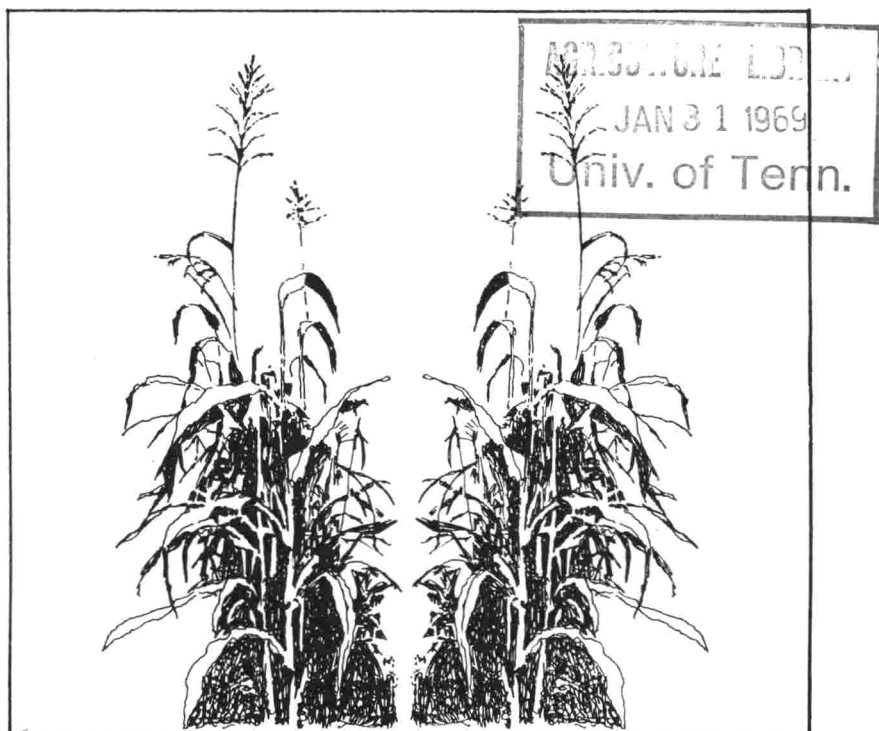


Bulletin 445

August 1968

Hydrocyanic Acid Potential of Sorghum Plants Grown in Tennessee

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SUMMARY

HYDROCYANIC acid poisoning of cattle following consumption of sorghum has occurred in several counties of the State in recent years. Studies of the hydrocyanic acid potential (HCN-p) of sorghum plants grown in Tennessee were conducted from 1963 to 1968. The results are summarized as follows:

The level of HCN-p of Suhi-1 leaves decreased progressively from the whorl to the basal leaves; however, no consistent differences were found among Piper leaves. The HCN-p of nodes was higher than that of internodes. The HCN-p of nodes tended to decrease progressively from the top to the base of the plant.

Throughout these studies Piper was low in HCN-p, Greenleaf was intermediate, and Suhi-1 was high, when sampled at comparable stages of growth. The sudangrass types were lower in HCN-p than the sorghum-sudangrass hybrids. Differences in HCN-p were found among the sorghum-sudangrass hybrids. The level of HCN-p of varieties varied with years.

In general, the concentration of HCN-p of above-ground plant parts decreased as the plants became taller and more mature. Plants of the 20-3, 30-8, and EB-4 cutting management tended to be high, intermediate, and low in HCN-p, respectively. The HCN-p level of the roots reached a maximum within 3 weeks after emergence and then generally decreased until maturity.

In general, the HCN-p level increased with increases in rates of applied nitrogen and decreased with increases in rates of applied phosphorus. The HCN-p of plants was not affected by the rates of applied potassium.

The effect of frost on HCN-p varied with severity of the freeze. Light frost which did not kill the plants resulted in an increase in HCN-p which was most evident from 1 to 6 days after frost. This increase varied with stage of growth, variety, and year. Heavy freezes which resulted in death of plants caused rapid release and decrease of HCN-p.

If 600 ppm (800 ppm for samples in which the results of two readings were summed) on a dry weight basis is considered to be the maximum safe level of HCN-p, all above-ground parts of the sudangrasses analyzed during these studies would have been safe for livestock utilization. The HCN-p of Suhi-1 exceeded this safe range several times during these studies. In the variety comparison study, all the varieties were considered safe in 1964. In 1965 and 1966, some of the sorghum-sudangrass hybrids exceeded the safe range.

ACKNOWLEDGMENTS

THANKS are expressed to L. N. Skold, Professor of Agronomy, for his suggestions during the preparation of this bulletin. Thanks are expressed to Dr. Henry A. Fribourg and Dr. John R. Reynolds of the Department of Agronomy for their assistance during the course of these studies. Several students have contributed substantially to these studies through Special Problems in Agronomy. Thanks are expressed to this group which includes: Steven Beckham, Richard Chapman, William Everette, Lynn Murray, and Emerson Shipe. Special thanks are extended to the Tennessee County Agricultural Extension Agents for their help in collecting data on the frequency of HCN poisoning.

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INTRODUCTION

ANNUAL sorghums are an important source of forage in Tennessee, especially from mid-summer until frost. Their heat and drought tolerance enables them to grow during this period when cool season forage crops are not very productive. Through the use of sorghums, it is possible to fill the summer gap in cool season forage production with high yields of nutritious forage. Interest in forage sorghums has increased as a result of the development of higher yielding and disease-resistant varieties and better management practices. They are suitable for use as pasture, hay, or silage.

The *Sorghum* genus contains several species of economic importance (23) including: *S. halepense* (L) Pers. (johnsongrass), *S. vulgare* Pers. (grain, sweet, and some forage types), and *S. sudanense* (Piper) Staph. (sudangrass). All are believed to contain dhuririn, a precursor of hydrogen cyanide (10). Dhuririn is a glucoside which occurs in root, stem, and leaf tissues. Under certain conditions it decomposes and hydrogen cyanide, a poisonous gas, evolves from the tissue (28).

Hydrogen cyanide (HCN) is one of the most toxic poisons found in nature (10). When ruminant animals consume feed containing the precursor of HCN, the HCN is liberated in the stomach, then absorbed by the blood and carried to body tissues where it interferes with oxygen utilization. If enough is absorbed the animal

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dies. The poison acts with extreme rapidity resulting in respiratory paralysis. Symptoms from lighter doses include: increased respiration, irregular pulse, frothing at the mouth, and staggering. HCN poisoning of livestock has been referred to as prussic acid-, hydrocyanic acid-, hydrogen cyanide-, and cyanide-poisoning.

HCN poisoning of cattle is believed to be less frequent in the South than in other parts of the United States. Information obtained from a questionnaire sent to County Agricultural Agents indicates that HCN poisoning has occurred in at least 18 counties in Tennessee (Figure 1). In all cases reported, cattle died after consuming fresh sorghum forage—usually after a period of drought or frost—in a few cases after the first grazing of the summer. A veterinarian's diagnosis was given for 10 of the 18 counties from which HCN poisoning was reported.

The fact that sorghum plants are sometimes toxic to animals has been known since the 1800's. Dhurrin was discovered in 1902 (14, 34). Subsequent work has shown that the amount of dhurrin in sorghum plants is affected by variety, stage of maturity, and environment.

The objectives of these studies were to determine: 1) the amount and distribution of HCN potential (HCN-p) in sorghum plants, 2) the relative amounts of HCN-p in plants of different varieties, 3) the effect of stage of growth on HCN-p, and 4) the effect of certain environmental factors on HCN-p of sorghum plants.

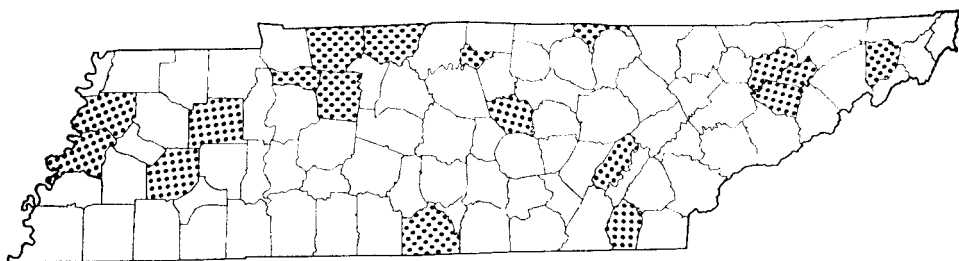


Figure 1. Counties where HCN poisoning from sorghums has been reported in recent years.

MATERIALS AND METHODS

These studies were conducted on sudangrass and sorghum-sudangrass hybrids at Knoxville from 1963 to 1968. Specific conditions for the various experiments will be given when the individual experiments are discussed. Some conditions were uniform for all field experiments. Seeds of all varieties were drilled at the rate of 25 pounds per acre in rows spaced 3 feet apart. Except for two experiments in which fertilizer treatments were studied, phosphorus and potassium were applied at the rate of 60 pounds per acre of P_2O_5 and 60 pounds per acre of K_2O or according to soil test results. Unless otherwise specified, nitrogen was applied at the rate of 60 pounds per acre at the time of planting and 60 pounds per acre after the July harvest.

Several sorghum varieties were compared for HCN-p; however, Greenleaf and Piper Sudangrass and Suhi-1, a sorghum-sudangrass hybrid, were used in most of the studies.

The laboratory procedure used in estimating HCN-p¹ was a modification of the procedure as presented by Anderson². In 1964 it was observed that the reaction of HCN with the picrate reagent continued beyond the recommended 24-hour incubation period. A study of the rate of release of HCN in the sodium picrate assay of sorghum plants was conducted (See Appendix). Based upon these results, two 24-hour incubation periods were used in all work conducted after the summer of 1964. Some of the results are reported on a fresh weight basis; others are reported on an oven-dry weight basis.

Since all the assumptions of the analysis of variance were not met by these data, this procedure was not used to determine whether differences were significant. Confidence intervals at the .05 level of probability were calculated for sample means. If the confidence intervals for two means had no common values, the means were considered to be significantly different.

¹ HCN gas is not normally found in plants. It is the potential for production of HCN when conditions are favorable for decomposition of dhurrin that is being estimated.

² Anderson, Laurens. 1960. Precise estimation of hydrocyanic acid in sudangrass and sorghum. Unpublished mimeograph, University of Wisconsin, Department of Biochemistry, College of Agriculture and Agricultural Experiment Station.

REVIEW OF LITERATURE, EXPERIMENTS AND RESULTS

HCN-p of Plant Parts

Literature Review—Martin, Couch, and Briese (29) found that HCN-p was higher in leaves than in culms of sorghum plants at the boot stage. HCN-p was greater in upper than in lower leaves and was greater in the basal half than in the tip half of the leaf blade. HCN-p of the internodes decreased progressively from the apex to the base of the plant. Tillers were higher than the main culm in HCN-p. Wolf and Washko (41) ranked plant parts in order of decreasing HCN-p as follows: leaf blades (minus midribs), stems, leaf sheaths, and midribs. Benson, Gray, and Fribourg (3) reported positive correlations between HCN-p of leaf tips and whole plants.

