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EFFECTS OF APPLICATION INTERVALS AND LEVELS OF N, P, AND K ON COLD HARDINESS RELATIONSHIPS IN TIFGREEN BERMUDAGRASS (*Cynodon* sp.) AND ST. AUGUSTINEGRASS (*Stenotaphrum secundatum*)

A Thesis

by

SIM ADAIR REEVES, JR.

Submitted to the Graduate College of
Texas A&M University in
partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

January 1969

Major Subject AGRONOMY

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Approved as to style and content by:

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(Chairman of Committee)

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(Head of Department) (Member)

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(Member) (Member)

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(Member) (Member)

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EFFECTS OF APPLICATION INTERVALS AND LEVELS OF N, P, AND K ON COLD HARDINESS RELATIONSHIPS IN TIFGREEN BERMUDAGRASS (Cynodon sp.) AND ST. AUGUSTINEGRASS (Stenotaphrum secundatum). (1968)

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Directed by: Dr. George G. McBee

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ABSTRACT

There appears to be a variable effect of late applications of N, P, and K, or several combinations of these, on the winter kill of common St. Augustinegrass and Tifgreen bermudagrass in the College Station area. Rates of N, P_2O_5 and K_2O were increased up to 3 lb./1000 ft./month during the late part of the growing season on field plots of these grasses. Under the low temperature condition of 18 F there was no winter kill from any treatment in the field. Plots receiving the higher N applications through December had the best appearance up to the first freeze and were the first to recover in the Spring. Tissue was collected from the various treatments for chemical analysis. These analyses showed a direct relationship between N-K and N-P. As tissue N levels increased, the P and K levels increased also.

Tifgreen bermudagrass grown under different nutrient levels, controlled conditions, and artificially frozen in a growth chamber showed that nutrient level has an effect on winter hardiness. This effect did not seem to change the range of the killing point for warm season turf grasses over 2-5 degrees F. Within this range the P/K ratio has the greatest effect on cold hardiness. A high P/K ratio increases

winterkill while low ratios showed little damage. The N level seems to exert the greatest effect of winterkill by influencing the levels of P and K. Under greenhouse conditions, the tissue levels of P and K tended to increase also as the N level increased.

Four-inch diameter plugs of cold hardened St. Augustinegrass were removed from the field and placed in the greenhouse. These plugs were artificially frozen after different lengths of time in the greenhouse (maintained at approximately 80 F) to determine the rate of loss of cold hardiness. St. Augustinegrass appeared to lose its cold hardiness between 48 and 72 hours when subjected to temperatures of 80 F. The same test was conducted on Tifgreen bermudagrass at a later date but the results were variable due to lack of sufficient cold temperatures to preharden the plants in the field.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. George G. McBee, the committee chairman, for his patience and guidance in the planning, conducting, and evaluation of this study.

Acknowledgment is also made to Dr. E.C. Holt, Dr. M.H. Ferguson, and Dr. H.E. Joham for their guidance and helpful suggestions in the preparation of this manuscript.

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C H A P T E R I

INTRODUCTION

Cold temperatures cause pronounced changes in nature. Many plants go through the winter with little change while other plants die after the first frost. To a large extent cold hardiness influences the selection of plants to be grown in an area. With the advent of cool temperatures, changes occur in some plants that make them more resistant to cold temperatures. This change has been given several names, among which are: winter hardiness, frost resistance, and cold tolerance. Determining the nature of this change in plants has been the objective of numerous researchers during the past century. A vast amount of research has been conducted as shown by the abundance of literature dealing with the physiological nature and the evaluation of winter hardiness in plants. Most of the research has been conducted on crop plants and little attention has been given to turfgrasses until recent years.

Beard (3) listed several major and secondary causes resulting in loss or serious damage to turfgrasses from cold temperatures: (1) direct freezing injury to hardened plant tissue, (2) direct injury to plants in a reduced state of cold hardiness, (3) desiccation, (4) toxic respiratory products, (5) heaving, (6) disease, (7) increased water content in tissues, (8) late fall fertilization with nitrogen material, (9) height of cut and excessive thatch accumulation.

"The citations on the following pages follow the style of the Journal of American Society of Agronomy."

With the rapid growth of the turf industry there also has been an increase in use of fertilizer for turf. It has been recognized for several years that N, P, and K may have an effect on cold hardiness in grass plants. This investigation was designed to study several aspects of the influence of N, P, and K on cold hardiness of two warm season turfgrasses, Tifgreen (Cynodon sp.) and St. Augustine (Stenotaphrum secundatum). Among these were the influence of various levels of N, P, and K on cold hardiness, effects of late season applications, and effects on rate of loss of cold hardiness by the two grasses.

CHAPTER II

LITERATURE REVIEW

Most investigations of cold hardiness have been conducted on plants other than turfgrasses. Worzella (29) and Livingston (23) working with wheat found that cold resistant was less under high rates of fertilization than under low fertility levels. Investigations on cabbage (11) and corn (12) showed that high and low fertility levels had very little effect on the cold hardiness of these plants.

The effect of N levels on cold hardiness of plants has been investigated by several workers, (1,5,6,7,12,22,23). According to Levitt (22), any factor that induces rapid growth will generally cause a decrease in cold resistance. Edgerton (12) observed less cold damage to Tung trees grown under higher N fertilization treatments. Carroll and Welton (6,7) reported that Kentucky bluegrass fertilized with high N was less resistant to low temperature than unfertilized grass. The grass fertilized with low levels of N always withstood the lower temperatures. Similar results have also been reported for orchardgrass (16).

P and K do not usually induce rapid and active growth and are generally considered to increase hardiness. Little work has been published on the effect of combinations of N, P, and K on cold hardiness (11,13,17). In investigations on wheat (13), manure and P in combinations decreased winterkill more than either manure or P added by itself. Davis (8), working with Tifgreen bermudagrass, showed that a fertilizer ratio of 4-1-5 increased winter hardiness. The addition of P and K improved cold tolerance and increasing the N level with the level of P and K remaining constant, hardiness appeared to be increased.

Alfalfa increased in cold resistance as K_2O was increased up to 200 lb./acre with P_2O_5 held constant at 80 lb./acre (17). As P_2O_5 was increased to 80 lb./acre, with K_2O held constant at 200 lb./acre, cold hardiness increased. It was found that a ratio of 5:2 of K_2O to P_2O_5 produced the most cold resistance in alfalfa.

Winter killing of Coastal bermudagrass was decreased with increasing levels of K when the N level was held constant (1). Winter survival was favored by a high ratio of K to N. Kuska (19) noted that applications of P and K along with normal soil N increased winter hardiness of wheat when P and K were applied in a ratio of 4:1. Saveljev (26) stated that three applications of P and K in the fall were more effective in increasing frost resistance in wheat than a single application.

It is a common statement that fertilizer applied in late fall to turfgrasses may increase winterkill. Carroll (6,7), working with 15 turfgrasses common to Ohio, showed that heavy N fertilization in the fall increased winterkill. Alexander (2) states that soluble N fertilizer applied in the fall will increase the danger of overgrowth and render grass highly susceptible to winter killing.

Some work has been conducted on the transition period of plants from winter dormancy to active growth. Laude (21), working with wheat varieties, showed them to lose most of their cold hardiness in 1-10 days depending upon the variety. Plants dehardened at 80 F lost their hardiness twice as fast as plants dehardened at 60 F. Temperature appears to be a major factor in the loss of cold resistance and the rate of change is associated with the amount of heat the plant receives. A plant will lose its cold hardiness at a rate proportional to the degree of hardiness (20). Brierley (4) found that Latham raspberry canes rapidly lose their cold hardiness after two days, but cold resistance may be regained if the temperature gradually drops. Thus, it is possible that much of the winter killing of plants is due to a loss of cold hardiness followed by a freeze rather than extreme low temperature.

CHAPTER III

METHODS AND MATERIALS

The first phase of this study was conducted on Tifgreen bermudagrass grown under controlled conditions. Grass plugs, four inches in diameter, were removed from field established turf. They were washed free of soil, roots trimmed, and transplanted into round plastic containers, 7-inches in diameter and 6-inches deep. A 2-inch layer of washed gravel was placed in the bottom and the remainder of the container filled with washed builder's sand. The grasses were fertilized with a complete Hoagland nutrient solution twice per week and leached once each week with distilled water. They were also watered with distilled water, as needed. This treatment was continued for approximately 6 weeks to allow the grass to become established in the containers. The containers were arranged in a randomized block design and each treatment was replicated 3 times.

