Utilization of High Nitrate Forages by Beef Cows, Dairy Cows and Stocker Calves

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Nitrates in the ruminal environment

The nitrate ion (NO_3), itself, is not toxic to animals. In the rumen, however, microorganisms convert nitrate to nitrite (NO_2: Sapiro et al., 1949) or hydroxylamine (NH_2OH). Nitrite is then absorbed through the ruminal wall into the blood stream where it converts hemoglobin to chocolate-colored methemoglobin. This compound is incapable of carrying oxygen so as methemoglobin concentrations increase, oxygen supply to tissues decreases and asphyxiation occurs. Clinical signs of nitrate toxicity occur when methemoglobin concentrations exceed 40% of total hemoglobin (Deeb and Sloan, 1975). Death occurs when methemoglobin concentrations exceed 70-80% of total hemoglobin. Methemoglobin is naturally converted back to hemoglobin by NADPH reductase in the body but this process may be too slow when blood nitrite concentrations are too high. Under these circumstances, an intravenous dose of methylene blue (2-7 mg methylene blue/lb body weight) reverses this process and restores the oxygen status of the animal (Burrows, 1984; Merck, 1986; Ruhr and Osweiler, 1986).

In the rumen, bacteria convert nitrate to nitrite with the enzyme nitrate reductase. Many ruminal microorganisms have the genetic capability to produce this enzyme so nitrites can accumulate rapidly (within 4-6 hours) when large quantities of nitrate are consumed. Nitrite can be converted to ammonia (Lewis, 1951) or other nontoxic compounds by many ruminal microorganisms (Cheng et al., 1988) although ammonia appears to be the major end product (Kaspar and Tiedje, 1981). Ammonia can then be used as a nitrogen source by ruminal bacteria to produce bacterial protein.

The key enzyme in the process of nitrite detoxification is nitrite reductase. This is an inducible enzyme which means that microorganisms exposed to nitrite will increase nitrite reductase activity and their ability to detoxify ruminal nitrite. Alaboudi and Jones (1985) demonstrated that nitrite reduction is 3 to 5 times higher in sheep adapted to nitrate. Ruminal microorganisms will begin to adapt as quickly as four hours after the initial nitrate exposure, although three to six days are required for optimal adaptation (Allison and Reddy, 1984). Thus, adaptation of the normal ruminal microflora to nitrates may not be rapid enough to avoid toxicity. Also, producers may not always have enough time to adapt the ruminal microflora to nitrate prior to exposure to high nitrate feeds. In addition, the nitrite detoxifying ability of ruminal microorganisms can be overcome when nitrate intake is too high. For example, when dietary nitrate exceeds 210 mg nitrate/lb body weight (equivalent to 18,000 ppm nitrate in the diet), nitrate reduction has been shown to be two fold greater than nitrite reduction (Allison and Reddy, 1984). Thus, nitrite accumulates.

Ruminal microorganisms will maintain the ability to detoxify nitrate as long as nitrate is present in the diet or water. These microorganisms will de-adapt, however, by reducing the quantity of these enzymes when nitrate is removed from the diet, sometimes as quickly

as four days after nitrate withdrawal. Consequently, animals with previous exposure to high nitrate feeds may not be protected.

The enzymatic conversion of nitrate to forms of nontoxic nitrogen requires a variety of cofactors. These cofactors include certain minerals such as copper, iron, magnesium and manganese. Consequently, animals routinely exposed to high nitrate feeds should have access to these important minerals. In addition, the process of nitrate detoxification is speeded by available energy. Consequently, another strategy to minimize the toxic effects of nitrites is to ensure adequate ruminal energy.

A third strategy for reducing ruminal nitrite concentrations is to establish a population of bacteria in the rumen capable of reducing nitrite to nontoxic nitrogen forms. Some strains of propionibacteria are capable rapidly detoxifying nitrite. Consequently, a component of a nitrate management system could include the use of propionibacteria.

Recognizing nitrate toxicity

Symptoms of nitrate intoxication include staggered gait, accelerated pulse, frequent urination, labored breathing and collapse (Deeb and Sloan, 1975). The most effective diagnostic tool is a blood sample analyzed for methemoglobin or nitrite. Upon sampling, affected blood will be chocolate brown in color. In addition, nonpigmented skin and vaginal membranes may show a brownish discoloration. At this point, treatment should be rapidly initiated because coma and death can occur within 2-3 hours after symptoms appear.

Chronic, low grade nitrate toxicity is more difficult to recognize. Symptoms include decreased weight gain, decreased milk yield and/or abortion (Wright and Davison, 1964; Deeb and Sloan, 1965). Lethargy and reduced eating time are frequently noticed with moderate nitrate intakes and may explain the reduced productivity. In some cases, decreased productivity can be explained by decreased feed intake due to the unpalatable nature of high levels of nitrate (>20,000 ppm) in the diet. Nitrates have been shown to reduce cellulolytic, xylanolytic and total microbial populations and cellulase and xylanase activities (Marais et al., 1988) which could decrease feed utilization. In addition, nitrates alter ruminal VFA profiles with increased acetate and reduced propionate as the most important changes (Allison and Reddy, 1984). Because propionate is a more energetically efficient end product than acetate, this change could reduce the energetic efficiency of the animal.

Nitrate intake: What is toxic?