Table 1. HCN-p (ppm dry weight) of tips of various leaves of Piper plants subjected to three cutting managements, Knoxville, 1963 ¹

Harvest date	Whorl	First ² leaf	Third leaf	Fifth leaf
	ppm	ppm	ppm	ppm
20-3 cutting management				
July 9	28±24 ³	120±70	217±105	215±111
July 25	9±13	36±40	49±35	
August 7	117±62	105±62		
August 20	56±39	42±37		
September 5	20±25	19±22	4±8	
September 30	17±25	21±23		
Average	41.2±13.9	57.2±9.4	90.0±42.8	215.0±111
30-8 cutting management				
July 12	6±8	32±30	41±29	99±52
July 23	3±5	6±7	33±27	
August 5	22±7	57±30		
August 23	19±22	13±12		
September 13	10±14	11±16		
Average	12.0±5.2	23.8±9.7	37.0±21.8	99.0±52
EB-4 cutting management				
July 29		10±19	32±51	45±53
August 29		8±12	30±4	
Average		9.0±10.1	31.0±23.6	45.0±49.7
Grand average	27.9±6.8	36.9±9.6	58.0±24.0	119.7±43.0

¹ Planted June 10 on a Lindside loam soil.

² The first leaf was the uppermost leaf which had developed a collar.

³ $\bar{x} \pm t_{(n-1)} S_{\bar{x}}$ (degrees of freedom = 14 for most harvest dates).

Experiments—In 1963 HCN-p was determined for various leaves of Piper, a sudangrass variety, and Suhi-1, a sorghum-sudangrass hybrid, subjected to three cutting managements. In the 20-3 management, the plants grew to a height of 20 inches before they were cut at a stubble height of 3 inches. In the 30-8 management, the plants were cut at 8 inches when they reached a height of 30 inches. In the EB-4 management, the plants were cut at a height of 4 inches when they reached the early bloom stage. Forage harvests were made throughout the season as often as plants reached the proper growth stage.

For HCN-p analysis, leaf tips were sampled before cutting from a whorl leaf, the first leaf (uppermost one with a collar), the third, and the fifth, moving downward. Fifteen plants of each variety and management treatment were sampled and each leaf analyzed separately.

For Piper, HCN-p appeared to increase progressively from the whorl to the basal leaves of the plants (Table 4); however, these differences were not significant at the .05 level of probability. Although leaves in the fifth position were available only in the first harvest of the 20-3 and 30-8 cutting managements, their HCN-p did not differ significantly from that of leaves in the third position.

The opposite was true for Suhi-1. There was a significant decrease in HCN-p from the whorl downward to the fifth leaf (Table 2). Some slight inconsistencies in this trend were associated with cutting management. For example, average HCN-p estimates of the first and third leaves were about equal in the 20-3 management and the whorl had less HCN-p than the first leaf in the 30-8 management. These findings for Suhi-1 support those of Martin *et al.* (29).

In 1964, the distribution of HCN-p in roots, leaves, stems, and heads of Greenleaf and Piper sudangrass and Suhi-1 plants was studied. Appropriate plant parts were sampled from 10 plants of each variety at the early seed stage of maturity and each sample was analyzed separately. No HCN-p was detected in certain plant parts of Greenleaf and Piper which are known to contain HCN-p at younger stages of growth (Table 3). In general, the parts ranked in order of decreasing HCN-p as follows: roots, nodes, internodes, and leaves and heads. The above-ground parts of Suhi-1 plants tended to be higher in HCN-p than corresponding parts of Greenleaf and Piper plants. A reverse trend was found in the roots but the differences were not significant.

Table 2. HCN-p (ppm dry weight) of tips of various leaves of Suhi-1 plants subjected to three cutting managements, Knoxville, 1963 ¹

Harvest date	Whorl	First leaf	Third leaf	Fifth leaf
	ppm	ppm	ppm	ppm
20-3 cutting management				
July 11	588 ± 111 ³	431 ± 92	456 ± 122	355 ± 52
July 23	1152 ± 242	550 ± 101	816 ± 316	
August 7	735 ± 222	596 ± 102	720 ± 147	
August 23	742 ± 172	511 ± 81	308 ± 87	
September 10	831 ± 182	748 ± 110	578 ± 200	
Average	809.6 ± 86.9	567.2 ± 45.5	575.6 ± 89.6	355.0 ± 52
30-8 cutting management				
July 15	352 ± 88	266 ± 72	193 ± 53	112 ± 70
July 24	396 ± 76	763 ± 117	695 ± 101	
August 5	371 ± 54	406 ± 114	343 ± 95	
August 20	330 ± 23	601 ± 100	495 ± 94	
September 5	705 ± 76	575 ± 126	252 ± 85	
September 30	660 ± 158	396 ± 112	158 ± 82	
Average	469.0 ± 52.5	501.2 ± 56.1	356.0 ± 47.2	112.0 ± 70
EB-4 cutting management				
July 31		430 ± 173	222 ± 25	174 ± 85
September 10		442 ± 107	229 ± 76	16 ± 18
Average		436.0 ± 30.3	225.5 ± 35.3	95.0 ± 48.2
Grand average	623.8 ± 54.9	516.5 ± 41.8	420.4 ± 44.7	164.2 ± 40.4

¹ Planted June 10 on a Lindside loam soil.

² The first leaf was the uppermost leaf which had developed a collar.

³ $\bar{x} \pm t_{(0.05)} S_{\bar{x}}$ (degrees of freedom = 14 for most harvest dates).

As was found in 1963, HCN-p of Suhi-1 leaves decreased from the top to the base of the plant. HCN-p of Piper and Greenleaf leaves was low with no significant differences among leaves within a variety. In general, HCN-p of the nodes of all varieties decreased progressively from the top to the base of the plant. The same was true for the internodes of Suhi-1 while internodes of Greenleaf and Piper were low in HCN-p and there was no apparent trend associated with position on the plant.

Although the plant parts used in these studies were not exactly the same as those used by other workers, the results are generally in agreement. Distribution of HCN-p in plant parts may not be the same in all varieties. Above-ground parts of Suhi-1 were higher than similar parts of Greenleaf and Piper, but HCN-p of roots of Suhi-1 were not significantly different from those of Greenleaf and Piper.

Table 3. Distribution of HCN-p (ppm dry weight) in mature plants of Green-leaf, Piper, and Suhi-1 grown at Knoxville in 1964 ¹

Plant part	Greenleaf	Piper	Suhi-1
	ppm	ppm	ppm
Heads	0 ^a	1±1	22±17
Leaves			
First—top			
blade tip	14±27	0	150±91
blade base	2±4	0	169±113
sheath	0	0	59±63
Third—from top			
blade tip	15±24	0	69±37
blade base	2±4	0	66±36
sheath	27±34	1±2	18±16
Fifth—from top			
blade tip	0	0	16±18
blade base	2±4	0	33±34
sheath	14±28	1±1	17±31
Seventh—from top			
blade tip	35±78	1±3	20±39
blade base	0	2±5	28±59
sheath	8±15	2±4	14±25
Average			
blade tip	16±19	0	64±29
blade base	2±2	0	74±36
sheath	12±10	1±1	27±17
Leaf average	9.9±7.3	1.8±0.6	52.9±16.3
Nodes			
First—top	75±68	83±57	514±303
Third—from top	54±34	9±20	258±138
Fifth—from top	15±11	27±14	132±89
Seventh—from top	13±9	21±14	94±58
Node average	39.2±18.6	30.2±16.5	249.5±91.9
Internodes			
First—top	7±11	1±3	189±95
Third—from top	0	1±1	80±56
Fifth—from top	0	4±6	28±39

Table 3. continued

Plant part	Greenleaf	Piper	Suhi-1
	ppm	ppm	ppm
Seventh—from top	9±15	7±11	16±24
Internode average	7.0±4.2	3.2±2.9	78.5±33.8
Roots	150±41	139±15	95±27

¹ Planted June 10 and sampled in mid-August at the early seed stage.

² Each value is an average of 10 plants.

HCN-p of Sorghum Varieties

Literature Review—William and West (40) in 1915 reported varietal differences in HCN-p. Sudangrasses usually contain less HCN-p than grain sorghums (21) and sorghum x sudangrass hybrids (7, 20, 26, 33). Benson (2) reported that sudangrasses, sorghum x sudangrass hybrids, and grain type sorghums were low, intermediate, and high in HCN-p, respectively. Harrington (20) found that the HCN-p of 6 sorghum x sudangrass hybrids ranged from 3 to 9 times higher than that of Piper sudangrass. Reported evidence (2, 26, 33) indicates that there is variation in HCN-p among sorghum x sudangrass hybrids. Sudangrass varieties such as Cumberland (19, 37) and Piper (21, 33) were developed for low HCN-p.

Experiments—The previously discussed data on the distribution of HCN-p in plant parts (Tables 1, 2, 3) indicate that HCN-p of the sudangrasses—Greenleaf and Piper—was lower than that of Suhi-1, a sorghum x sudangrass hybrid. Greenleaf was usually higher than Piper in HCN-p. This relative ranking of Piper, Greenleaf, and Suhi-1 for HCN-p was found throughout these studies.

HCN-p was estimated for several diverse varieties ³ during the 3-year period from 1964 through 1966 (Table 12, Appendix). HCN-p estimates were made in August using aftermath plants that were about 30 inches tall. For each plant, the uppermost leaf which had a formed collar was analyzed for HCN-p. Some of the sudangrasses such as Cumberland, Greenleaf, Piper, and the Tru-

³ For other performance characteristics of these varieties, see Tennessee Agricultural Experiment Station Bulletins 373, 396, 413, and 436.

dans were generally lowest of the varieties for HCN-p. There was considerable variation among HCN-p estimates for the sorghum x sudangrass hybrids. HCN-p estimates were lower in 1964 than in either 1965 or 1966. As was mentioned previously—beginning after the summer of 1964—two 24-hour incubation periods were used for each sample and the results were added together. This would partly account for the lower estimates in 1964 than in 1965 or 1966. However, HCN-p estimates do vary with different years. Such variation is believed to reflect differences in growing conditions and stage of growth at the time the plants were sampled for HCN-p.

Effect of Stage of Growth on HCN-p

Literature Review—Several workers have found that HCN-p decreases as plant height and maturity increase (4, 9, 17, 20, 25, 33, 35). Harrington (20) reported that plant height affected HCN-p of sorghum x sudangrass hybrids more than that of sudangrasses. Hybrid plants which were 2 feet or more high had less than one-half as much HCN-p (ppm) as plants which were about 1 foot high. HCN-p of young Piper sudangrass plants was low and did not change appreciably as plant height increased from 1 to 2 feet.

