Toxic Nitrate Accumulation in the Sorghums

B. R. Clay, *D.V.M., M.S.;* **W. C. Edwards,** *D.V.M., M.S.;* **D. R. Peterson,** *D.V.M., M.S.*
College of Veterinary Medicine
Oklahoma State University
Stillwater, Oklahoma 74074

Introduction

The sorghums are well known as toxic plants. Their notoriety comes from the dramatic and devastating effects attributable to prussic acid (CN) which can accumulate in young or stressed sorghum plants. The classical awareness of this poison tends to distract attention from other toxins or toxic manifestations which may be associated with these plants, namely, hybrid sorghum poisoning in equine and nitrate poisoning in cattle. Because the sorghums are valuable and productive crop plants, the danger of their unguarded management and use is sometimes overlooked. Nitrates can accumulate to *excessive levels* in any of the sorghum species commonly grown in the United States. With continued intensification of farming and ranching and widespread usage of the intra- and inter-special sorghum hybrids as hay crops, nitrate poisoning has become a growing menace to the cattleman. An understanding of the plant and its soil and animal relationships is essential to the prevention and management of poisoning due to nitrates in the sorghums.

Characteristics of the Sorghums

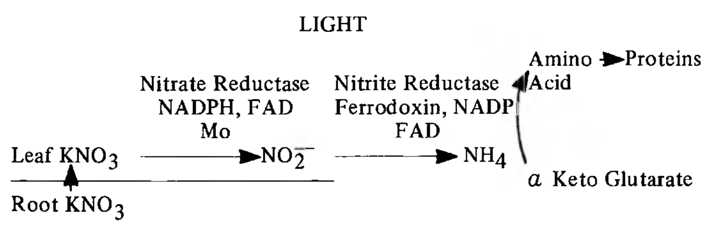
Three species consisting of numerous varieties and hybrids make up the population of plants known as sorghums, Table 1. They are widely adapted, somewhat drought tolerant and are hardy soil feeders. They are warm season plants that are cultivated throughout the United States for grain, forage, and the panicle in the case of broomcorn. About eighteen million acres are planted annually in this country. Forages from these plants are used in a variety of ways, e.g., silage, greenchop, hay, bundle feed and grazing forage (green, winter-killed, or grain stubble).

Sorghums, like many grasses, have both male and female parts in each flower, thus permitting considerable self-pollination. The discovery of genetic male sterility has allowed for convenient hybridization and mass production of hybrid seed in both forage and grain types. The heterosis acquired through hybridization has resulted in increased yields of both types. More recently, the hybridization of grain sorghums and sorgos with sudans has produced sudan forage types with greatly increased dry matter yields–up to six to eight tons per acre. These yields are possible only in the warmer humid climates with a long growing season where multiple harvests are possible. The usual production is three to four tons per acre which represents a nutrient removal of 100-200 pounds of nitrogen, 20-40 pounds phosphorus and 50-80 pounds potassium. Even higher amounts of nitrate and potassium may be removed from the soil when they are more abundant than is necessary for maximum growth. This "luxury consumption" is rather common in the case of potassium with accumulations occurring up to six percent of the dry weight.

Table 1
Classification of the Sorghums Grown in the United States

Species and/or type	Principal use
Sorghum bicolor	
Grain sorghum	Grain feeding
Sorgo	Silage
Sorghum sudanense	
Sudangrass	Grazing and hay
Sorghum halepense	
Johnsongrass	Grazing and hay
Sorghum X Sudan hybrids	
"Dekalb SX-11," "Horizon SP-110," etc.	Grazing and hay
Sorgo X Sudan hybrids	
"Haygrazer," "Sweet Sioux," etc.	Grazing, silage, greenchop and hay

Nitrate accumulation in sorghums is quite variable and may occur even when the soil level is less than adequate for maximum production. In this case, the accumulation results from a lack of reduction to nitrite by the nitrate reductase enzyme while root uptake continues. This enzyme is found throughout the plant tissues but is most abundant in the leaf where the reduction and incorporation into proteins occurs according to the following scheme:



Another living, breathing reason for using LEPTOMUNE®-GHP

. . . the only single bacterin providing protection against the 3 major serotypes of leptospirosis in cattle and swine.

Three serotypes, grippotyphosa, hardjo, and pomona, are largely responsible for the losses that result from leptospirosis. An animal may be infected with one or a combination of serotypes.

"3-in-1" LEPTOMUNE-GHP protects cattle and swine against all three serotypes. The 2 cc. dose is extremely syringeable and easily administered. There is no interference with viral vaccines. Safe for use in pregnant animals.