After the grass had become established and all containers were uniform in growth, they were thoroughly leached with distilled water before a series of 12 nutrient treatments were started. The treatments and nutrient sources are shown in Table 1. Other essential elements shown in Table 2 were added to all nutrient solutions. The pH of the solutions was maintained at about 6 throughout the investigation by the use of HCl or $Ca(OH)_2$. The sand cultures were thoroughly flushed with distilled water once each week to remove excess salts (14). Fresh nutrient solutions were applied twice each week to supply the quanti-

Table 1. Nutrient treatments and their source.

Treatment[1/]	N	P_2O_5	K_2O
1. ON OP OK			
2. ON HP OK		$CaH_4(PO_4)H_2$	
3. ON OP HK			KCl
4. ON HP HK		KH_2PO_4	KH_2PO_4
5 MN OP OK	NH_4NO_3		
6. MN HP OK	$NH_4H_2PO_4$	$NH_4H_2PO_4$	
	NH_4NO_3		
7. MN OP HK	NH_4NO_3		KCl
8. MN HP HK	NH_4NO_3	KH_2PO_4	KCl KH_2PO_4
9. HN OP OK	NH_4NO_3		
10. HN HP OK	NH_4NO_3	$NH_4H_2PO_4$	
	$NH_4H_2PO_4$		
11. HN OP HK	NH_4NO_3		KCl
12. HN HP HK	NH_4NO_3	$NH_4H_2PO_4$	KCl

[1/] ON = No N, MN = 1 lb N/1000 ft^2, HN = 3 lb. N/1000 ft^2, OP = No P_2O_5 HP = 3 lb. P_2O_5/1000 ft^2, OK = No K, HK = 3 lb. K_2O/1000 ft^2.

Table 2. Elements and their source.

Element	PPM	Source
Fe	11.2	Sequestrene Fe
Mn	1.1	$MnCl_2 \cdot 4H_2O$
Cu	0.128	$CuSO_4 \cdot 5H_2O$
Zn	0.13	$ZnSO_4 \cdot 7H_2O$
B	0.74	H_3BO_3
Mo	0.0966	$NaMoO_4 \cdot 2H_2O$
Mg	96.72	$MgSO_4 \cdot 7H_2O$
S	127.4	$MgSO_4 \cdot 7H_2O$
Ca	400.00	$CaCl_2 \cdot 2H_2O$

ties shown in Table 1 and the grass watered with distilled water as needed. The grasses were clipped twice each week at a height of 1 inch.

When the grasses showed nutrient deficiency symptoms, they were subjected to a controlled freezing cycle. Approximately 3 days before freezing the grasses were clipped with hand clippers at a height of 1 inch and the clippings saved for chemical analysis. Twelve hours before being placed in the growth chamber, the containers were saturated with water and natural drainage left the soil in each container with approximately the same moisture content (27). The freezing was conducted in two Sherer growth chambers with the light cycle set for ten hours of light and fourteen hours of dark (10,15,27).

The freezing cycle consisted of placing the containers in the growth chamber and hardening them for 72 hours at 35 F (15,16) and subjecting them to a sub-freezing temperature program for 16 hours. The time allowed for hardening will not create maximum hardiness in these grasses but preliminary studies showed that it was sufficient to differentiate hardened from unhardened plants, and to show the effects of N, P, and K on hardening. Also, two containers of Tifgreen bermudagrass grown with complete nutrient solution were placed in the growth chamber at the start of each freezing cycle. These containers of grass which had not been hardened for the 3-day period were used to show the effect of nonhardening. After the grasses had been hardened for 72 hours, the temperature was then lowered at the rate of 2 degrees/hour until the desired temperature was reached (8,9,22). The 2 degrees/hour was considered to be slow enough to permit normal equilibrium and diffusion processes to occur within the tissues and the formation of extracellular ice crystals. If the drop is too rapid, ice will form intercellularly regardless of the state of hardiness.

Different plants were subjected to 3 freezing temperatures: 28, 26, and 24 F. These 3 freezing temperatures were selected from preliminary work conducted with grass samples prepared in an identical manner to determine the approximate killing point for Tifgreen bermudagrass under these conditions. Following freezing, the temperature was raised 2 degrees/hour until it reached 40 F where it remained for 24 hours to allow the plants to thaw. The same cycle was followed as in freezing the plants to 28, 26, and 24 F. After the slow thawing period the grass was transferred to the greenhouse (approximately 80 F) for a recovery period. When the plants were placed in the greenhouse, a complete nutrient solution was applied to all treatments. Visual ratings to determine percent recovery were taken 2 weeks after plants were placed in the greenhouse.

Grass clippings collected prior to freezing were ground in a Wiley mill to pass a 40-mesh screen and analyzed for N, P, and K content. Total N was determined by analyzing with a Model 29A Coleman Nitrogen Analyzer II. P was determined by the vanadate-molybdate-yellow method (18) utilizing a Beckman Model DB Spectrophotometer. K was determined by the dry ashing technique utilizing a Beckman DU-2 Spectrophotometer equipped with a photomultiplier and flame attachment.

The second part of this investigation was conducted on Tifgreen bermudagrass and St. Augustinegrass grown in the turf research plots located on the campus of Texas A&M University. N, P_2O_5, and K_2O were applied at the rate of 3 lb./1000 ft^2 at different times to determine the effects of late application of fertilizer on cold tolerance. Treatments, dates of application, and rates of fertilizer that were applied are listed in Table 3. A randomized block design with 3 replications was used. The blocks were visually rated for topkill during the winter and rate of recovery during the spring. Topkill as used throughout this text is to denote killing of the upper plant growth and does not refer to complete killing of the plant. Visual ratings on topkill were made several days after a cold temperature. A rating scale of 1-3 was used for each individual treatment with the value of 1 representing the most severe topkill. The visual rating for recovery was made after sufficient warm weather had allowed the grass to initiate growth. The rating scale as previously described was used with 1 representing the best recovery and 3 the poorest. Daily temperatures were recorded by an official weather recording station located 100 yards from the plots. Clippings were taken from each block before the first freeze to determine N, P, and K content.

The objective of the final phase was to study the effect of N, P, and K on the rate of loss of cold hardiness by two warm season turfgrasses. The study was conducted on Tifgreen bermudagrass and St. Augustinegrass obtained from previously described plots located in the turf research area. When these grasses had hardened under existing winter conditions, five plugs, 4-inches in diameter and 5-inches in

Table 3. Treatments and dates of application and rates of fertilizer applied to Tifgreen bermudagrass and St. Augustinegrass in the field.

Treatments	Sept. 1	Oct. 1	Nov. 1	Dec. 1
1.	N,P,K[1/]			
2.	N,P,K	N,P,K		
3.	N,P,K	N,P,K	N,P,K	
3A.	N,P,K	N,P,K	N,P,K	N,P,K
4.	N,P,K	N[2/]		
5.	N,P,K	N	N	
5A.	N,P,K	N	N	N
6.	N,P,K	P[3/]		
7.	N,P,K	P	P	
7A.	N,P,K	P	P	P
8	N,P,K	K[4/]		
9.	N,P,K	K	K	
9A.	N,P,K	K	K	K

[1/] N,P,K - 3 lb. N,P_2O_5, K_2O/1000 ft^2 supplied by 12-12-12 fertilizer.

[2/] N - 3 lb. N/1000 ft^2 supplied by $(NH_4)_2SO_4$.

[3/] P - 3 lb. P_2O_5/1000 ft^2 supplied by superphosphate $Ca(H_2PO_4)_2 \cdot H_2 + CaSO_4 \cdot 2H_2O$.