Experiments—A study was conducted in 1964 to learn the effect of stage of maturity on HCN-p of different parts of plants of Greenleaf, Piper, and Suhi-1. Random plants were analyzed for HCN-p at weekly intervals until mature. Data for various plant parts of increasing age are presented graphically in Figures 2, 3, and 4.

HCN-p of leaves of Greenleaf and Piper decreased rather consistently as the plants grew older. The same trend occurred with Suhi-1 except for an increase between the fifth and seventh weeks. In stems the decrease in HCN-p associated with increase in age of plants was consistent except for the last week for Suhi-1 in which there was a slight increase. For all varieties, HCN-p in roots of 1-week-old seedlings was about equal to or lower than that in the leaves. However, during the second and third weeks, HCN-p of the roots increased to a level much higher than that measured for any other plant part. Following this peak, HCN-p of roots generally decreased as the plants became older. HCN-p of plant heads was low for all varieties and did not change greatly during the short period of observation.

HCN-p ppm

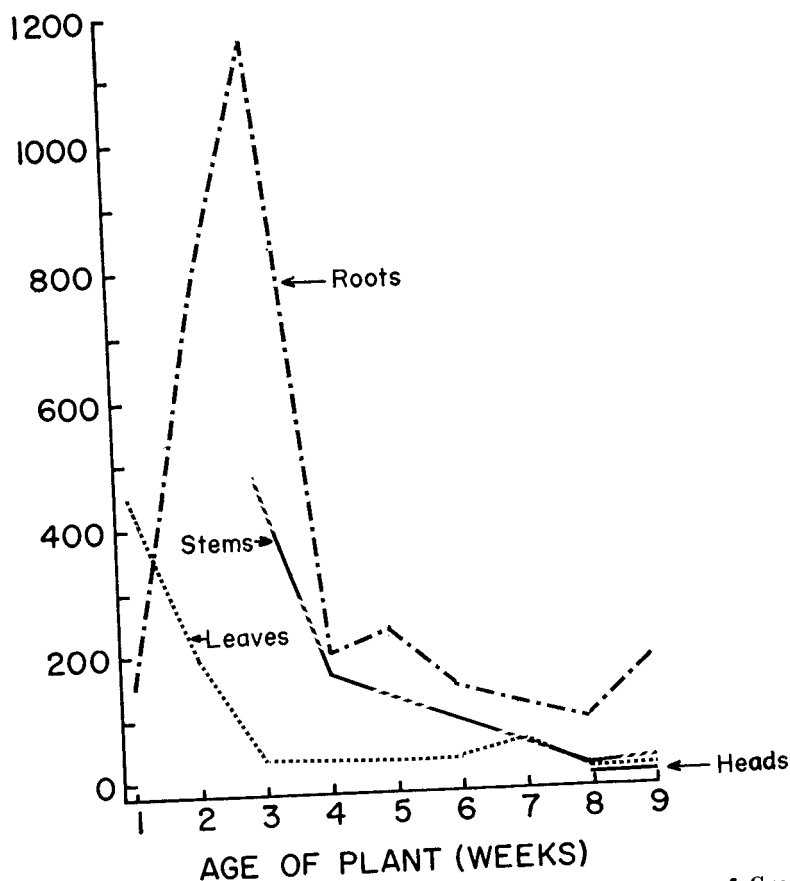


Figure 2. HCN-p (dry weight) of various parts of plants of Greenleaf in 1964.

The data on HCN-p of plant parts (Tables 1 and 2) indicated that HCN-p of leaves of Piper and Suhi-1 decreased as the plants became taller. Leaves of the plants in the 20-3, 30-8, and EB-4 cutting managements ranked high, intermediate, and low in HCN-p, respectively. HCN-p of whole plants of the 20-3, 30-8, and EB-4 cuttings were also high, intermediate, and low, respectively (Figures 5 and 6).

Effect of Growth Period on HCN-p

Literature Review—Much of the reported work has shown that HCN-p was higher for the first harvest than for aftermath harvests

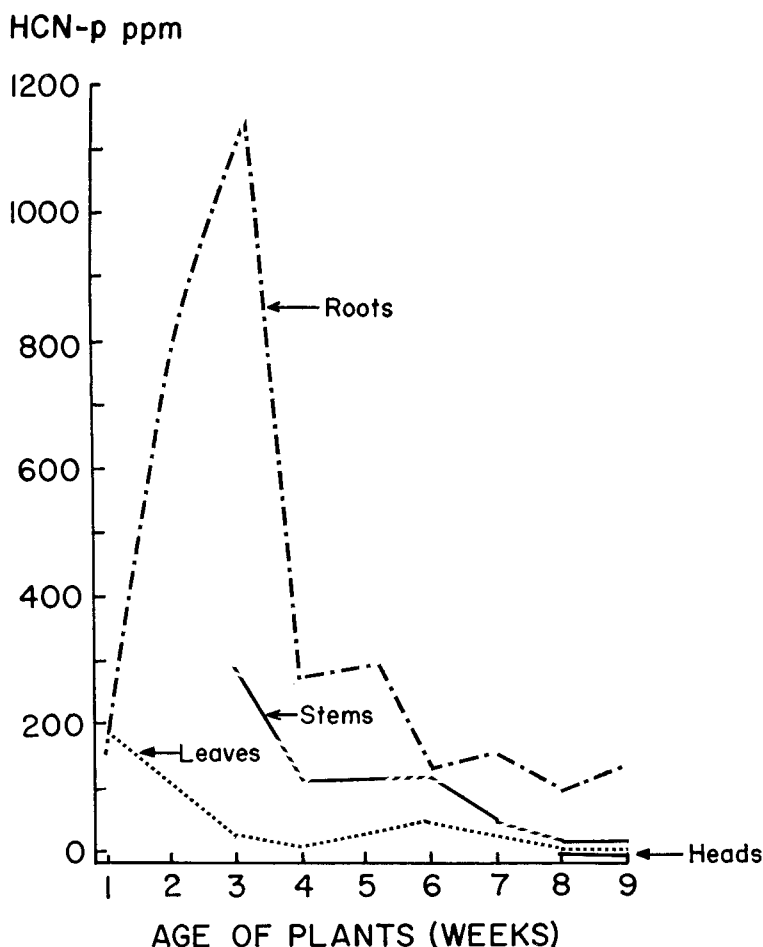


Figure 3. HCN-p (dry weight) of various parts of plants of Piper in 1964.

(10, 6, 13, 32). Hogg and Ahlgren (24) found the average HCN-p of plants in the seedling stage to be about one-half of that of second growth plants. Harrington (20) studied HCN-p of Piper, Trudan I, and six sorghum x sudangrass hybrids through three growth periods. Decreasing order of HCN-p for the three growth periods was as follows: Piper—1, 3, 2, Trudan I—3, 1, 2, sorghum x sudangrass hybrids—3, 1, 2. He concluded that growing conditions, particularly rainfall, influenced the amount of HCN-p of plants at a given growth period.

Experiments—HCN-p data were obtained in 1963 from Piper and Suhi-1 plants subjected to three cutting managements (Figures

HCN-p ppm

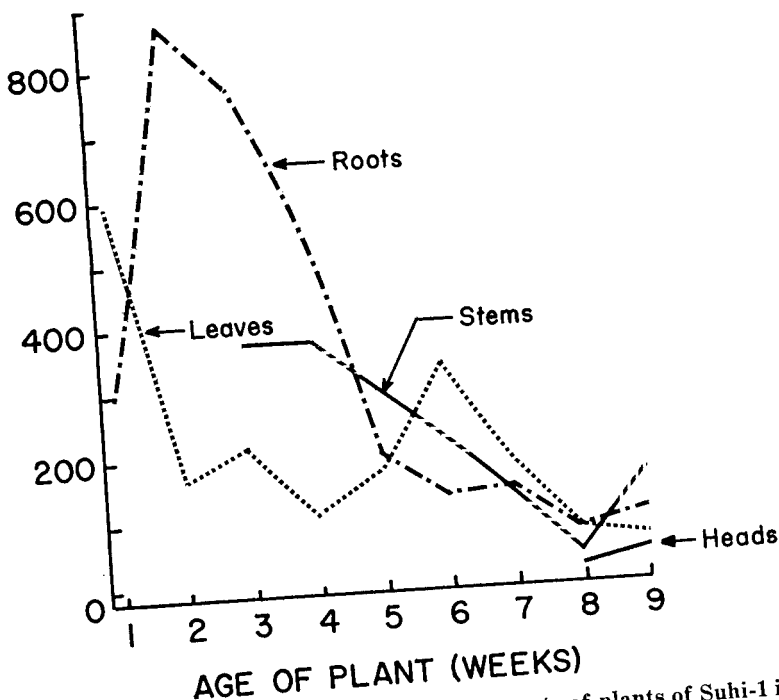


Figure 4. HCN-p (dry weight) of various parts of plants of Suhi-1 in 1964. 5 and 6). Plants were harvested each time they reached a prescribed stage during the growing season. For the plants harvested at 20 inches, the highest HCN-p was in the first harvest of Piper and the second harvest of Suhi-1. For the plants harvested at 30 inches, the highest HCN-p was in the third harvest of Piper and the second and fourth of Suhi-1. For the plants which were harvested at the early bloom stage, the first harvest was higher in HCN-p than the second in both varieties but lower than for any other management. HCN-p was lower at the end than at the beginning of the season for all the cutting managements, except for the 20-inch Suhi-1 plants.