AFFILIATED
LABORATORIES DIVISION
WHITMOYER LABORATORIES, INC.
HORSHAM, PENNSYLVANIA 19044
SUBSIDIARY OF **ROHM AND HAAS COMPANY**

Since these enzymes are energy dependent, then any adversity which results in reduced photosynthesis will cause impaired reductase activity. Photosynthesis, as the name implies, is a light dependent process and will continue at a maximum rate only when adequate amounts of all essential nutrients are present. When nitrogen is adequate in sorghum culture, the nutrients most often lacking are water and phosphorus. When either is inadequate, then impairment or deficiency of nitrate reductase results and nitrates may accumulate.

Accumulation is possible during impaired reductase activity because of the sorghum plant's innate ability to voraciously absorb nutrients as long as enough moisture is present to maintain a soil solution. This great capacity for nutrient uptake, even under duress, may be the reason why sorghums and some other annual plants can readily accumulate nitrates while others such as the perennial pasture grasses function more slowly in nutrient uptake, Table 2. This generalization should be applied with caution since accumulation can occur in many of the crop plants if adverse conditions become severe. If accumulation does occur, the concentration in various plant parts will be roots > stems > leaves > flower or seed.

Table 2

A Generalized Rating of Some Common Forage Plants as to Their Tendency to Accumulate Nitrates[1]

High	Low
Sorghums	Bermudagrass
Sudangrass	Orchardgrass
Johnsongrass	Timothy
Wheat	Fescue
Oats	Gramagrasses
Rye	Bluestems
Barley	Bromegrasses
Corn	Weeping Lovegrass
Sugar Beet	Buffalograss
Turnip	
Rape	
Soybean	
Sweet Clover	

[1]Adapted from a list prepared by Tucker, 1973.

In addition to excessive nitrogen fertilization and impaired reductase activity, stage of maturity and genotype of the plant can also influence the level of nitrate accumulation in sorghums. The rate of uptake of nitrate reduces with maturity. Sorghum plants with seeds in the "hard dough" stage are unlikely to contain sufficient nitrate to produce poisoning; whereas, immature plants, particularly those that recover following harvest and supplemental nitrogen fertilizer, will have the greatest potential for accumulation. Variation in accumulation potential also exists within varieties and hybrids and between species. In general, the sudan varieties and hybrids and johnsongrass have a lower potential than the sorgo by sudan and sorghum by sudan hybrids.

Ironically, some of the same conditions which enhance nitrate accumulation also influence the accumulation of cyanide. These nitrogen compounds are not totally dependent variables because one can accumulate without the other. When both accumulate in the growing plant (with nitrate at the sublethal level), there is the potential for a built-in therapy for the cyanide. Ingested nitrate is reduced by rumen micro-organisms to nitrite which is absorbed to produce methemoglobin which in turn binds cyanide as cyanmethemoglobin.

Properly cured hay made from the forage sorghums is not likely to contain toxic levels of cyanide even though it was present prior to harvest. The curing process and a few weeks of storage should allow for enzymatic release of cyanide as HCN which escapes as a gas into the atmosphere. On the other hand, nitrate is concentrated during the curing process. The loss of plant tissue water results in a relative increase in the nitrate level of the plant.

Conditions of Poisoning

The minimum lethal level of nitrate for cattle is often reported to be 1.0 percent of the daily dietary intake (dry-weight basis). This level is a useful guide but does not allow for the adaptive nature of rumen microbes and the varying dietary carbohydrate levels that cattle receive. With acclimation to nitrates and high carbohydrate diets, as in feedlot rations, animals have tolerated greater than 2.0 percent without any signs of acute toxicosis. The sorghums can accumulate nitrates to levels greater than 3.0% and are frequently offered to cattle as hay when there has been no chance for acclimation nor access to supplementary carbohydrates. This practice oftentimes results in numerous deaths, Table 3.

Table 3

A Compilation of Nitrate Poisoning Cases in Cattle Fed Sorghum Hays[1]

Case No.	Month of Occurrence	No. and Kind of Animals Lost	Percent Nitrate
1	December	8 cows	2.86
2	December	20 cows	3.08
3	December	8 cows	3.60
4	January	16 calves	2.62
5	March	2 cows	1.60
6	March	4 cows	2.75
7	January	3 cows, 5 abortions	2.75
8	April	4 abortions	1.70
9	November	4 cows, 5 abortions	3.22

[1]Cases reported to the College of Veterinary Medicine, Oklahoma State University, during 1972-1975.