Nitrate risk is usually characterized by the nitrate concentration in livestock feeds (Table 1). However, we have all heard accounts of cattle consuming feeds much higher in nitrate (12-15,000 ppm) with no observable toxicity. It is important to remember that these concentrations (Table 1) are for the total diet and not for a smaller portion of the total diet. For example, a 500 lb steer might consume 12-14 lb of a 10,000 ppm nitrate sorghum/sudan hay and succumb to nitrate toxicity. But, if the intake of this 10,000 ppm nitrate hay was limited to 5 lb/day, nitrate intake would be decreased to the extent that toxicity symptoms would not be expected.

Table 1. Effect of nitrate concentration in feeds on livestock.

Nitrate (ppm)	Comment
0-1,500	Safe for pregnant cattle
1,500-5,000	Potential early term abortions Reduced breeding performance
0-5,000	Safe for nonpregnant cattle
5,000-10,000	Mid to late term abortions Weak newborn calves Decreased growth Reduced milk yield
10,000 +	Abortions Acute toxicity symptoms and death

A second concern is that the toxic nitrate concentrations (Table 1) do not consider other dietary alterations that can reduce the impact of nitrate on the animal. For example, energy feeds stimulate the conversion of nitrate to nontoxic nitrogen compounds and lessen the potential for toxicity (Burrows et al., 1987). In addition, rate of ingestion of high nitrate forage along with source of nitrate (green forage, dry hay or water) also affect the toxicity of consumed nitrate. Finally, previous exposure to nitrate helps both microbes and the animal to adapt to higher levels of nitrate intake.

A more appropriate expression for nitrate toxicity is mg nitrate/lb body weight (Table 2). This expression combines the nitrate concentration in the feed and the intake of that feed by the animal. In addition, it removes the variation due to animal size or weight. This expression still ignores adaptation or energy intake. Actual nitrate intake (mg nitrate/lb body weight) is important, however, because 10 lb of 20,000 ppm nitrate hay would be much more toxic to a 500 lb steer (400 mg nitrate/lb body weight) than a 1,000 lb steer (200 mg nitrate/lb body weight). The values for a lethal dose of nitrate range from 90 to 454 mg nitrate per lb body weight. This variation is due to the fact that these values were generated with both nitrate salts and nitrate in feeds. Generally, nitrate salts are immediately available in the rumen and are much more toxic than nitrates contained in feeds. Consequently, we have chosen 450 mg nitrate/lb body weight as the toxic level for nitrates consumed in feeds. Nitrates in water are probably toxic at much lower levels (150-200 mg nitrate/lb body weight).

Table 2. Toxic dose of nitrate (LD_{50}) for ruminants.

Dose (mg nitrate/lb body weight)	Source
90-454	O'Hara and Fraser, 1975
148	Bradley et al., 1940
454	Crawford et al., 1966
321-449	Wright and Davison, 1964
140	Deeb and Sloan, 1975
227	Ruhr and Osweiler, 1986
150-450	Faulkner and Hutjens, 1989

Using these values and the nitrate concentrations from Table 1, nitrate intake guidelines were developed (Table 3). The value of these numbers is that they allow consideration of: 1) nitrate content of feeds, 2) level of feed intake, 3) contributions from water or other nitrate sources, and 4) body weight.

Table 3. Effect of nitrate intake (mg nitrate/lb body weight) on livestock.

Nitrate (ppm)	Comment	mg nitrate/lb BW
0-1,500	Safe for pregnant cattle	0-20
1,500-5,000	Potential early term abortions Reduced breeding performance	20-60
0-5,000	Safe for nonpregnant cattle	0-60
5,000-10,000	Mid to late term abortions Weak newborn calves Decreased growth Reduced milk yield	60-120
10,000 +	Abortions Acute toxicity symptoms and death	120

These comments help explain some of the variation in livestock responses to nitrate intake. There remains, however, a significant amount of animal to animal variation. For example, some light beef heifers received a toxic dose of nitrate (Winter, 1962; Table 4). After 6 hours, blood methemoglobin ranged from 18.6 to 70.0% of total hemoglobin. Of these animals, three were probably safe (0-40% methemoglobin), two were borderline (40-60% methemoglobin) while one animal was very susceptible (70.0% methemoglobin). Very simply, some animals can tolerate much more dietary nitrate than others. Unfortunately, it is difficult to predict which animals are more nitrate tolerant so we must design management programs that protect all animals.

Table 4. Blood methemoglobin content (6 h postdosing) of six beef heifers receiving an oral dose of 21.0 g nitrate/cwt (Winter, 1962).

Animal	Methemoglobin (% of total hemoglobin)
665	18.6
689	32.6
690	70.0
691	40.1
696	58.5
697	28.8

Factors that predispose ruminants to nitrate toxicity

Certain factors or circumstances appear to predispose animals to nitrate toxicity. Other factors or circumstances offer some protection. It is important to understand the difference.

Hunger. Hungry animals eat more feed. Thus, hungry animals released onto or fed a marginally toxic forage might become poisoned because of higher than expected intake (Kretschmer, 1958). Dollahite and Holt (1970) demonstrated that a calf consuming 1.1 g nitrate-N over 24 hours showed no toxicity but a calf force fed 0.32 g nitrate-N died within four hours. Environmental conditions also impact hunger in that cold weather or snow or ice cover may create circumstances where hungry cattle are capable of consuming extremely large quantities of feed.

It is also important to realize that many high nitrate forages are palatable and digestible and thus promote high consumption. In studies at Stillwater, 500 lb beef heifers were fed chopped prairie hay for one week prior to an abrupt conversion to high nitrate (20,000 ppm) pearl millet hay. Intake increased from 1.3% BW on the prairie hay to 1.8% BW on the pearl millet. