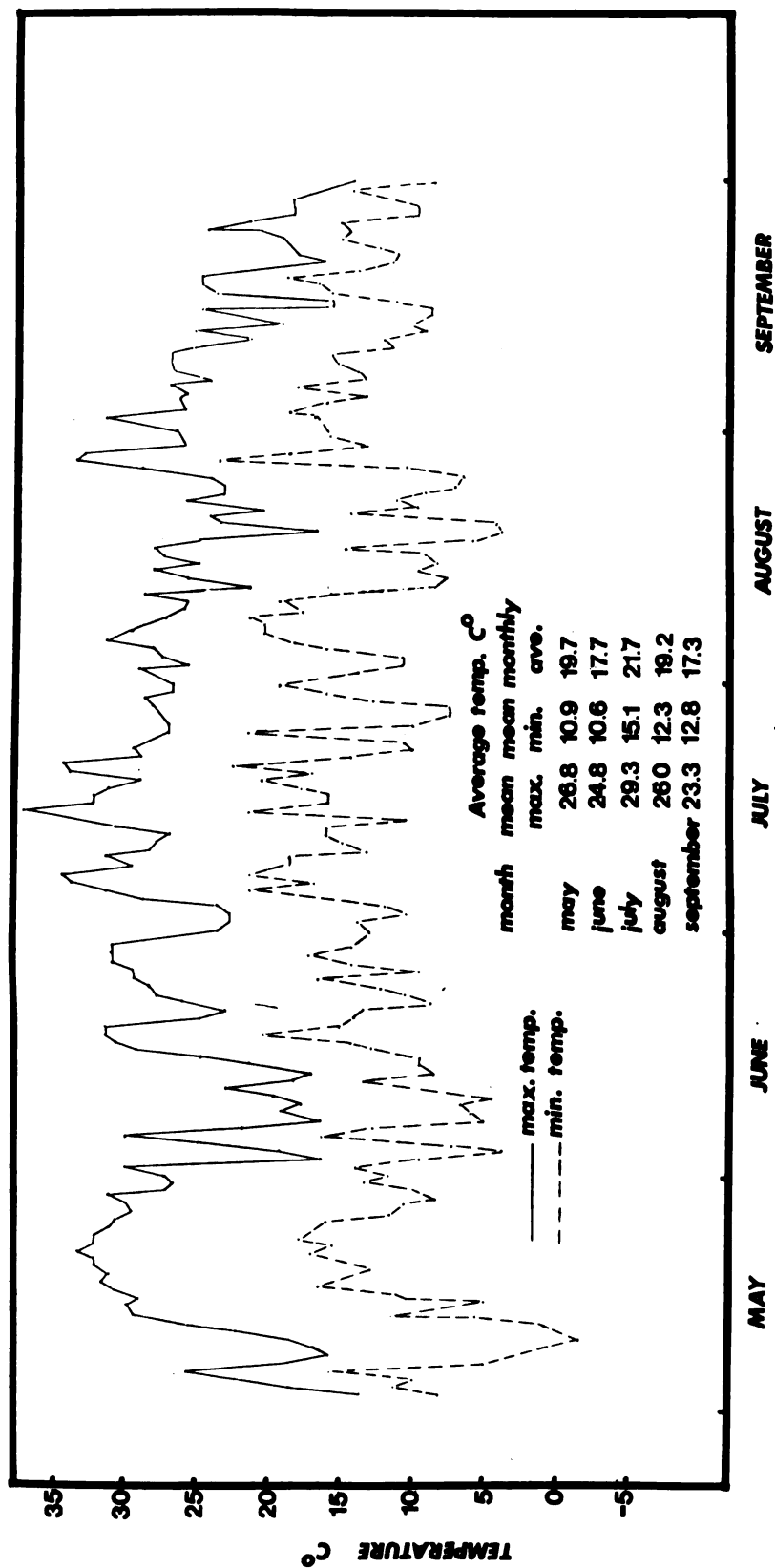


Figure 1. Daily minimum and maximum temperatures from May to September, 1977. Temperature data taken at the Crop and Soil Science Barns, Michigan State University, 300m from the study area.