In the 1966 study concerning the effect of nitrogen fertilization on HCN-p, plants of Greenleaf, Piper, and Suhi-1 were harvested each time they reached a height of 30 inches. Plants of the second harvest consistently had the highest HCN-p of any of the four harvests (Table 4). Plants of the fourth harvest consistently had the lowest HCN-p of any of the harvests. HCN-p data from Table 4

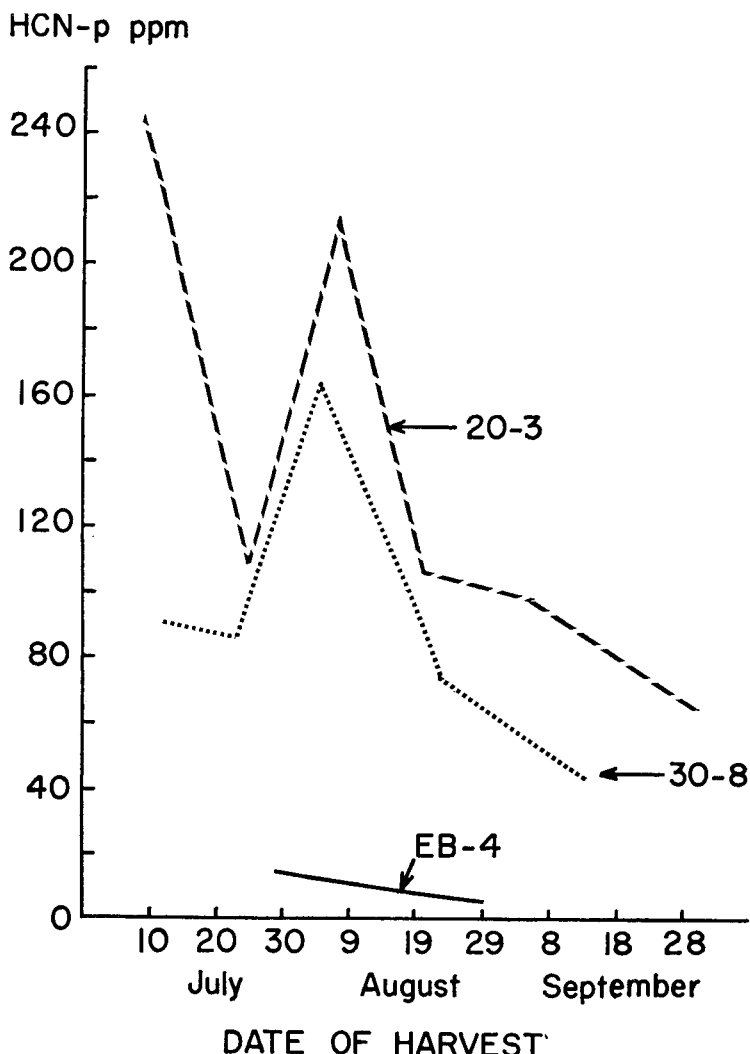


Figure 5. HCN-p (dry weight) of whole plants of Piper at different harvest dates for three cutting managements in 1963.

for treatments number 4 (120 pounds per acre of N at planting) and number 5 (30 pounds per acre of N at planting time plus 30 pounds per acre of N after the first, second, and third harvests), along with the rainfall distribution, are presented graphically in Figures 7 and 8. The amount and distribution of rainfall in the summer of 1966 were such that the plants did not show much evidence of moisture stress. The highest levels of HCN-p occurred during a period of intermediate rainfall.

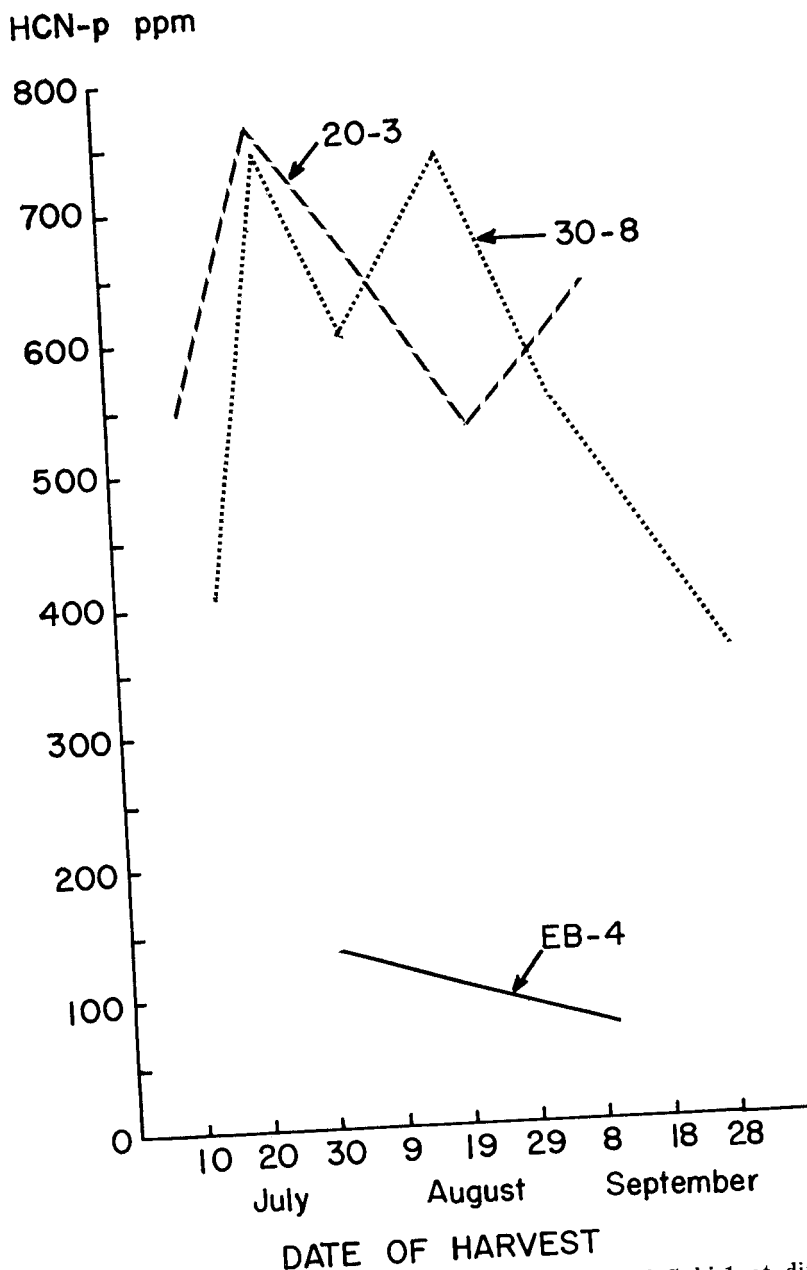


Figure 6. HCN-p (dry weight) of whole plants of Suhi-1 at different harvest dates for three cutting managements in 1963.

Table 4. HCN-p (ppm fresh weight) of whole plants of Greenleaf, Piper, and Suhi-1 when grown at different levels of nitrogen fertilization,¹ Knoxville, 1966

Nitrogen Treatment	Harvest		Greenleaf	Piper	Suhi-1
	Number	Date			
			ppm	ppm	ppm
1. None applied	1	7-6	75±15 ^a	43±7	132±12
	2	8-1	98±15	47±11	216±34
	3	8-26	77±3	17±1	153±5
	4	10-5	29±5	18±3	83±9
2. 60 lb/A at planting	1	7-6	73±6	48±7	159±15
	2	8-1	139±14	56±11	262±21
	3	8-26	94±6	19±2	172±6
	4	10-5	24±2	24±3	83±13
3. 30 lb/A at planting 30 lb/A after second harvest	1	7-5	114±10	56±9	200±16
	2	7-27	152±12	108±17	238±15
	3	8-16	119±11	59±16	214±20
	4	9-23	38±5	21±2	100±13
4. 120 lb/A at planting	1	6-30	144±14	77±13	232±15
	2	7-26	150±16	110±14	242±17
	3	8-15	129±8	72±7	225±17
	4	9-22	28±5	29±6	94±21
5. 30 lb/A at planting 30 lb/A after first, second, and third harvests.	1	7-5	133±16	56±10	176±22
	2	7-25	168±13	104±14	266±22
	3	8-15	122±17	50±8	226±17
	4	9-22	42±6	26±5	147±17

Table Summary

Variety	Average	Harvest	Average	Nitrogen treatment	Average
	ppm		ppm		ppm
Greenleaf	97±4	1	114±6	1	82±6
Piper	52±3	2	157±7	2	96±7
Suhi-1	181±5	3	117±6	3	118±7
		4	52±4	4	128±7
				5	126±8

¹ Planted May 12 on an Etowah silt loam soil. All plots received 60 pounds per acre of P₂O₅ and 60 pounds per acre of K₂O.

² $\bar{x} \pm t_{(n-1)} S_{\bar{x}}$. Each value is an average of 20 plants, 5 each from 4 replications.

Effect of Soil Fertilization on HCN-p

Literature Review—Franzke and Hume (16) and Nelson (30) reported that soil fertilization with nitrogen resulted in an increase in HCN-p. Boyd *et al.* (4) and Willaman and West (40) reported

HCN-p ppm

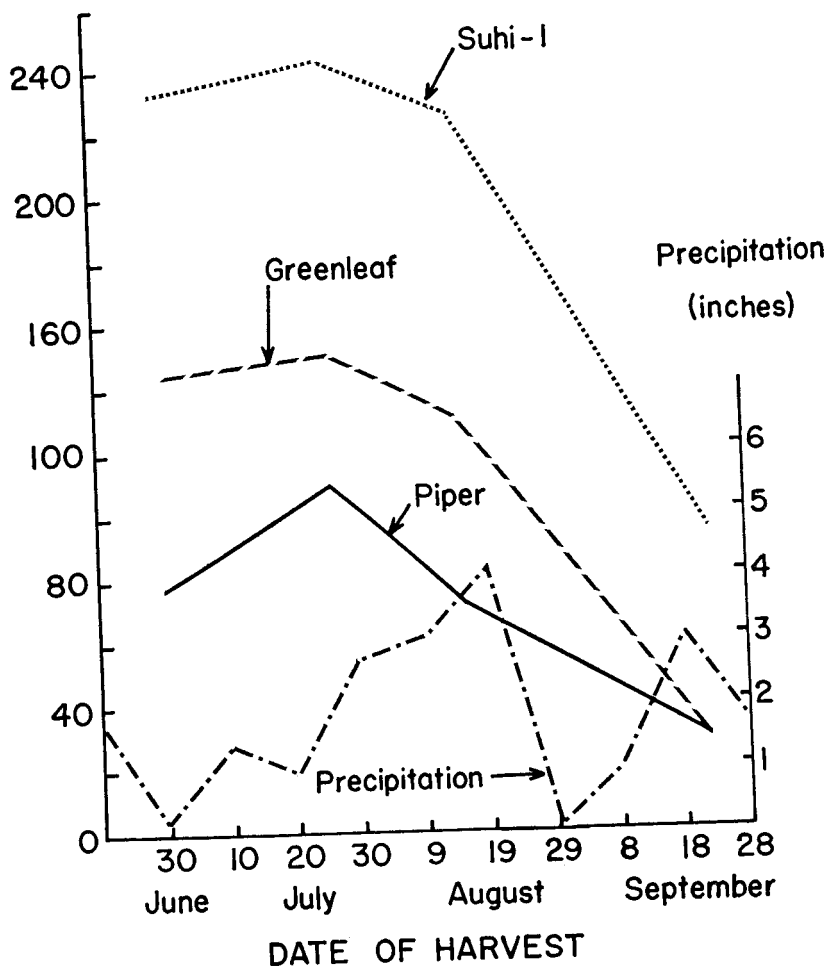


Figure 7. HCN-p (fresh weight) of whole plants of Greenleaf, Piper, and Suhi-1 and precipitation (10-day averages) in 1966. The plants received 120 pounds per acre of N at planting time.

that application of nitrogen to soils deficient in nitrogen resulted in an increase in HCN-p, whereas similar nitrogen treatments on soils well supplied with nitrogen had little or no effect on HCN-p. Patel and Wright (31) observed a positive relationship between levels of nitrogen in nutrient solutions and HCN-p of sudangrass plants. Fertilizations with phosphorus have been shown to result in