The cattleman and sometimes his veterinarian may become confused by the circumstances under which these toxicoses occur. For example, the forage from which the hay was made may have been used for pasture prior to harvest or the hay may have been fed several weeks prior to the toxicity without any signs of illness in the cattle. The former case may have been possible due to the grazing habits of livestock. The grazing animal selects the tender leaves, which are lowest in nitrate, leaving the stem; therefore, the total nitrate intake is lower than when fed the entire plant as hay. In the latter case, hay from different harvests of the same field may be stacked in the same barn or there may be areas of the field where the topsoil depth is shallow, producing water stress or areas where nitrates have accumulated in the soil.

Since hay is often used as an emergency feed supply, cattle may receive their entire daily ration from nitrated hay during the first day of inclement winter weather. From four to six hours post feeding, signs of severe nitrite poisoning (methemoglobinemia) become evident and death follows shortly. Unfortunately, the cattleman who is feeding beef animals seldom sees his cattle until the next daily feeding period when all that remains to do is count and dispose of the dead. From three to five days after the acute poisoning those surviving pregnant animals may abort. The delayed development of toxicity signs coincides with microbial nitrate reduction to nitrite and subsequent increasing methemoglobin ($HbFe^{+++}$) to a point where the reconversion to hemoglobin ($HbFe^{++}$) by methemoglobin reductase enzyme is overpowered. When this occurs, the methemoglobinemia rapidly increases to a level of 70 to 80 percent which soon becomes fatal unless a powerful electron donor such as methylene blue is provided intravenously.

Ruminal nitrate reduction has been suggested as a stepwise conversion to ammonia similar to that described for green plants. The difference here is that ruminal carbohydrate serves as the substrate for microbial protein production, additional metal cofactors are involved, and light is not required for the reactions to proceed. Unfortunately, the rate of nitrite reduction to ammonia and incorporation into protein does not coincide with nitrate reduction. Nitrite is then absorbed and robs an electron from the ferrous iron (Fe^{++}) of hemoglobin.

This same microbial reduction scheme occurs in silage fermentation. Therefore, high nitrate sorghum or corn silage should not be expected to contain toxic levels of nitrate if normal and complete fermentation has progressed. Silage fermentation may, however, result in the production of nitrogen dioxide and other nitrogen oxide gases which are also toxic when inhaled.

Prevention and Management

Prevention of toxicity is most expeditiously accomplished through avoidance of use of sorghum hay as the sole diet at any one time. Judicious promotion of this restriction might encourage many to abandon the use of sorghums entirely, which would be unfortunate since they are some of the most productive annual forage crops available to the producer. Careful management of the crop and testing for nitrate content can alleviate most of the worries that might accompany its use.

A balanced fertilizer program consistent with the temperature and moisture conditions of the growing area is essential to minimize nitrate accumulation. In areas where the rainfall is less than 30 inches per year, nitrogen levels greater than 100 pounds per acre per growing season should be discouraged. Phosphorus and potassium levels should be established on the basis of a soil test of available nutrients and a recommendation by a soils diagnostician in the area. Where the rainfall (or irrigation) is greater than 30 inches per year, higher nitrogen applications up to 200 pounds per acre are possible. For sorghum hay crops the nitrogen should be applied in two or three equal portions, depending on the number of harvests and available moisture. This is essential if prevention of "luxury consumption" of nitrate is to be accomplished. Some producers attempt to avoid the nitrate accumulation by applying formulations of nitrogen fertilizers other than nitrate. This is of no benefit since under warm conditions the soil microbes readily convert other forms to nitrates. Selection of sudan varieties and hybrids over the sorgo or sorghum-sudan hybrids may be beneficial to those who can afford the reduced yield. The producer should be made aware that these can also accumulate nitrates to a toxic level but the potential is reduced.

If evidence of moisture stress appears in the crop prior to harvest, extra caution should be exercised. Random samples of entire plants should be collected from different areas of the field and submitted to a diagnostic laboratory for nitrate analysis. If the level should prove to be dangerous, harvest can be delayed until rains come and the plant approaches maturity. If this is impractical, harvest should be begun late in the afternoon which should coincide with the lowest daily level of nitrate in the plant. Since nitrate reductase activity is light dependent, the least accumulation will occur at the end of the daylight period. Hay from shallow topsoil areas or high nitrogen soils, such as abandoned livestock lots, should be isolated and tested separately following harvest.

When the level of nitrate in the forage is known, it is possible to calculate the dilution, if any, that is necessary before feeding. A level of 0.6 percent of the total diet should be safe for all livestock. If the level is not known, test feeding of a few animals should be advised.