[4/] K - 3 lb. K_2O/1000 ft^2 supplied by KCl.

depth, were removed from each block. They were transplanted into 7-inch round plastic containers, surrounded with sand, and moved to the greenhouse where the temperature was maintained at approximately 75-80 F. Immediately after transplanting, one plug from each block was artificially frozen in a Sherer growth chamber at 24 F for 16 hours. The temperature was then raised to 40 F for 12 hours allowing the plugs to thaw. They were then placed in the greenhouse and allowed to recover. After twenty-four hours in the greenhouse, a second plug from each treatment was frozen and then returned to the greenhouse. This same procedure was followed after 48, 72, and 96 hours for each treatment to determine the rate of loss of cold hardiness. A second sample of each treatment was subjected to the same freezing cycle.

Due to lack of freezer space, St. Augustinegrass and Tifgreen bermudagrass were removed from the field at different times. St. Augustinegrass plugs were taken from the field January 12, after approximately 20 days of freezing or near freezing temperatures and Tifgreen bermudagrass plugs were removed February 23 after 3 days of freezing temperatures. Visual ratings on percent cover and general appearance were taken 2 weeks after freezing.

All data were subjected to analysis of variance utilizing the Data Processing Center, Texas A&M University, College Station, Texas. The means of the data subjected to analysis of variance were tested for significance at the 0.05 levels by Duncan's Multiple Range Test and arrayed.

CHAPTER IV

RESULTS

Tifgreen Bermudagrass Grown Under Greenhouse Conditions

Tifgreen bermudagrass was grown in sand culture using a modified Hoagland solution to produce N, P, and K deficiencies. Various levels of the elements used are shown in Table 1. Treatments with no N added were the first to show deficiency symptoms. In these containers the grasses changed from a dark green to a yellowish green color, and the growth rate was greatly reduced. In the various treatments where N was deleted, P and K deficiencies did not show up or were over-shadowed by the low N. Plants grown under medium and high N with P and K deleted did exhibit deficiency symptoms. The deficient plants showed a definite thinning and the leaves became very narrow. The P deficient plants exhibited a dark green color, slightly reduced growth and a slight cupping of the leaf tips. Both P and K deficiencies were more pronounced under high N than medium N.

After producing plants that exhibited deficiency symptoms for N, P, and K, the plants were subjected to tissue analyses and freezing at 3 temperatures as previously described. Results of the elemental tissue analyses and percentage recovery after freezing at the 3 temperature levels are presented in Table 4.

In the tisse there appears to be a direct relation between the N level and the P and K levels. As the N level increases the P and K levels increase also. P level was the lowest in treatments where no N

Table 4. Effects of various nutrient treatments on tissue content of N, P, and K and percent recovery of Tifgreen bermudagrass exposed to three temperature levels.

Treatments	Elemental analysis[1/]				% Live cover[2/]		
	N	P	K	P/K	28	26	24
ON OP OK	2.1 d[3/]	60.0 b	89.3 e	0.67	100 a[4/]	100 a	5i
MN OP OK	2.7 c	53.9 b	104.4 cde	0.52	100 a	95 ab	7i
HN OP OK	3.8 bc	17.6 d	92.7 de	0.18	100 a	82 bcd	0i
ON HP OK	1.9 d	34.2 c	104.2 cde	0.33	100 a	60 g	0i
MN HP OK	4.0 bc	105.5 a	112.2 cd	0.94	80 cde	68 def	0i
HN HP OK	4.4 a	112.3 a	89.5 e	1.24	65 fg	27 h	0i
ON OP HK	2.1 d	7.6 d	121.2 c	0.06	100 a	100	3i
MN OP HK	3.8 bc	51.3 b	155.5 b	0.32	100 a	88 abc	1i
HN OP HK	3.7 bc	8.5 d	166.3 ab	0.05	100 a	92 abc	1i
ON HP HK	2.0 d	58.0 b	114.5 c	0.51	100 a	100 a	1i
MN HP HK	4.0 b	101.4 a	181.0 a	0.56	95 ab	78 cde	1i
HN HP HK	4.3 a	106.2 a	186.0 a	0.57	82 bcd	65 efg	1i

1/ Respectively, % N, ppm P x 10^2, ppm K x 10^2.

2/ Visual ratings taken 2 weeks after freezing.

3/ Number within a column followed by the same small letters do not differ significantly at the 0.05 level by Duncan's test.

4/ Numbers for these temperature levels not followed by the same letter are significantly different at the 0.05 level by Duncan's test.

and high N were applied in combination with high K. The highest levels of P were found in the high N treatment where P was applied. The same is true of the K levels. The highest levels of tissue K were under high N and K, while the lowest levels occurred under treatments with no K added. P and K do not seem to influence each other.

The percent cover obtained after a 2-week recovery period in the greenhouse is also presented in Table 4. When the grass was removed from the growth chamber and placed in the greenhouse to recover, a complete Hoagland solution was applied to each container. This was done so that any lack of recovery could be attributed to freezing and not continued lack of adequate nutrients. Grasses placed in the freezer at the beginning of the freezing cycle without hardening were completely killed at 24 and 26 F while approximately 50% of those maintained at 28 F were killed. A variation in freezing damage was evident for prehardened grass between 28 and 26 F but when the temperature was lowered to 24 F no significant difference existed between treatments. The difference in freezing damage between 26 and 24 F is shown in Fig. 1 and 2. Among treatments, the greatest injury occurred in those which received high rates of P and no K. The tissue analysis showed these treatments all contained high levels of P and low levels of K. The P/K ratio and percent cover after freezing are plotted against treatments in Fig. 3. The line for the P/K ratio follows the line for percent cover at 26 and 28 F very closely with the exceptions of 2 treatments. This shows that high P/K ratios result in the greatest winterkill for temperatures at 26 F and above. A pictorial illustration

Figure 1. Tifgreen bermudagrass two weeks after freezing at 26 F showing slight damage.

Figure 2. Tifgreen bermudagrass two weeks after freezing at 24 F showing almost complete kill.