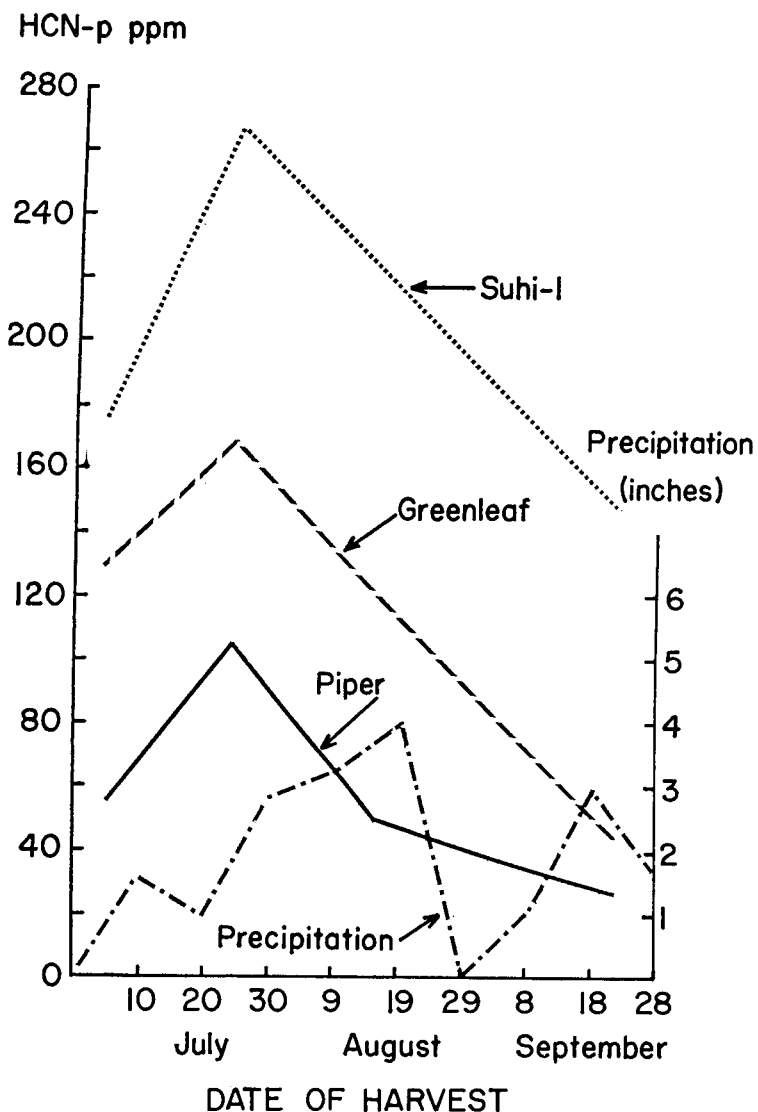


Figure 8. HCN-p (fresh weight) of whole plants of Greenleaf, Piper and Suhi-1 and precipitation (10-day average) in 1966. The plants received 120 pounds per acre of N— 30 at planting time, plus 30 pounds after the first, second, and third harvests.

a decrease in HCN-p (4, 25, 16). Patel and Wright (31) found that the increase in HCN-p resulting from nitrogen fertilization was reduced by a combined treatment of nitrogen and phosphorus.

Potassium fertilization has been found to have no consistent effect on HCN-p of sorghum plants.

Experiments—In 1966, Greenleaf, Piper, and Suhi-1 were grown on an Etowah silt loam soil. All plots received a uniform application of 60 pounds per acre of P_2O_5 and 60 pounds per acre of K_2O . The nitrogen treatments and HCN-p data are given in Table 4. HCN-p of the plants was positively associated with the amount of applied nitrogen. Plants which received no applied nitrogen had the lowest average HCN-p (82 ppm). Plants which received 60 pounds per acre of nitrogen at planting had an average HCN-p of 96 ppm, whereas, plants which received 30 pounds per acre of nitrogen at planting plus another 30 pounds per acre after the second harvest had an average HCN-p of 118 ppm. Plants receiving 120 pounds per acre of nitrogen at planting had an average HCN-p of 128 ppm. Plants which received a total of 120 pounds per acre of nitrogen in split applications—30 at planting, plus 30 after the first, second, and third harvests—had an average of 126 ppm. HCN-p of first harvest plants fertilized with 120 pounds per acre of nitrogen at planting was higher than that of plants fertilized with 0, 30, or 60 pounds per acre of nitrogen at planting. HCN-p of first harvest plants fertilized with 60 pounds per acre of nitrogen per acre was lower than that of plants receiving 30 pounds per acre of nitrogen at planting, but was higher than that of plants receiving no applied nitrogen.

The effect of varying nitrogen, phosphorus, and potassium was studied in the greenhouse during the summer of 1967. A Lindside loam soil which tested high in available phosphorus and medium in available potassium was used. The fertilizer treatments, varieties, and the HCN-p results are given in Table 5. The results are summarized in Table 6. HCN-p increased as the level of applied nitrogen increased and generally decreased as the amount of applied phosphorus increased. HCN-p of the plants was not affected by level of applied potassium. These results agree with those reported by other workers (17, 30, 31).

Effect of Frost on HCN-p

Literature Review—Contradicting results have been reported concerning the effect of frost or freezing on HCN-p of sorghum plants. Peters *et al.* (32) in 1903, and several more recent workers (4, 17, 35, 8) have observed a decrease in HCN-p after frost. Other investigators (12, 39, 15, 27) have reported an increase in HCN-p

Table 5. HCN-p (ppm fresh weight) of whole plants of Greenleaf, Piper, and Suhi-1 when grown in the greenhouse at different levels and combinations of applied nitrogen, phosphorus, and potassium, ¹ Knoxville, 1967

Fertilizer treatments ²			Greenleaf	Piper	Suhi-1
N	P	K	ppm	ppm	ppm
0	0	0	43±16 ³	38±40	110±69
60	60	60	69±70	91±103	156±100
120	120	120	82±41	46±40	146±57
240	240	240	78±35	54±38	174±19
480	480	480	76±49	60±20	151±45
60	0	0	146±35	104±32	172±45
120	0	0	85±13	57±22	118±6
240	0	0	137±9	92±40	214±134
480	0	0	151±129	55±17	170±64
120	60	60	102±52	84±6	170±21
240	60	60	68±15	56±21	148±94
480	60	60	138±44	102±10	214±41
0	60	0	42±30	22±18	89±28
0	120	0	48±19	67±26	116±23
0	240	0	28±21	31±24	74±48
0	480	0	54±78	30±37	69±47
60	120	60	69±43	40±31	66±31
60	240	60	60±67	34±19	80±10
60	480	60	50±45	28±18	78±30
0	0	60	42±40	30±22	88±108
0	0	120	68±28	46±9	118±55
0	0	240	48±36	42±35	76±82
0	0	480	85±75	54±7	162±26
60	60	120	96±33	49±16	130±14
60	60	240	74±38	42±15	113±28
60	60	480	66±45	42±53	88±66

¹ The plants were grown in 8-inch clay pots during the summer of 1967. The soil was a Lindside loam which had a pH of 6.4, 30 pounds per acre of available P₂O₅ and 170 pounds per acre of available K₂O. Plants were sampled for HCN-p when they were about 18 inches tall.

² Pounds per acre of N, P₂O₅, and K₂O.

³ $\bar{x} \pm t_{0.05} S_{\bar{x}}$ Each value is an average of 4 plants, 2 each from 2 replications.

following frost. Boyd *et al.* (4) suggested that the increase in HCN-p after frost resulted from the production of new leaves and shoots which were higher in HCN-p than the older plant material. Some recent work (20, 38) has shown that the magnitude of increase in HCN-p after frost depends upon the variety, the stage of growth, and the intensity of freezing. The increase in HCN-p after

Table 6. Average HCN-p of all plants of Greenleaf, Piper, and Suhi-1 which received different levels of nitrogen, phosphorus, and potassium¹

Amount of fertilizer applied in pounds per acre	Nitrogen N	Phosphorus P ₂ O ₅	Potassium K ₂ O
0	64±8	94±8	87±11
60	81±9	94±10	86±11
120	99±14	75±20	87±15
240	113±22	68±16	78±15
480	124±21	66±14	87±16

¹ Summary of data from Table 5.

frost has been found to decrease to pre-frost, or lower, levels within 2 weeks after the frost (20, 38).

Experiments—The effect of frost or freezing on HCN-p of plants of Greenleaf, Piper, and Suhi-1 was studied during the autumns of 1964, 1965, and 1966. Plants at different stages of growth were analyzed for HCN-p before frost and for a few days thereafter each year. The results are given in Tables 7, 8, and 9.

Growth stage indicates the approximate height of the plants at the time of first frost. During early autumn, HCN-p decreased in plants of all growth stages of all varieties.

Light Frost or Freeze—Frosts which occurred at recorded temperatures of 2 or 3 degrees above or below freezing caused only slight visible injury to leaves, and the plants continued to grow. HCN-p usually increased following these frosts. The extent of the increase was difficult to determine because frost sometimes occurred on successive days, while at other times a frost was followed by temperatures which were favorable for growth. The increase was not detected the morning in which frost occurred, but it was most evident from 1 to 6 days later. Following the post-frost peak, HCN-p decreased within about 10 days to a point lower than the pre-frost level. The increase in HCN-p after frost became less later in the autumn.

During the first autumn frost period in 1964, frosts were observed October 6, 7, 8, 9, and 12. Significant increases in HCN-p were measured October 12 and 15 (Table 7). During the second frost period, frosts were observed October 20, 21, 23, 24, and 26 and these frosts were followed by significant increases in HCN-p October 24, 26, and 29. The third frost period consisted of one

Table 7. HCN-p (ppm dry weight) of whole plants of Greenleaf, Piper, and Suhi-1 at two stages of growth, Knoxville, 1964

Frost dates	HCN-p sampling dates	20-in. stage			30-in. stage		
		Greenleaf	Piper	Suhi-1	Greenleaf	Piper	Suhi-1
	October	ppm	ppm	ppm	ppm	ppm	ppm
	1	150±58†	41±26	360±48	22±14	22±11	200±46
6	6	99±44	48±48	187±36	28±28	8±9	65±27
7	7	18±11	4±3	156±41	11±6	8±7	78±63
8	8	52±31	11±11	159±47	27±22	13±7	80±64
9	9	18±12	2±2	93±20	9±4	5±4	57±14
12	12	25±19	2±3	232±110*	9±8	4±5	66±30
	15	82±30*	0	148±44	7±3	8±9	118±107
	19	16±17	2±2	124±40	1±2	3±4	48±24
20	20	10±6	2±4	79±23	1±1	0	51±17
21	21	10±6	1±1	46±16	1±2	0	41±18
23	23	29±18	1±3	83±33	14±11	0	113±56
24	24	95±26*	55±4*	170±30*	29±6*	23±4*	189±74*
26	26	51±22*	5±5*	73±39	27±15*	2±5	51±19
	27	12±10	0	37±14	4±4	0	24±21
	29	20±8	10±8	133±59*	2±6	1±3	47±21
	November						
	2	14±7	5±5	97±52	5±3	3±4	56±27
	5	9±4	12±4*	30±8	5±3	1±1	44±15
	9	6±5	4±5	38±17	11±6*	0	24±12
	12	2±2	4±3	36±13	4±4	1±2	62±26
15							
	16	1±4	0	110±30*	1±1	19±25	59±25
	19	27±20*	21±14*	159±53*	1±2	1±2	71±30*
20							
21	21	7±6	8±5	70±29	11±9	1±2	40±30
22†	22	6±5	14±9	117±74*	8±6	0	48±36
23	23	1±1	0	52±28	0	0	36±19
24	24	6±5	1±1	90±34*	0	0	23±10

Table 7. continued

Frost dates	HCN p sampling dates	20-in. stage			30-in. stage		
		Greenleaf	Piper	Suhi-1	Greenleaf	Piper	Suhi-1
	November	ppm	ppm	ppm	ppm	ppm	ppm
27	27	0	0	19 ± 28	0	0	1 ± 1
29							
30	30	0	0	0	0	0	0

† $\bar{x} \pm t_{(n-1)} S_{\bar{x}}$. Each variety mean is an average of 10 determinations, two samples from each of five plants.