controlled environment (7). It was speculated that a silver nitrate drench would prevent ethylene action and/or synthesis to give a lowered bud activity. Reductions in shoot density was apparent in June when 100 $\mu\text{l/L}$ silver nitrate was applied in combination with 100 and 1000 $\mu\text{l/L}$ in Ethephon to Merion. This was also observed in September when 10 and 100 $\mu\text{l/L}$ silver nitrate were combined with 10 $\mu\text{l/L}$ Ethephon and compared to their controls. However, in the case of July no differences were observed in the cultivar. In other cases the higher silver nitrate rate, combined with 100 and 1000 $\mu\text{l/L}$ Ethephon in August, indicated a significant increase in density when compared to its control. Similar interactions occurred for Nugget Kentucky bluegrass. No strong trend developed supporting the above concept when silver nitrate was applied under field conditions.

The influence of field temperature should not be underestimated in this study. Although all drenches were applied over a 6 hour period, with the silver nitrate treatments applied in late evening, subsequent field temperatures were found to have a large influence on shoot density and quality. The daily maximum and minimum temperatures from May to September are presented in Figure 1, allowing examination of previous months application and the subsequent climatic pattern. The May applications were followed by a month in which the average temperature was 17.7. The June temperatures were optimum for tiller bud growth (5) and significant improvements were found in density and quality due to Ethephon and nitrogen drenches. In Merion Kentucky

bluegrass, all drenches applied in June generally maintained the status quo but the high July temperatures did adversely effect quality. The significant increase in shoot density of Merion in August was more apparent than in Nugget Kentucky bluegrass. This improvement in density may be influenced by the cooler growing temperatures, as it was independent of treatment. It can also be speculated that the growth of buds in June were inhibited by the supraoptimal July temperatures and were only fully expressed in the cooler fall months.

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CONCLUSIONS

1. Bud growth was described and illustrated by stages, 1) initiation of bud activity to first primordial leaf; 2) second primordial leaf to leaf unfold and, 3) ligule formation to leaf emergence above the subtending leaf sheath.
2. Bud growth in Nugget Kentucky bluegrass compared to Merion was less sensitive to inhibition at high temperature. In both cultivars the increase in the number of active buds (bud activity) never ceased but was reduced at supraoptimal temperatures. Temperatures of 22C were found to significantly increase bud length. The number of buds at the stem base and nodes were reduced by supraoptimal temperatures compared to cooler temperatures in both cultivars.
3. Hypobaric ventilation studies at 22C showed that endogenous ethylene levels reduced the number of active buds. Bud activity was returned to normal when ethylene was reintroduced. Under supraoptimal temperatures bud activity could not be restored by reintroduction of ethylene. High ethylene production was found to be a contributing factor in bud inhibition at 33C.
4. Natural ethylene production, measured at 5C increments from 15 to 40C peaked at 27C, in Merion Kentucky bluegrass and 34C in Nugget. In another study, temperatures of 22C generated increased ethylene production upon application of kinetin, compared to the distilled water control. At supraoptimal temperatures a three-fold increase in ethylene production was generated by the turfgrass tissue both

with and without kinetin application.

5. Foliar applied kinetin was found to increase the number of active buds through stimulation of ethylene production when grown at 22C. Hypobaric studies revealed that under supraoptimal temperatures, inhibition of bud activity resulted from increased ethylene production generated endogenously or by kinetin application.
6. A twenty-four hour exposure at 33C inhibited bud activity of Merion and Nugget Kentucky bluegrass. The number of active buds increased when cultivars, exposed to 33C, were returned to cooler temperatures of 22C.
7. Ethephon rates less than 1000 $\mu\text{l/L}$, applied as drenches, were ineffective in improving shoot numbers under summer field conditions. Monthly nitrogen drenches of 0.40 kg N/100m² were more effective in improving shoot density and quality in both cultivars compared to combinations of nitrogen and ethephon. No strong trend developed to support field applications of silver nitrate for suppressing ethylene synthesis and/or action.

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