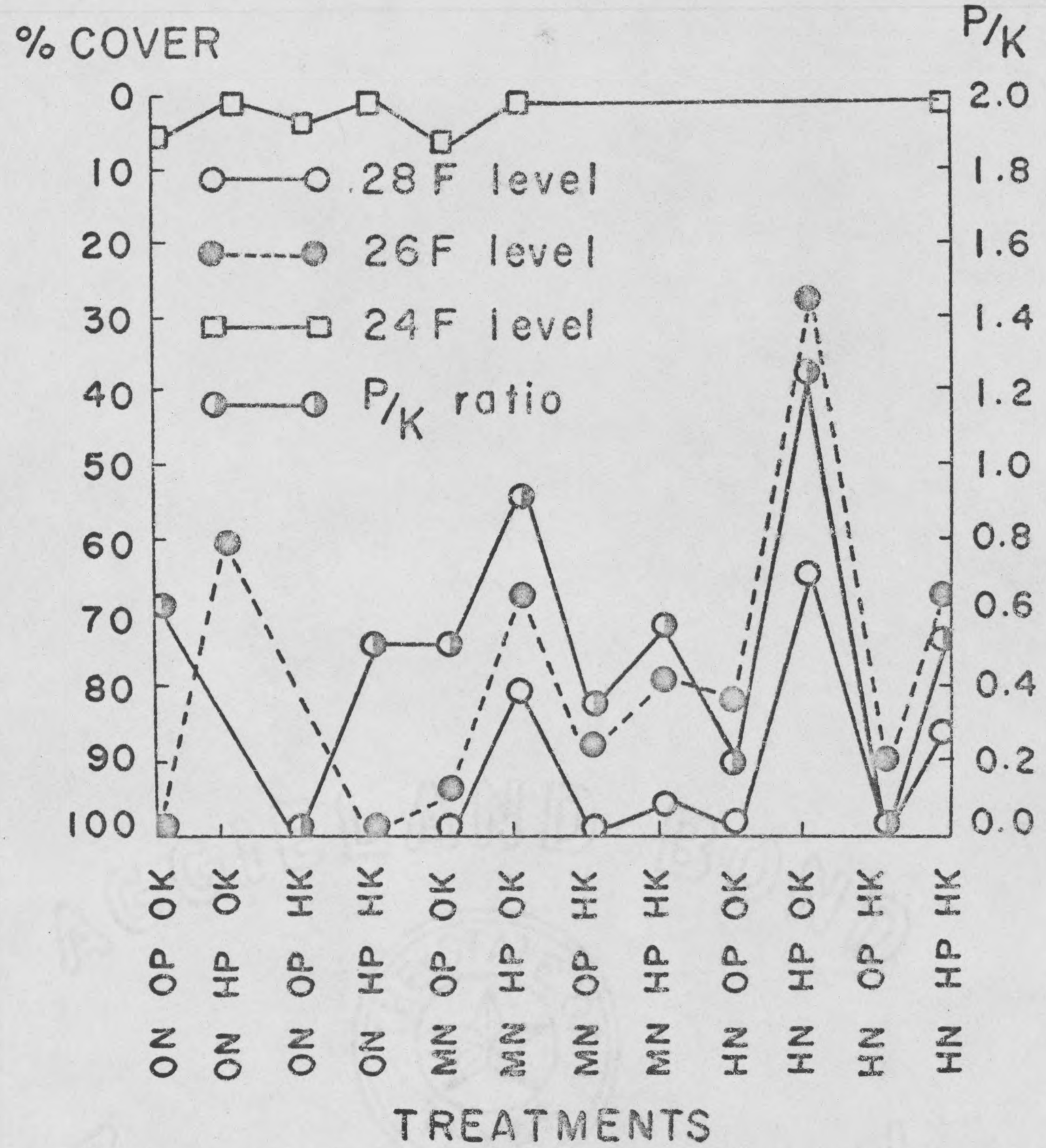

Figure 3. Percent cover of Tifgreen bermudagrass 2-weeks after exposure to three temperature levels and the P/K ratio plotted against fertilizer treatments.

showing the effect of high P and low K is shown in Figures 4,5,6.

These results show that N did not have a major effect on winterkill of Tifgreen bermudagrass. High N does show a decrease in cold hardiness but this is overshadowed by the fact that high N increases the K level which increases cold hardiness. Under medium to high N, the P/K ratio shows the effect on cold hardiness of the 3 major elements used.

Late Fertilization of Tifgreen Bermudagrass

As previously described, a variable fertilizer schedule was followed (Table 3) to study the effects of late fall fertilization on the winterkill of Tifgreen bermudagrass and St. Augustinegrass. Since temperature was one of the variables under study, the daily minimum temperatures were recorded and the reading plotted in Fig. 7.

Late fertilization of Tifgreen bermudagrass was conducted on an experimental golf green located at the Texas A&M University turf research plots. Samples were taken from the golf green on December 11, eleven days before the first freeze (Fig. 7). These samples were analyzed for N, P, and K and the results are presented in Table 5. The tissue levels of N show a significant increase from late fall application of fertilizer. The highest level of N found in the tissue was from plots fertilized with N through December. There was no apparent difference in N level from the two sources of N fertilizer.

The tissue level of P increased with late applications of N, P, and K fertilizer but where N and P were not added together there was no significant increase in the P level. The tissue content of K appeared

Figure 4. Tifgreen bermudagrass grown under No-N fertilization pictured horizontally and subjected to three temperatures shown vertically. After freezing the grass was grown under complete fertilization for three weeks before being photographed.

Figure 5. Tifgreen bermudagrass grown under Medium-N fertilization and varying P and K pictured horizontally and subjected to three temperatures shown vertically. After freezing the grass was grown under complete fertilization for two weeks before being photographed.

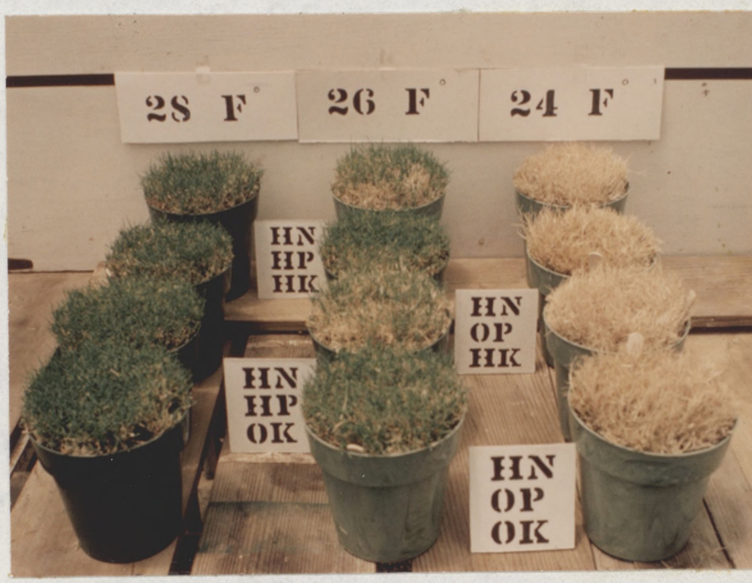

Figure 6. Tifgreen bermudagrass grown under different High-N fertilization and varying P and K pictured horizontally and subjected to three temperatures shown vertically. After freezing the grass was grown under complete fertilization for two weeks before being photographed.

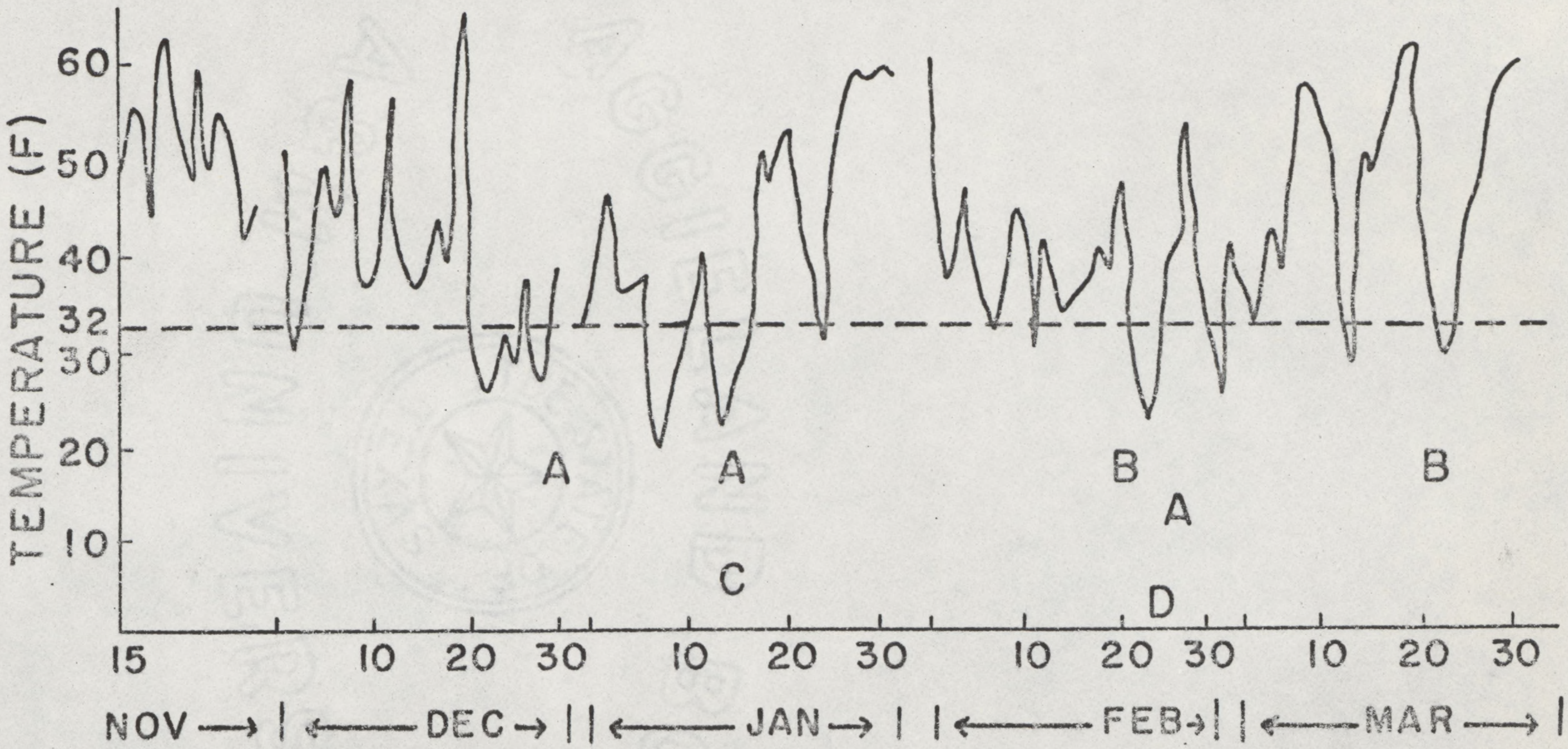

Figure 7. Minimum temperatures recorded November 15, 1967 - March 30, 1968 at Turf Research Plots, Texas A&M University, showing dates that were rated for winterkill and spring recovery.