* This mean is significantly higher than the lowest mean for one of the earlier sampling dates within a given column of data.

‡ Daily minimum recorded temperature was -6 C. This was the first date on which the plants were frozen.

frost November 15 which was followed by significant increases in HCN-p November 16 and 19. The fourth period consisted of several frosts between November 20 and 30. Significant increases in HCN were noted November 22 and 24.

In the autumn of 1965, the first frost period included frosts which occurred October 25 and 26. These frosts were followed by significant increases in HCN-p on October 26, 27, 28 and 29 (Table 8). No significant increases in HCN-p were measured following the second frost period (October 30, 31, November 1, 2, 3). The third frost period consisted of a single frost November 15 and was followed by a significant increase in HCN-p November 16.

In 1966 the first autumn frost occurred October 21 and significant increases in HCN-p were detected on October 24 (Table 9). The second frost period, October 25, 28, and 31, was followed by significant increases in HCN-p which were measured October 28 and 31. The third frost period occurred on November 3, 4, and 5 and was accompanied by increases in HCN-p during the same period.

Samples for HCN-p analysis were taken twice daily on October 25 and 26 and on November 18, 1965 (Table 8). Although frost occurred on these days, there were no consistent differences between morning and afternoon HCN-p readings.

The effect of frost on HCN-p was influenced by variety, height of plant, and year. The magnitude of increase following light frosts was usually greater for Suhi-1 than for either of the two sudan-grass varieties. HCN-p of shorter plants of all varieties increased more than that of taller plants. The response to light frosts was

Table 8. HCN-p (ppm dry weight) of whole plants of Greenleaf, Piper, and Suhi-1 at two stages of growth, Knoxville, 1965

Frost dates	HCN-p sampling dates	20-in. stage			30-in. stage		
		Greenleaf	Piper	Suhi-1	Greenleaf	Piper	Suhi-1
	October	ppm	ppm	ppm	ppm	ppm	ppm
	6	86±22†	6±10	315±93	72±18	12±15	264±181
	12	27±21	25±16	85±45	22±30	0	221±86
	21	30±11	0	91±64	20±10	0	60±25
25	25 a.m.‡	21±12	4±4	116±37	5±4	1±3	110±40
	25 p.m.	6±7	8±9	202±87	10±13	6±10	102±45
26	26 a.m.‡	15±11	5±7	145±22	1±1	1±3	67±34
	26 p.m.	36±27	5±5	186±36*	7±10	1±1	7±7
	27	15±12	5±7	120±64	1±1	0	42±17*
	28	22±12	0	196±38*	2±2	2±3	47±20*
	29	10±9	1±1	106±27	1±1	1±1	77±33*
30							
31							
	November						
1							
2							
3	3	4±4	4±6	137±41	6±5	0	46±35
	8	12±12	4±7	95±24	3±2	0	55±31
15							
	16	4±3	1±1	160±43	1±1	0	36±16*
18§	18 a.m.‡	1±2	0	64±55	0	0	17±10
	18 p.m.	4±4	0	61±32	0	0	22±19
	19	0	0	8±12	0	0	16±10

† $\bar{x} \pm t_{(1,15)} S_{\bar{x}}$. Each variety mean is an average of 10 determinations, two samples from each of five plants.

‡ Plants were sampled twice on this date, once in the morning and once in the afternoon.

* This mean is significantly higher than the lowest mean for one of the earlier sampling dates within a given column of data.

§ Daily minimum recorded temperature was -5 C. This was the first date on which the plants were frozen.

Table 9. HCN-p (ppm dry weight) of whole plants of Greenleaf, Piper, and Suhi-1 at three stages of growth, Knoxville, 1966

Frost dates	HCN-p sampling dates	12-in. stage			30-in. stage			48-in. stage		
		Greenleaf	Piper	Suhi-1	Greenleaf	Piper	Suhi-1	Greenleaf	Piper	Suhi-1
		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
October										
	5	—	—	—	120±41	120±31	415±105	140±46	87±22	490±163
	17	162±78†	285±138	443±176	96±35	41±10	170±59	37±13	27±7	106±33
21										
	24	373±167	163±13	1092±292*	149±83	85±32*	338±94*	53±11	31±8	176±64
	27	144±49	172±13	311±85	84±31	39±7	269±136	24±4	50±13*	103±39
28										
	28	387±178*	229±95	1025±185*	92±19	68±28	73±24	27±3	43±9	137±69
	31	215±89	161±14	500±18*	109±7	80±10*	106±22	67±23	65±47	200±20
November										
	3	102±7	121±33	867±21*	116±5	58±53	414±80*	66±29	26±12	247±93*
	4	190±7*	111±43	384±7*	88±8	53±24	155±36*	53±56	54±5*	142±107
	5	140±3*	132±22	442±16	46±4	29±39	140±17*	42±9	25±1	100±40
	7‡	69±39	37±17	239±131	44±9	23±8	120±30	26±27	21±3	35±2
	9	26±8	49±13	66±31	14±2	9±1	52±11	14±3	10±2	35±15

† $\bar{x} \pm t_{(1-05)} S_{\bar{x}}$. Each variety mean is an average of 10 determinations, two samples from each of five plants.
 * This mean is significantly higher than the lowest mean for one of the earlier sampling dates within a given column of data.
 ‡ Daily minimum recorded temperature was —5 C. This was first date on which the plants were frozen.

less in 1965 than in 1964 or 1966. The first frost came late in 1965 (October 25) when the plants had ceased to grow rapidly.

The fact that the increase in HCN-p reached a peak within 1 to 6 days after frost suggests that an increase occurred in the frosted plant material. This observation is in opposition to the suggestion by Boyd *et al.* (4) that the increase in HCN-p following frost was due to the production of new leaves and shoots.

Heavy Freeze—The plants were frozen when the recorded temperature dropped to -5°C or lower. As they thawed, the plants appeared water-soaked and produced a distinct odor. Such freezes which occurred November 22, 1964, November 8, 1965, and November 7, 1966 resulted in death of plants and a decrease in HCN-p which continued until little or none was detected. The decrease in HCN-p following heavy freezes was consistent for plants of all varieties, growth stages, and years.

The difference in response of HCN-p to light and heavy freezes may partly explain the conflicting reports concerning the effect of freezing on HCN-p. In these experiments, a freeze caused either an increase or a decrease in HCN-p. When the freeze was light, and the plants continued to grow, HCN-p increased for a period of 1 to 6 days after frost and then decreased. Freezes which resulted in death of the plants caused a rapid decrease in HCN-p.

Effect of Drying on HCN-p

Literature Review—There are conflicting reports on the effects of drying on HCN-p of sorghum plants. Several workers have reported that drying of plants resulted in a decrease in level of HCN-p (1, 9, 11, 17, 36). Acharya (1) and Franzke *et al.* (17) found that drying in the sun caused a greater decrease in HCN-p than drying in the shade or in an oven. Swanson (36) found more HCN-p in plant material dried in the sun than in that dried in the shade. Boyd *et al.* (4) reported that neither air drying nor sun curing appreciably decreased the HCN-p of sorghum plants. Harrington (6) found an increase in HCN-p when sorghum plants were cured as hay.

Experiments—A study was conducted in 1967 to determine the effect of drying on HCN-p of 15-inch plants of Greenleaf, Piper, and Suhi-1 grown in the greenhouse. HCN-p of fresh plants was compared with that of oven- and air-dried plants. The air-dried plants were divided into two groups, one exposed to light

and the other protected from light. Estimates of HCN-p in the dried samples were about one-third to one-half of those for the fresh samples within each variety. There were no consistent differences in HCN-p associated with oven- or air-drying or with light or dark conditions under which air-drying occurred.

DISCUSSION

Effect of Ensiling on HCN-p

The effect of ensiling on HCN-p is not well understood. Briese and Couch (5) suggested that silage contained toxic amounts of HCN, but that it was in a free form and was lost when exposed to the air during feeding. Boyd *et al.* (4) concluded that plants high in HCN-p would remain high for several weeks after ensiling. Franzke *et al.* (17) found that the amount of HCN-p lost through simulated ensiling varied with years and depended upon date of harvest and plant maturity at harvest. Harrington (20) found that the HCN-p of once-frosted Piper and Trudan I harvested at an 18- to 22-inch height remained at about the same level during 8 weeks of preservation as simulated silage. The HCN-p of similarly treated sorghum-sudangrass hybrids increased to more than twice that before ensiling. Twice-frosted plants tended to be lower in HCN-p after ensiling than were the once-frosted plants. Air drying of ensiled samples for 3 days reduced the HCN-p by about one-half. The author concluded that once-frosted 18- to 22-inch sudangrass may be used safely before ensiling or after 1 or 2 months preservation as silage.

Once-frosted and immediately-ensiled 10- to 18-inch sorghum-sudangrass hybrids should be air-dried for at least 3 days before feeding. Although no data were cited, Rohweder *et al.* (33) stated that silage made from sorghum containing harmful amounts of HCN-p can be fed safely because the HCN escapes as gas during silage making. If plants are harvested for silage at the soft-dough stage, they are relatively mature and contain less HCN-p. These authors suggested that sorghum should not be fed for 2 or 3 weeks after being ensiled because HCN is produced during the heating period and needs time to escape. When green-chopped sorghum is left overnight on a wagon, heating occurs and the possibility of HCN poisoning is increased.