In cases where hay has become heavily laden with nitrate, it can be best used when ground and mixed with concentrates. The added nitrogen, through reductive processes in the rumen, provides for an additional source of protein and

the carbohydrate will enhance the utilization of nitrate.

A semi-quantitative quick test for nitrate is available and can be used to test hay samples before feeding or as an aid in diagnosis. The test solution may be prepared by mixing 0.5 grams of diphenylamine with 20 milliliters of distilled water and then bringing the q.s. to 100 milliliters with concentrated sulfuric acid. This solution, when placed on the inner stem tissues of the plant, will produce an intense blue color within ten seconds if greater than 1.0 percent nitrate is present. False positive reactions may occur with bromides, iodates, chlorates, molybdates, iron, antimony, and perioxides. These ions are usually not present in plant tissues in sufficient concentration to produce a positive reaction so these are of little concern when testing hay. However, soil with high iron content on the surface of vegetation could produce a false positive. It is imperative that the test be performed on the inner stem tissues to avoid this error.

Summary

The sorghums are valuable crop plants to the cattle industry. Their use as forages is varied and widespread throughout the United States. As pasture they may become hazardous to grazing ruminants if toxic accumulations of cyanide and/or nitrates exist. As hay the major toxic threat is excessive nitrates since cyanide is readily lost as gaseous HCN during the curing process.

The sorghum plant is a hardy soil feeder which allows for tremendous dry matter production in a relatively short period of time. This feature also allows for excessive nitrate accumulations when there is a luxury of soil nitrogen or if the plant becomes stressed. An understanding of sorghum culture and the plant's growth processes is essential to the prevention and management of toxic nitrate accumulations.

References

Beevers, L., and R. H. Hageman. Nitrate Reduction in Higher Plants. Ann. Rev. of Plant Physio. p. 495, 1969. - Buck, W. B., G. D. Osweiler and G. A. Van Gelder. Clinical and Diagnostic Veterinary Toxicology. Kendall Hunt Pub. Co., Dubuque, Ia. pp. 55 and 223, 1973. - Crawford, R. F., and W. K. Kennedy. Factors Influencing the Toxicity of Forages that Contain Nitrate when Fed to Cattle. Cornell Vet. 56(2):3, 1966. - Crawford, R. F., and W. K. Kennedy. Nitrates in Forage Crops and Silage. New York State College of Ag. Misc. Bull. 37, 1960.- Deeb, B. S., and K. W. Sloan. Nitrates, Nitrites and Health. Bulletin 750. Agri. Exp. Sta., University of Ill. at Urbana-Champaign, 1975. - Dollahite, J. W., and E. C. Holt. Nitrate Poisoning. Southwestern Veterinarian. p. 23, Fall, 1969. - Eck, H. V., and R. H. Hageman. Nitrate Reductase Activity in Sudangrass Cultivars. Crop Sci. 14:283, 1974. - Gillingham, J. T., M. M. Shirer, J. J. Starnes, N. R. Page and E. F. McClain. Relative Occurrence of Toxic Concentrations of Cyanide and Nitrate in Varieties of Sudangrass and Sorghum-Sudangrass Hybrids. Agron. Jour. 61:727,1969. - Harms, C. L., and B. R. Tucker. Influence of Nitrogen Fertilization and Other Factors on Yield, Prussic Acid, Nitrate and Total Nitrogen Concentrations of Sudangrass Cultivars. Agron. Jour. 65:21, 1973. - Heath, M. E., D. S. Metcalfe and R. S. Barnes. Forages. 3rd ed. Iowa State University Press. p.544, 1973. - Housholder, G. T., J. W. Dollahite and R. Hulse. Diphenylamine for the Diagnosis of Nitrate Intoxication. JAVMA. 148(6):662, 1966. - McCreery, R. A., S. M. Hojjati and E. R. Beaty. Nitrates in Annual Forages as Influenced by Frequency and Hight of Clipping. Agron. Jour. 58:381, 1966. - Radebaugh, D., and B. Dicke. Nitrate levels in Animal Production. Proc. of 35th Semi-annual Meeting of Nutrition Council of Am. Feed Mfg. Assoc. p. 12, Nov. 12-13, 1975. - Tucker, B. B. Nitrate-Nitrogen Accumulation in Summer Forages. Oklahoma Agric. Ext. Serv. Unpublished Manuscript. 1973 - Varsa, E. C., and G. Kapusta. N-Serve® Nutrient Stabilizer and Nitrogen Distribution in a Claypan Soil. Down to Earth. 29(1):15, 1973.