A,B = Winterkill and percent recovery (respectively) rated for St. Augustine- and Tifgreen bermudagrass.

C,D = St. Augustine - and Tifgreen bermudagrass plugs removed respectively from field to study loss of cold hardiness.

Table 5. Effects of fertilizer treatments on N, P, and K content of Tifgreen bermudagrass tissue.

Treatments	Elemental analysis[1/] N	P	K	P/K
N,P,K through Sept.	2.2 d*	38.0 b	64.9 b	0.59
N,P,K through Oct.	2.6 cd	42.7 b	74.1 b	0.58
N,P,K through Nov.	3.3 b	52.9 a	125.0 a	0.42
N,P,K through Dec.	3.8 a	59.0 a	133.9 a	0.44
N through Oct.	2.8 c	40.6 b	72.5 b	0.56
N through Nov.	3.3 b	44.3 b	118.1 a	0.38
N through Dec.	3.7 ab	42.5 b	132.2 a	0.32
P through Oct.	2.3 d	38.6 b	52.9 b	0.72
P through Nov. & Dec.	2.6 cd	37.6 b	57.8 b	0.65
K through Oct.	2.3 d	44.4 b	61.0 b	0.73
K through Nov. & Dec.	2.4 cd	41.2 b	76.7 b	0.54

[1/] Respectively % N, ppm P x 10^2, ppm K x 10^2 analysis reported on tissue harvsted.

*Those values within a column not followed by the same small letter are significantly different at the 0.05 level by Duncan's test.

to be influenced by the level of N. As the N level increased so did the K content. There was a significant increase in the K content of the grass plots fertilized with N during November and December. The soil application of K alone appeared to have little influence on the tissue level of K. When K was added to the plots without N application there was no increase in the K content of the tissue.

On December 22, the temperature dropped to 24 F with the effect on topkill as reflected in Table 6. Before the freeze, plots receiving N in October, November, and December had good appearance and color whereas plots which had not received N since September were yellowish in color and had reduced growth. The ratings show that topkill was heaviest on plots receiving N fertilizer in November and December. Plots not receiving N showed the least damage. Comparatively low temperature during the first part of January (Fig. 7) resulted in topkill of all treatments (Table 6). Following this cold period, the temperature increased and the grass began to resume growth. On February 21, ratings were made on recovery (Table 7) which showed that the plots receiving N late in the fall recovered the best. Topkill ratings were made again on February 26 following a low temperature of 22 F on February 22. The plots which had sufficient N to make the most regrowth earlier, showed the greatest topkill again. Recovery ratings taken again in March and April showed that the late fall application of N fertilizer resulted in the quickest recovery. After the April rating all plots were fertilized with 12-12-12 at the rate of 2 lb./1000 ft^2/month. Ratings taken in June showed that all plots had com-

Table 6. Effects of fertilizer treatments on topkill of Tifgreen bermudagrass.

Treatments	Rating period[1/]		
	12/30/67	1/15/68	2/26/68
N,P,K through Sept.	2.2 cd*	3.0 a	1.5 cd
N,P,K through Oct.	2.3 bc	3.0 a	1.8 bc
N,P,K through Nov.	3.0 a	3.0 a	3.0 a
N,P,K through Dec.	3.0 a	3.0 a	3.0 a
N through Oct.	2.7 ab	3.0 a	2.2 b
N through Nov.	3.0 a	3.0 a	2.8 a
N through Dec.	3.0 a	3.0 a	3.0 a
P through Oct.	1.8 d	3.0 a	1.3 d
P through Nov. & Dec.	1.6 d	3.0 a	1.3 d
K through Oct.	1.7 d	3.0 a	1.6 d
K through Nov. & Dec.	1.7 d	3.0 a	1.3 d

[1/] Visual ratings were made on a comparison basis (1-slight, 3-severe). Numbers cannot be compared across dates because ratings were based on comparison of the block with the most severe topkill at each rating period.

*Those values within a column not followed by the same small letter are significantly different at the 0.05 level by Duncan's test.

Table 7. Effect of fertilizer treatments on rate of spring recovery of Tifgreen bermudagrass.

Treatments	Rating period[1/]			
	2/21/68	3/22/68	4/13/68	6/1/68
N,P,K through Sept.	3.0 a*	2.6 ab	2.6 b	1.5 a
N,P,K through Oct.	2.0 c	2.6 ab	2.0 c	1.0 a
N,P,K through Nov.	1.0 d	1.0 d	1.0 d	1.0 d
N,P,K through Dec.	1.0 d	1.0 d	1.0 d	1.0 a
N through Oct.	2.0 c	2.0 c	2.0 c	1.0 a
N through Nov.	1.0 d	1.0 d	1.0 d	1.0 a
N through Dec.	1.0 d	1.0 d	1.0 d	1.0 a
P through Oct.	3.0 a	3.0 a	3.0 a	1.5 a
P through Nov. & Dec.	2.6 b	3.0 a	3.0 a	1.5 a
K through Oct.	3.0 a	2.6 ab	3.0 a	1.5 a
K through Nov. & Dec.	3.0 a	3.0 a	2.6 a	1.5 a

[1/] Visual ratings were made on a comparison basis (1-best, 3-poorest). Numbers cannot be compared across dates because ratings were based on comparison of block with the best recovery at each rating period.

* Those values within a column not followed by the same small letters are significantly different at the 0.05 level by Duncan's test.

pletely recovered.

Loss of Cold Hardiness by Tifgreen Bermudagrass

Loss of cold hardiness was studied on the same Tifgreen bermudagrass green discussed in the previous section. Due to limited freezer space, Tifgreen bermudagrass could not be removed from the field at the same time as the St. Augustinegrass. There was not a second prolonged period of low temperature and finally Tifgreen plugs were moved to the greenhouse on February 23, (Fig. 7), after approximately 3 days of sub-freezing temperatures. These plugs were subjected to freezing temperatures after varying lengths of time in the greenhouse as previously described for St. Augustinegrass. Visual ratings made on the general appearance and the percentage of cover after recovery from the freezing temperatures are presented in Tables 8 and 9. The results of dehardening Tifgreen did not follow any pattern. There was a significant decrease in percentage of cover and general appearance ratings between the 0 hour and 96 hours dehardening treatments but the time interval for loss of cold hardiness was inconclusive. There was considerable variation in the percent cover for most treatments. The percentage cover increased and decreased without following any pattern. Two treatments did not show any significant change until 96 hours, while other treatments showed significant decrease in percent cover after 24 hours. From these results it can be concluded that intermittent high temperature during the winter causes loss of cold hardiness, but in these trials there was no clear indication of the

Table 8. Effect of fertilizer treatments and dehardening periods at 80 F on loss of cold hardiness by Tifgreen bermudagrass.

	% cover 2 weeks after freezing 1/				
	Hours of dehardening				
Treatments	0	24	48	72	96
N,P,K through Sept.	44a* ABCD	8b D	34a ABC	0b D	0b A
N,P,K through Oct.	71a A	34b BCD	2c C	2c CD	4c A
N,P,K through Nov.	57a AB	65a BC	67a A	35b ABCD	33b A
N,P,K through Dec.	37c BCD	100a A	66b A	45c ABC	30c A
N through Oct.	33a BCD	34a BCD	17a BC	23a BC	20a A
N through Nov.	23a CD	34a BCD	3b BCD	1b CD	6b A
N through Dec.	56a ABC	34a BCD	40a AB	10b BCD	3b A
P through Oct.	40a ABCD	45a BCD	33a BCD	33a BCD	7b A
P through Nov. & Dec.	33b BCD	32b CD	36b BCD	65a A	3c A
K through Oct.	17b D	17b CD	2b C	28a BCD	0b A
K through Nov. & Dec.	48a ABCD	23b CD	36a BCD	10b BCD	20b A

1/ Samples frozen for 12 hours at 26 F after dehardening periods indicated

* Those values within a column not followed by the same capital letter are significantly different at the 0.05 level by Duncan's test. Those values across dates not followed by the same small letter are significantly different at the 0.05 level by Duncan's test.