Effect of Soil Moisture on HCN-p

The HCN-p of sorghum plants has been found to increase when plants are grown under drought conditions (4, 16, 17, 20, 33). This increase is believed to occur regardless of stage of plant maturity (11, 27). Franzke and Hume (16) reported that plants grown on soil at 15%, 25%, and 35% moisture produced plants with HCN-p

of approximately 1,200, 500, and 250 ppm on a dry weight basis, respectively. Heinrichs and Anderson (22) found HCN-p to be twice as high in plants grown under drought conditions as in similar plants grown under normal moisture conditions. In a greenhouse experiment, Hogg and Ahlgren (24) observed that HCN-p increased from 159 ppm in plants growing under normal moisture conditions to 222 ppm for plants at the permanent wilting point.

Differences in available soil moisture may be largely responsible for the geographic and seasonal effects on HCN-p. Franzke *et al.* (17) grew 13 strains of sorghum at two locations in South Dakota and observed differences in HCN-p associated with location. Hogg and Ahlgren (24) tested 10 inbred lines of sorghum at six locations in the Midwest and Canada. They found differences of up to 1,200 ppm in HCN-p of the same line grown at different locations. In 1964 Harrington (20) grew sorghums in southeastern, central, and southwestern Pennsylvania where the rainfall deficits during July and August were 3.60, 0.64, and 0.76 inches, respectively.

When grown in the southeast, the area having the greatest rainfall deficit, the HCN-p of these varieties was 2.5 times higher than that of plants grown in the areas of less rainfall deficit.

Differences in soil moisture may be responsible for much of the uncontrolled variability in HCN-p studies. In the present studies, the sample standard deviations appeared to be unduly large.

Toxic Levels of HCN-p

With the available information, it is not possible to accurately predict what effect different HCN-p levels in sorghum will have on the animal. Whether sorghum is safe or dangerous for livestock consumption depends upon several factors, such as HCN-p of the plant material, amount consumed, rate of HCN release, type of ration, and the animal's ability to detoxify HCN.

It has been shown that a dose of about 1 gram (1/28 oz. or $\frac{1}{454}$ lb.) of HCN will kill a 1,000-pound cow (4). Rabbits and dogs have been found to be able to detoxify HCN at the rate of 0.5 milligram per hour per pound of body weight with no toxic effects. On this basis a 1,000-pound cow should be able to detoxify about 0.5 gram of HCN per hour. Poisoning occurs when the rate of release of HCN exceeds the detoxification rate.

Several workers have considered the level of HCN-p in sorghum which would result in poisoning of cattle. Couch (11) stated that

plant material containing 200 ppm of HCN-p could be fatal to animals if grazed rapidly. Rohweder *et al.* (33) reported that there is danger of poisoning when cattle consume large amounts of sorghum containing more than 600 ppm of HCN-p. Harrington (20) divided HCN-p levels of sorghums into three toxicity groups as follows: 1) safe, 0-500 ppm, 2) doubtful, 500-750 ppm, and 3) dangerous, greater than 750 ppm. In his work, Piper and Trudan I sudangrasses were found always to be within the safe range. However, several instances were found where the HCN-p of 10- to 18-inch sorghum-sudangrass hybrids were in the doubtful and dangerous ranges. Out of 958 HCN-p determinations performed on sorghum-sudangrass hybrids, he found that 94.9% were safe, 4.8% were doubtful, and 0.3% were dangerous.

The HCN-p of sorghum varieties is one of the criteria considered in the recommendation of varieties by the University of Tennessee (18). Only those varieties in which the HCN-p of the blade of the top leaf of 30- to 36-inch plants is less than 200 ppm on a fresh weight basis are recommended.

If it is assumed that the maximum safe level of HCN-p of sorghum is approximately 600 ppm on a dry weight basis, some of the plant material analyzed during these studies would have been unsafe for animal consumption. None of the above-ground parts of Greenleaf and Piper which were analyzed during the course of these studies had HCN-p greater than 600 ppm. These findings agree with results of Harrington's studies (20) in which the HCN-p of Piper and Trudan I sudangrass never reached the dangerous level. In the present study the HCN-p of roots of Greenleaf, Piper, and Suhi-1 exceeded 600 ppm when the plants were sampled at 2 and 3 weeks of age (Figures 2, 3, 4).

The HCN-p of Suhi-1 plants exceeded the safe level several times during these studies. In the 1963 field study, the HCN-p of the whorl approached or exceeded 600 ppm consistently in the 20-3 cutting management, and for one-third of the harvests in the 30-8 cutting managements (Table 2). The HCN-p of the first and third leaves was above the safe range for some harvests of the 20-3 and 30-8 cutting managements. All the Suhi-1 leaves sampled in the EB-4 cutting management were within the safe range. Considering the whole plant data for the 1963 study (Figure 6), average HCN-p of the Suhi-1 plants was beyond the safe range for about one-half the harvests in the 20-3 and 30-8 cutting managements. The HCN-p of whole plants in the EB-4 management was well within the safe region.

The HCN-p data for sorghum varieties (Appendix Table 12) were calculated only on a fresh weight basis. Dry matter content of 30- to 36-inch sorghum plants is usually about 20%; therefore, the fresh weight HCN-p data would be multiplied by 5 to make them comparable to those on a dry weight basis. In 1964 all of the varieties appeared to be within the safe range. Beginning in 1965, two incubation periods were used for each sample. The second reading increased the HCN-p estimate by about one-third. Since the efficiency of estimation—not the amount—of HCN-p was increased by one-third, the maximum safe level was increased accordingly from 600 to 800 ppm. In 1965 and 1966, any variety having more than about 160 ppm fresh weight was considered to be dangerous. In 1965, 15 of the 59 varieties tested exceeded the safe range for HCN-p. However, in 1966 only 2 of the 59 varieties were considered unsafe.

In the study of the effect of nitrogen fertilization on HCN-p, average HCN-p on a fresh weight basis was greater than 160 ppm for one or more harvests of each nitrogen treatment (Table 4). In the greenhouse study (Table 5), several of the treatments resulted in unsafe HCN-p levels in Suhi-1 plants. These levels occurred only in treatments which received applied nitrogen.

In the frost studies, dangerous levels of HCN-p were detected only in Suhi-1 plants which were about 12 inches high. The dangerous levels occurred within 3 days after frost.

Reducing the Risk of HCN Poisoning

Although sorghums make a valuable contribution to the forage program in Tennessee, some risk of HCN poisoning is involved in their utilization by livestock. The HCN problem can be avoided by growing forages other than sorghum. For example, the pearl-milletts have most of the advantages that the sorghums have, but do not contain HCN. However, through variety selection and careful management practices, sorghum can be grown and utilized by livestock with a minimum amount of risk in Tennessee.

It is generally agreed that the sudangrasses are lower in HCN-p than are the other forage sorghums. Results reported herein and those reported by other workers indicate that dangerous levels of HCN-p are not often found in sudangrass varieties. Cumberland and Piper, which are recommended for Tennessee, are very low in HCN-p. Suhi-1 was used in this study as a representative of the sorghum-sudangrass hybrids. In comparison with

other hybrids, Suhi-1 was intermediate in HCN-p (Table 12). The sorghum-sudangrass hybrids as a group are high in HCN-p but differences exist among the hybrids. More attention must be given to their management as it affects HCN-p.

The HCN-p of sorghum plants is affected by fertility of the soil. Application of nitrogen, especially to soils deficient in nitrogen, generally results in an increase in HCN-p. The application of 60 or 120 pounds per acre of nitrogen, the amounts recommended for forage sorghum in Tennessee⁴, resulted in a measurable increase in HCN-p (Tables 4, 5, 6). However, the differences due to nitrogen treatments were less than the differences associated with varieties and harvest dates. The decrease in HCN-p associated with increments of applied phosphorus and the independent relationship between HCN-p and applied potassium would indicate that a balanced fertility program would increase yield and simultaneously reduce the risk of HCN poisoning.

From a cutting management viewpoint, the goals for high quality and low HCN-p forage are in opposition. Both quality and HCN-p are high in young plants and decrease as the plants become older and more mature. When sorghum plants are grazed or green-chopped, it is desirable to utilize the plants when they are from 12 to 36 inches high. Such plants would be in the vegetative stage and would be higher in HCN-p than at more mature stages. When plants are harvested for silage at the soft dough stage, they are more mature and contain less HCN-p. Unless factors other than stage of growth (frost, drought, etc.) are causing an increase in HCN-p, the risk involved would not warrant delaying grazing or green chopping until later stages of maturity.

Some of the individual leaves of Suhi-1 (Table 2) were considerably higher in HCN-p than the whole plants of Suhi-1 (Figure 6). For plants that are high in HCN-p, it would perhaps be safer if the plants were chopped and fed as green-chop or silage. The cattle would be more likely to consume a mixture of plant parts. Through selective grazing, the animal would likely consume more of the young leaves which would be higher in HCN-p.

When sorghum plants which are high in HCN-p are used for greenchop or silage, certain precautions should be taken. In the case of greenchop, temporary storage conditions which result in heating and HCN build-up should be avoided (33). Feeding of

⁴1968 Fertilizer Recommendations. Tennessee Agricultural Extension Service Publication 381.

silage should be delayed from 1 to 2 months after ensiling to permit the HCN to escape (20, 33). Results of this study and most of those in the literature indicate that drying as occurs during hay curing results in a decrease in HCN-p. Harrington (20) concluded that short-growth sorghum-sudangrass hybrids grown under droughty conditions should not be used as hay.

There are some conditions under which cattle should not be given access to sorghum-sudangrass hybrids. The reported cases of HCN poisoning of cattle in Tennessee have occurred primarily as a result of grazing sorghum either after drought or after frost. Several reported studies (4, 16, 17, 20, 33) indicate that HCN-p of sorghum plants increased during drought periods. Young sorghum plants which are inherently high in HCN-p should not be grazed when they are showing visible symptoms of moisture stress. The new growth made immediately after a severe drought may also be unsafe. In the present study, the HCN-p of Suhi-1 reached a dangerous level following frost in 1966 (Table 9). The precautions needed after frost vary with the degree of freezing. If the frost is light and the plant continues to grow, HCN-p increases from 1 to 6 days following frost. Extent of the danger during this period depends upon the variety, stage of growth, and vigor of the plants. In this study and the one reported by Harrington (20), the greatest increase in HCN-p following frost occurred in short sorghum-sudangrass hybrids. Such plants should not be grazed during this post-frost period of HCN-p increase. Following the post-frost peak, HCN-p decreased to lower than pre-frost levels within 10 days. A killing frost resulted in rapid release of HCN-p from sorghum plants. After being frozen, the plants became dry and the level of HCN-p dropped to near zero. After such plants become dry, they should be safe for livestock feed.

Based upon Harrington's (20) results, frosted and immediately ensiled sudangrass may be safely used after 1 or 2 months preservation. Frosted and immediately ensiled short-growth sorghum-sudangrass hybrids should be air-dried at least 3 days before being fed to cattle.