Table 9. Effect of fertilizer treatments and dehardening periods at 80 F on the general appearance of Tifgreen bermudagrass.

Treatments	Hours of dehardening 0[1]	24	48	72	96
N,P,K through Sept.	3.5 b* AB	4.7 a A	3.8 b ABC	5.0 a A	5.0 a A
N,P,K through Oct.	3.5 b AB	3.7 b A	5.0 a A	5.0 a A	5.0 a A
N,P,K through Nov.	3.0 b B	2.5 b B	3.8 a ABC	3.8 a AB	3.8 a A
N,P,K through Dec.	3.5 a AB	1.0 c B	2.5 b D	3.2 a B	3.8 a A
N through Oct.	3.8 a AB	3.7 a A	4.0 a ABC	4.2 a AB	4.5 a A
N through Nov.	4.0 b AB	3.7 b A	4.8 a AB	5.0 a A	4.8 a A
N through Dec.	3.0 c B	3.7 bc A	4.3 ab ABC	4.7 a A	4.7 a A
P through Oct.	3.0 c B	4.0 b A	5.0 a A	5.0 a A	4.8 a A
P through Nov. & Dec.	4.0 b AB	3.8 b A	3.5 bc CD	3.0 c B	4.8 a A
K through Oct.	4.7 b A	4.5 b A	4.8 a ABC	4.0 b AB	5.0 a A
K through Nov. & Dec.	3.5 b AB	4.2 b A	3.7 b BCD	4.8 a A	4.2 b A

1/ Visual ratings taken from 1-5, (1-best, 5-poorest). Samples frozen for 12 hours at 26 F after treatment.

* Those values within a column not followed by the same capital letter are significantly different at the 0.05 level by Duncan's test. Those values across time not followed by the same letter are significantly different at the 0.05 level by Duncan's test.

time interval after which cold hardiness is lost.

Late Fertilization of St. Augustinegrass

A variable fertilizer schedule was conducted on St. Augustinegrass in the field to determine the effect of late fertilization on winterkill. Clippings were taken December 18, 1967, four days prior to the first freeze (Fig. 7), analyzed for N, P, and K and the results shown in Table 10. There was a highly significant increase in tissue levels of N obtained from plots fertilized with N, opposed to those receiving no N after September. There was no significant difference in tissue levels of N from N applied in the form of 12-12-12 or ammonium sulfate on comparable dates.

The P content of the tissue was consistently higher where P was applied in a complete fertilizer and the level increased with late application. Where N alone was added to the plots, the tissue P content increased slightly and tended to increase as the N level increased, especially where P was applied.

The K content in tissue increased significantly as N level increased. The tissue content of K tended to increase at about the same rate with the late soil applications of N whether or not K was included. Where N was not applied, the K content in tissue remained about the same, even when K was added by soil applications. The topkill ratings, taken December 30, (Fig. 7), after the first freeze, were made on the same tissue as the chemical analysis. Chemical analyses were not made on later regrowth. The kill of the upper topgrowth

Table 10. Effect of fertilizer treatments on N, P, and K content of St. Augustinegrass tissue.

Treatments	Elemental analysis[1/] N	P	K	P/K
N,P,K through Sept.	1.5 d*	29.9 fg	70.6 cde	0.42
N,P,K through Oct.	2.3 bc	44.5 bcd	94.9 bc	0.47
N,P,K through Nov.	3.1 a	51.3 abc	117.7 ab	0.44
N,P,K through Dec.	3.3 a	57.1 a	125.1 ab	0.46
N through Oct.	2.3 bc	35.0 ef	88.5 c	0.40
N through Nov.	2.9 ab	42.3 de	116.1 ab	0.36
N through Dec.	3.3 a	42.0 bcd	120.9 ab	0.36
P through Oct.	1.2 d	27.5 fg	49.0 e	0.56
P through Nov. & Dec.	1.4 d	52.2 ab	52.6 e	0.99
K through Oct.	1.2 d	25.0 g	50.6 e	0.49
K through Nov. & Dec.	1.7 d	25.3 g	65.9 de	0.38

[1/] Respectively % N, ppm P x 10^2, ppm K x 10^2.

* Those values within a column not followed by the same letter are significantly different at the 0.05 level by Duncan's test.

(Table 11) was more severe where N fertilizer was applied in November and December. Also, the tissue levels of N and K were the highest in these treatments. Where no N was applied after September, the least topkill was apparent but the grass showed N deficiency symptoms, yellow leaves and thin, reduced growth. Basal growth of turf in the plots where N was added in November and December had a good green color and general appearance.

Topkill ratings (Table 11) taken January 15, 1968, show that all treatments exhibited severe topkill. It might be noted that these values were obtained 9 days after the season low temperature of 18 F (Fig. 7). There were no differences among treatments. Since ratings were made on a relative basis for each rating period, the different rating periods are not directly comparable. Following the topkill ratings, a warm period caused the grass to resume growth. Recovery ratings made February 21 show that plots receiving N in November and December had the best recovery (Table 12). The plots receiving no N since September showed very little regrowth. Ratings for topkill again were taken three days after a freeze of 22 F on February 23. These ratings (Table 11) showed that plots receiving late applications of N also had the most severe damage to topgrowth.

Additional ratings on spring recovery were made in March and April. They follow the same trend showing that plots receiving late applications of N had the best spring recovery and those not receiving N had poor spring recovery. After the April rating all the plots were fertilized with N, P, and K in the form of 12-12-12 at the rate of 2

Table 11. Effect of fertilizer treatments on topkill of St. Augustinegrass.

Treatments	Rating period[1/]		
	12/30/67	1/15/68	2/26/68
N,P,K through Sept.	1.3 c*	3.0 a	1.3 cd
N,P,K through Oct.	2.3 b	3.0 a	2.0 b
N,P,K through Nov.	2.7 ab	3.0 a	2.8 a
N,P,K through Dec.	3.0 a	3.0 a	3.0 a
N through Oct.	2.3 b	3.0 a	2.0 b
N through Nov.	3.0 a	3.0 a	3.0 a
N through Dec.	3.0 a	3.0 a	3.0 a
P through Oct.	1.6 c	3.0 a	1.3 c
P through Nov. & Dec.	1.6 c	3.0 a	1.1 cd
K through Oct.	1.3 c	3.0 a	1.0 d
K through Nov. & Dec.	1.3 c	3.0 a	1.1 cd

[1/] Visual ratings made on a comparison basis (1-slight, 3-severe). Numbers cannot be compared across dates because ratings were based on comparison of blocks with most topkill at each rating period.

* Those values within a column not followed by the same small letter are significantly different at the 0.05 level by Duncan's test.

Table 12. Effect of fertilizer treatments on rate of spring recovery of St. Augustinegrass.

Treatments	Rating period 1/			
	2/21/68	3/22/68	4/13/68	6/1/68
N,P,K through Sept.	2.3 b*	3.0 a	3.0 a	1.5 a
N,P,K through Oct.	2.0 c	2.0 b	2.0 b	1.0 a
N,P, K through Nov.	1.0 d	1.3 c	1.0 c	1.0 a
N,P,K through Dec.	1.0 d	1.0 d	1.0 c	1.0 a
N through Oct.	2.0 c	2.0 b	2.0 b	1.0 a
N through Nov.	1.0 d	1.0 d	1.0 c	1.0 a
N through Dec.	1.0 d	1.0 d	1.0 c	1.0 a
P through Oct.	3.0 a	3.0 a	3.0 a	1.5 a
P through Nov. & Dec.	3.0 a	3.0 a	3.0 a	1.5 a
K through Oct.	3.0 a	3.0 a	3.0 a	1.5 a
K through Nov. & Dec.	3.0 a	3.0 a	3.0 a	1.5 a

1/ Visual rating made on comparison basis (1-best, 3-poorest). Numbers cannot be compared across dates because ratings were based on comparison of block with the best recovery at each rating period.