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APPENDIX

Release of HCN in the Sodium Picrate Assay of Sorghum Plants

THE RATE OF release of HCN (as indicated by change in color of the filter papers impregnated with picric acid and suspended above the plant tissue in a test tube) was studied by using leaf and stem tissues of Piper and Suhi-1. Twenty aftermath plants of each variety grown in the field were cut at an 8-inch height when they were about 30 inches tall. The stem of each plant was separated from the leaf blade and sheath and chopped into 1 centimeter pieces. The top two leaves with developed collars were chopped into 1 centimeter pieces. HCN was determined from the following samples from each plant:

L.5 approximately 0.5 gram leaves

L.1 approximately 1.0 gram leaves

S.5 approximately 0.5 gram stems

S1 approximately 1.0 gram stems

Samples were incubated at 22 to 26 C. During incubation, filter papers were replaced at approximately 24-hour intervals. Incubation of each sample was continued until no light absorption could be detected.

The release of HCN from leaf and stem tissues of Piper and Suhi-1 is shown in Figure 9. In Piper, the release of HCN from stems and leaves continued for approximately 125 to 240 hours, respectively. In Suhi-1, HCN was released from stems over a 170-hour period and from leaves over a 264-hour period. Average percentages of total HCN measured after the first incubation period were 49.3% and 35.1% for Piper and Suhi-1, respectively (Table 10). Only 62.0% of the total HCN of Suhi-1 was measured after three incubation periods.

The correlation coefficients between HCN measured after the first incubation period and the total amount measured for leaves and stems of both varieties were positive and highly significant (Table 11). Additional HCN measured after the second and third incubation periods tended to increase the correlation coefficients.

Although HCN of leaves and stems of Piper and Suhi-1 was not completely released during the first 24-hour incubation period, the amount released during this time was highly correlated with total release. Measurements of HCN released during a 24-hour

incubation period from either leaves or stems could be used to rank genotypes for comparing treatment effects. However, more additional incubation periods.

reliable rankings and comparisons would be obtained with ad-

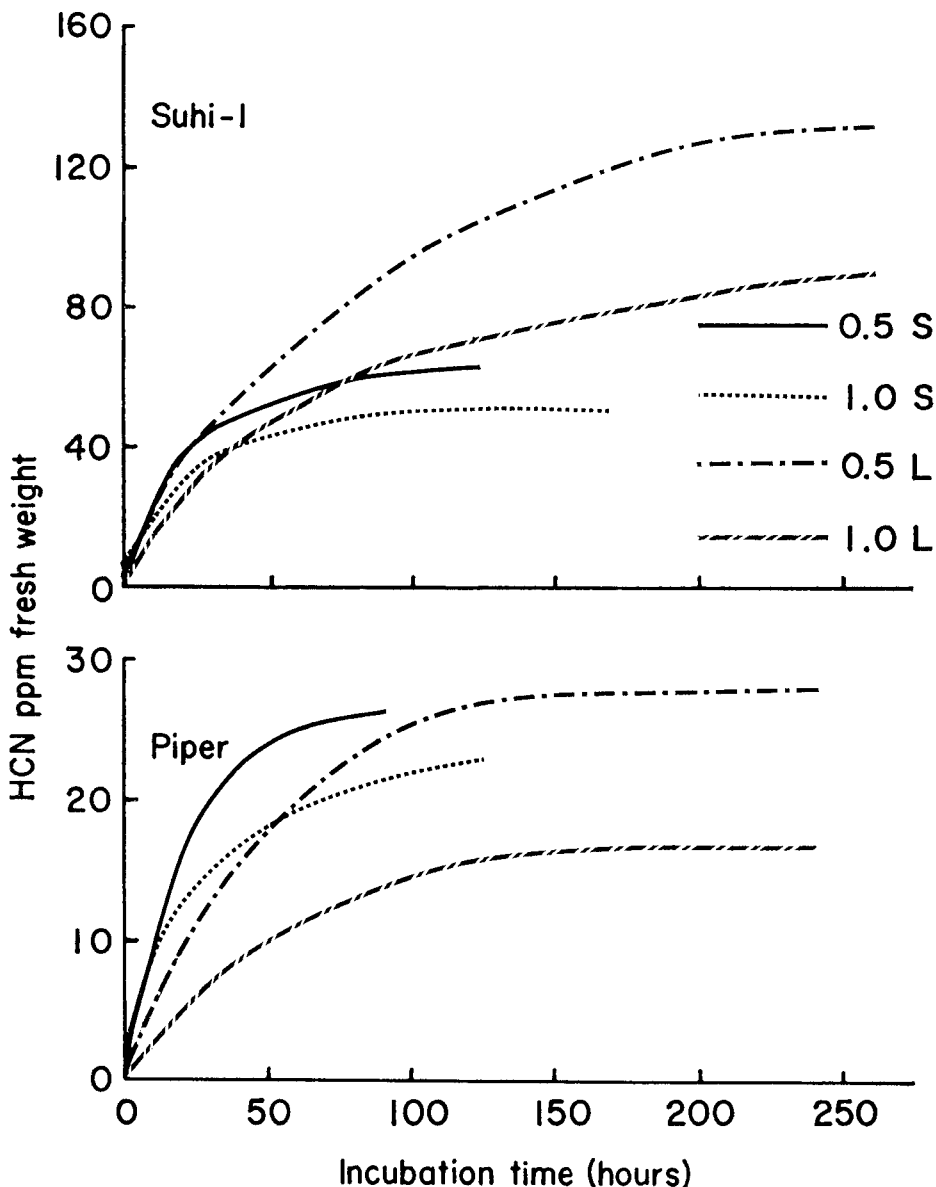


Figure 9. Cumulative amounts of HCN released from leaf and stem tissues of Piper and Suhi-1.

Table 10. Percentages of total HCN measured after various incubation periods of leaf and stem tissues of Piper and Suhi-1

Incubation periods	Approx- imate hours	Piper				Average for Piper	Suhi-1				Average for Suhi-1
		Leaves *		Stems†			Leaves		Stems		
		L.5	L1	S.5	S1		L.5	L1	S.5	S1	
1	24	38.3	33.9	63.4	57.5	49.3	13.1	30.7	65.5	62.2	35.1
1 + 2	48	60.6	59.5	88.8	75.1	71.9	27.7	47.7	82.4	79.8	51.3
1 + 2 + 3	68	74.5	71.4	94.8	85.0	82.2	38.7	60.4	92.0	87.4	62.0

* L.5 and L1 designate leaf samples weighing approximately 0.5 and 1.0 gram, respectively.

† S.5 and S1 designate stem samples weighing approximately 0.5 and 1.0 gram, respectively.

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Table 11. Simple correlation coefficients between HCN estimates after various incubation periods and total HCN estimates of leaf and stem tissues of Piper and Suhi-1 plants

Incubation periods	Approx- imate hours	Piper				Average for Piper	Suhi-1				Average for Suhi-1
		Leaves †		Stems ‡			Leaves		Stems		
		L.5	L1	S.5	S1		L.5	L1	S.5	S1	
1	24	.87**	.82**	.94**	.64**	.78**	.84**	.78**	.96**	.94**	.73**
1 + 2	48	.91**	.92**	.95**	.63**	.83**	.91**	.84**	.99**	.98**	.83**
1 + 2 + 3	68	.92**	.94**	.98**	.86**	.91**	.87**	.86**	.99**	.99**	.86**

† L.5 and L1 designate leaf samples weighing about 0.5 and 1.0 gram, respectively.

‡ S.5 and S1 designate stem samples weighing about 0.5 and 1.0 gram, respectively.

** Significant at the .01 level of probability.

HCN-p of Sorghum Varieties

Table 12. HCN-p (ppm fresh weight) of leaves of sudangrass and of sorghum x sudangrass hybrids, ¹ Knoxville, 1964, 1965, and 1966

Variety or Strain	1964	1965	1966
	ppm	ppm	ppm
Advance 1038 GE	16 ²	61	
1071 F	14		
1085 F		210	
Arkansas AKS 20			131
AKS 22			102
Leafmaster 43			71
Asgrow Beefbuilder T	52	181	146
Duet	66	209	
Grazer A	35	152	88
H6553			225
Sorgusbord			134
Titan R	65	235	
Caladino Greenlan	31	128	68
Conlee Mor-Gain			142
Cotton Hyb. Res. Southern Cross			130
Cumberland	7	7	
Crown Su-Sorg	12		
DeKalb Sudax SX-6			158
Sudax SX-11	54	125	102
Sudax SX-12	41	193	94
Dorman Sure-Graze	17	200	146
Excel Chow-Maker		140	98
Chow-Maker 21		106	89
Exp. 102		89	

Table 12. continued

Variety or Strain	1964	1965	1966
	ppm	ppm	ppm
Exp. 104		204	
Exp. 106		100	
Exp. 107		127	102
Exp. 108		88	39
Exp. 762			96
Exp. 861			99
Exp. 1107			128
Silo Fill 33		135	100
XP-1		99	
Frontier Hi-dan 37	46		
Hi-dan 38	65	157	
Hi-dan 39		136	123
Gilbreath Honey Sweet		129	
Green Bros. Green Graze	53	166	
Greenleaf	32	52	38
Hunt & Tipps Green-M	30	131	59
Ho-K	56		
Lindsey 77F	56	69	142
Miller P-100		83	
SP-110		54	
Northrup-King Sordan	25	116	88
Trudan I	21	9	
Trudan II		19	22
Trudan III		87	
Trudan IV		34	35
Paymaster Aztec	49	176	
Crop Guard	50	215	
Exp. 3801			69
Exp. 3811			48

Table 12. continued

Variety or Strain	1964	1965	1966
	ppm	ppm	ppm
Exp. 3813			113
Exp. 3816			72
Exp. 3822			89
Exp. 4814			60
Exp. 4839			116
Exp. 5817			41
Exp. 5859			51
Exp. 5870			64
Sweet Sioux	26	73	68
Sweet Sioux A			80
Thunderbird		92	48
3 Little Indians	50		
Pfister Si-Chow-2	18		
Su-Chow 34	12	79	
Su-Chow 35	56	98	86
Pioneer 930		238	
931		234	204
936			118
980		58	
981		48	
985		106	102
Piper	0	11	14
Piper X S. Propinquum	32		
Riley Ga-Su	35	124	
Hy-Su	26	92	
Su-Graze	44	125	
Rudy-Patrick Mor-Su	51	123	129
Su-1	66	144	69
Scott Grazer	11	116	

Table 12. continued

Variety or Strain	1964	1965	1966
	ppm	ppm	ppm
Suhi-1	57	110	
Taylor-Evans Grazemaster	27	155	130
Haygrazer	52	166	106
3083 x		116	97
3084 x		208	
Tennessee Farmers Co-op Exp. No. 1	60		
FFR 66			121
FFR 74			129
GHS-1	46	172	106
GHS-2		115	104
GHS-2A			137
W A C 99			151
R. G. Young Kow Kandy	34	127	122

¹ The varieties were grown on Huntington and Sequatchie silt loams and were sampled for HCN potential when the plants were about 30 inches in height.

² Each value is an average of 10 determinations.

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