* Those values within a column not followed by the same small letters are significantly different at the 0.05 level by Duncan's test.

lb./1000 ft^2/month. All plots presented good density, green color and a good appearance at the June rating period.

Loss of Cold Hardiness by St. Augustinegrass

On January 12, 1968, following a cold period, 4-inch plugs of cold hardened St. Augustinegrass were removed from the fertility plots discussed in the previous sections. These plugs were frozen after different lengths of time in the greenhouse to study the transitory period of dehardening. Ratings for the percentage of cover and general appearance, after a 2-week period of recovery in the greenhouse, are shown in Tables 13 and 14, respectively. An analysis of variance for the percentage of cover showed no significant difference between treatments but a significant difference in dehardening time. St. Augustinegrass appears to lose the majority of its cold hardiness between 48 and 72 hours at a temperature of 80 F. This loss of cold hardiness is shown in Figures 8-10. All treatments with the exception of three showed a significant drop in percentage of cover and general appearance ratings during these intervals of time. The three other treatments showed a significant drop in percentage of cover 24 hours later. There were significant differences between a few treatments for the time intervals but no consistent trend was noted. This suggests that fertility treatment may be of minor importance in loss of cold hardiness in St. Augustinegrass.

Upon the dehardening of St. Augustinegrass an interesting effect was obtained. Figure 11 shows the variegation which appeared on 28

Table 13. Effect of fertilizer treatments and dehardening periods at 80 F on loss of cold hardiness by St. Augustinegrass.

Treatments	% cover 2 weeks after freezing[1/]				
	Hours of dehardening				
	0	24	48	72	96
N,P,K through Sept.	78 a ABCD	70 ab A	76 ab AB	63 b ABC	38 c ABC
N,P,K through Oct.	77 a ABCD	77 a A	72 a ABC	34 b CD	40 bc ABC
N,P,K through Nov.	73 a BCDE	85 a A	53 b BC	27 c CD	32 bc BC
N,P,K through Dec.	88 a ABCD	68 b	72 ab ABC	15 d D	31 c BC
N through Oct.	80 a ABCD	78 a A	65 bc ABC	68 ab AB	55 c A
N through Nov.	92 a ABC	68 b A	77 b A	31 c CD	27 c C
N through Dec.	98 a A	82 b A	73 b AB	33 c CD	32 c BC
P through Oct.	67 ab CDE	72 a A	66 ab ABC	33 c CD	53 b AB
P through Nov. & Dec.	85 a ABCD	90 a A	57 b ABC	42 c BCD	47 bc ABC
K through Oct.	63 ab DE	73 a A	57 bc ABC	31 d CD	45 c ABC
K through Nov. & Dec.	53 b E	79 a A	50 b C	70 a A	50 b AB

1/ Samples frozen for 12 hours at 26 F after treatment.

*Those values within a column not followed by the same capital letter are significantly different at the 0.05 level by Duncan's test. Those values across dates not followed by the same small letter are significantly different at the 0.05 level by Duncan's test.

Table 14. Effects of fertilizer treatments and dehardening periods at 80 F on the general appearance of St. Augustinegrass.

Treatments	Hours of dehardening 0	24	48	72	96
N,P,K through Sept.	2.7 b* AB	3.0 b A	2.5 b BCD	2.7 b C	3.7 a AB
N,P,K through Oct.	2.0 c BC	2.0 c BC	2.3 c BCDE	5.0 a A	3.1 b ABC
N,P,K through Nov.	2.7 c AB	1.7 d C	2.8 bc ABCD	3.8 a B	3.3 b ABC
N,P,K through Dec.	2.0 c BC	2.2 c ABC	2.0 c CDE	4.0 a B	3.2 b ABC
N through Oct.	2.0 b BC	1.7 c C	2.7 a ABCD	2.5 ab C	3.0 a BC
N through Nov.	1.3 b CD	1.8 b C	1.5 b E	3.8 a B	3.8 a AB
N through Dec.	1.0 c D	1.5 b C	1.8 b DE	3.8 a B	4.0 b A
P through Oct.	2.7 bc AB	2.3 c ABC	2.8 bc ABCD	3.8 a B	3.2 b ABC
P through Nov. & Dec.	2.7 b AB	1.5 c C	2.5 b ABCD	3.8 a B	2.8 b C
K through Oct.	3.5 ab A	2.8 c ABC	3.2 bc ABC	4.0 a B	3.5 ab ABC
K through Nov. & Dec.	3.5 a A	2.0 b BC	3.5 a A	2.3 b C	3.7 a AB

1/ Visual ratings taken from 1-5, (1-best, 5-poorest), samples frozen for 12 hours at 26 F after treamtent.

*Those values within a column not followed by the same capital letter are significantly different at the 0.05 level by Duncan's Test. Those values across time not followed by the same small letter are significantly different at the 0.05 level by Duncan's test.

Figure 8. St. Augustinegrass frozen at 26 F for 12 hours immediately after removal from the field.

Figure 9. St. Augustinegrass frozen at 26 F for 12 hours after 48 hours of 80 F temperature.

Figure 10. St. Augustinegrass frozen at 26 F for 12 hours after 72 hours of 80 F temperature.

Figure 11. Variegation on St. Augustinegrass resulting from artificial freezing.

out of the 165 pots. The variegation first appeared on leaves which had not been killed by the freezing and appeared later on new leaves. The effect was unusual in that the yellow stripes were perpendicular to the length of the leaves instead of parallel. Some new leaves emerged completely chlorotic and soon died. Also, new leaves on which the tip was yellow soon died. If the new leaf had a green tip, it was apparently able to carry on photosynthesis and survive. These plants remained variegated for 6 weeks, then the variegation disappeared completely and the plants resumed normal growth. Freezing seems to have destroyed the chlorophyll and the production of chlorophyll in certain parts of the leaf and new buds present at the time of freezing. After 6 weeks the plants were producing shoots from new buds which had not been present during freezing, and the visible freezing damage in old leaves disappeared.

Plants were taken from the field at later times in an attempt to duplicate this variegation but the attempts were unsuccessful. A variety of compounds were applied to the pots in an effort to determine what process had been blocked in the production of chlorophyll but after the 6-week period all plants lost their variegation, treated or untreated.

CHAPTER V

DISCUSSION

These results show that the fertility level of a plant has an effect on winter hardiness. However, fertility did not change the temperatures point required for killing more than 2-5° in warm season grasses under greenhouse conditions. In this study, fertility had an effect on winter killing at 26-38 F, but all treatments were killed at 24 F. Much emphasis has been placed on high N fertilizer and reduced cold hardiness. This study did not show N alone to have a major influence on cold hardening. N seems to have an indirect effect by influencing the uptake of K. As the tissue level of N increases, K content also increases if sufficient soil K is available. This increase in K may offset the effect of N on cold hardiness.

Two of the main ideas (9,22) connected with nutrition and cold hardiness are that high N increases winterkill and high K decreases winterkill. With the tissue level of K increasing with the N level, these would seem to be conflicting forces, or else different groups of plants react differently in cold hardening. Warm season grasses may have a slightly different process for cold hardiness than cool season grasses. Carroll (7) working with cool season grass showed that increased sugar content increased hardiness, but this is not the sole reason for cold hardiness. The main carbohydrate forms in cool season grasses are the more simple soluble sugars, whereas in warm season grasses, starch is the main carbohydrate. Also, many of the warm season grasses have rhizomes and runners where carbohydrates can be stored while in many cool season grasses the various carbohydrate forms are stored in the crown. A carbohydrate reserve is necessary for a plant to overwinter and N is necessary for photosynthesis which produces carbohydrates for the plant. In addition, K presumably may function as a catalyst for production of carbohydrates. This may be the reason that high N did not increase winterkill markedly and one of the reasons that K decreased winterkill. This date is in agreement with Adams (1) where he showed that if the K level is increased with the N level, the winter killing in Coastal bermudagrass is decreased.

The P/K ratio was closely related to the percentage of cover except for the low N treatments. Possibly these low N treatments did not follow this trend since the K level may not decrease at the same rate as the N level. The reverse may not be true and the low N levels are evidently insufficient to exert a strong influence on uptake of K. N level also had an influence on the uptake of P. Where P was applied with N, the P tissue content increased as the N level increased. The plants had definite deficiency symptoms present when frozen but the symptoms would not necessarily have to be present for nutrition to have an effect on cold hardiness.

There seems to be a close connection between the ratio of P/K and cold hardiness (Fig. 4). P seems to have a detrimental effect on cold hardiness but when K is applied, it appears to counteract the P effect. With a high P/K ratio there was considerable damage;

whereas, a low ratio produced plants with greater cold tolerance. Jung (12) also showed this to be true in alfalfa. The higher the N level the greater was the effect of the P/K ratio. The high P effect may be caused by increasing the high energy compounds such as ATP, and affecting the form of sugars produced from photosynthesis. Levitt (22) states that increased sugar increases cold hardiness and that the increased sugar comes from two sources: photosynthesis or the conversion of starch to sugar. With increased P the conversion of starch to sugar may not take place due to excess P forcing the reaction from sugar to starch, thereby reducing cold hardiness. Davis (8) has shown that there is a change in the soluble protein fraction during cold hardiness. The P/K ratio may also have an effect on these protein changes.

Late fall fertilization of Tifgreen bermudagrass and St. Augustinegrass did not produce complete winter killing in the College Station area. It has been generally accepted that late fall applications of N would increase winterkill. This may have resulted from a misinterpretation of data from cool season grasses when applied to warm season grasses. With the cool season grasses, peak growth periods may be expected in cooler months thus presenting a green attractive color and a good appearance except during periods of severe low temperatures. In contrast, the topgrowth of warm season grasses is expected to be desiccated and turned brown. If weather conditions are not suitable for growth, the grass will go dormant until spring. In this area, the temperature does not usually remain low enough to produce complete dormancy. After a hard freeze, the grass will be in an intermediate state and upon the advent of mild temperatures, immediate regrowth will be initiated from the rhizomes or stolons.

Where N was applied in the fall the plant probably had a better food reserve which caused it to begin regrowth as soon as the temperature warmed up. Plots not receiving N fertilizer after September had a very slow regrowth which was probably due to their reserves being low. There was little difference between the two types of grasses. St. Augustinegrass has a faster response and regrowth following a cold spell than Tifgreen bermudagrass. Neither of the two grasses showed any winterkill in the spring.

The only plots showing a high P/K ratio in each variety were plots where P fertilizer alone was applied. However, these plots showed no permanent winter damage in the field. An explanation for this may be the fact that nutrition appears to have an effect only within a limited temperature range for warm season grasses, possibly 2-5°. Apparently the temperature was not low enough for nutrition to be effective. For nutrition to become a major factor the temperature may have to approach the killing point. The killing point may differ depending upon several factors of hardiness, length of freezing, amount of moisture, etc.

As may be noted in Figure 4, St. Augustinegrass was exposed to sufficient cold temperatures to harden it before it was removed from the field and placed in the greenhouse. The results show that

St. Augustinegrass loses the majority of its cold hardiness between 48 and 72 hours. There were 3 treatments which lost their hardiness after 72 hours. If the interval had been slightly greater than 24 hours, the intermediate time might have included all treatments. The treatments had little effect on rate of loss of hardiness indicating that fertility may not be the major factor in controlling winter hardiness in St. Augustinegrass. Thus, treatments may have an effect by increasing or decreasing the time required for plant to winterkill but the effect appears to amount to less than 24 hours. To more nearly ascertain this would require intervals less than the 24-hour period used in these trials.

This rate of loss of cold hardiness plays an important role in winter damage in the South. The weather is variable, changing from freezing one day to warm the next. After 2-3 days of warm temperatures, warm season grasses will have lost their cold hardiness and become susceptible to killing by a quick freeze. If the temperature gradually lowers, however, the grass will reharden and be better able to survive. Rate of loss of cold hardiness appears to be a primary result of temperature and not treatments.

The same experiment was conducted on Tifgreen bermudagrass as on St. Augustinegrass, but Tifgreen did not have the length of cold weather exposure prior to removal as did St. Augustinegrass. The variable results obtained may be explained by the fact that the grass only had approximately 3 days of cold weather for hardening before removal. The percentage of cover definitely decreased during the 0-96 hour dehardening interval with the major decrease occurring between 24 and 72 hours. There was also variation between the replications. Since the grass did not follow a definite pattern it appears that the plugs were in various stages of hardening due to the short length of cold temperature prior to removal from the field. The rate at which plants lose cold hardiness is roughly proportional to the degree of cold hardiness attained (24), and this is suggested as the main reason for variability of the results. Also, the soil under Tifgreen bermudagrass varied. This was grown on a golf green in which the soil was not thoroughly mixed and which resulted in different soil conditions. These conditions could have also affected the temperature range at which the break in loss of cold hardiness occurs. It does seem to show, though, that variable winter temperature is the major factor in loss of cold hardiness.

CHAPTER VI

CONCLUSIONS

This study was conducted to study the effects of N, P, and K fertilizers and dehardening cycles on the winter killing of two warm season turfgrasses, St. Augustinegrass and Tifgreen bermudagrass. Part of this work was conducted in the field under natural conditions and part in the greenhouse under more controlled conditions.

Tifgreen bermudagrass grown under different nutrient levels, and artificially frozen in a growth chamber showed that nutrient level has an effect on winter hardiness. However, the nutrient treatments do not seem to affect the temperature point required for killing more than 2-5 degrees. The P/K ratio within the tissue appears to have a definite relationship to cold hardiness. A high P/K ratio resulted in the greatest freezing damage, while a low ratio showed less damage. High tissue N levels did not have a large effect on decreasing cold hardiness as has been reported in the literature. There appears to be a definite relationship between the tissue level of N-K, and the level of N-P. As N level increases, the K and P levels do also. P does not seem to increase as rapidly as K with increased N and this may be one reason that N did not show a large increase in winterkill.

Late fertilization of these two grasses in the field had limited effect on winter killing. Plots to which N was applied in November and December showed the greatest topkill after each freeze, but they were the first to resume growth when the temperature warmed up. In the College Station area, the late application of fertilizer appears to have little effect on winter killing. With late application of N fertilizer, the grass stays green longer in the fall and resumes green growth during each warm period within the winter. In the spring the plots receiving late fall applications of N fertilizer were the first to resume growth and provide a dense cover.

St. Augustinegrass lost the majority of its cold hardiness between 48 and 72 hours. According to Laude (20) the rate at which plants lose cold resistance is related to the degree of hardiness. The greater the cold hardiness of the plant the longer period of warm temperature required to lose cold hardiness. Tifgreen bermudagrass which had little time to winter harden before sampling showed a wide variation in loss of hardiness. In the South where there is not sufficient cold temperature to keep the grass dormant throughout the winter, part of the winter damage may result from loss of cold hardiness by intermittent warm temperatures.

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VITA

Sim A. Reeves, Jr. was born at Alpine, Texas, August 30, 1934, to Mr. and Mrs. Sim A. Reeves.

He was married April 11, 1952, to the former Ruth Ann Olson and they have three children, Vicki, age 16, Trey, age 15, and Roger, age 9.

He entered the first grade at Ft. Stockton, Texas, and graduated from Ft. Stockton High School in 1952. He entered Texas A&M College in the fall of 1957 and graduated with a B.S. in Agronomy, January, 1961. He returned to Texas A&M University and entered graduate School in January, 1967, and currently is receiving a NSF fellowship while working toward a Ph.D. degree.

In 1951 Sim bought an irrigated farm with proceeds from 4-H calves. He farmed 640 acres from 1951-1957 at which time he entered college. After graduation in 1961, he purchased a second farm and returned to Ft. Stockton to farm. During this time he was a member of the First Baptist Church, served as a trustee for the Ft. Stockton Independent School District, and belonged to the Lions club.

The typist for this thesis was Mrs. Inga Lovelace.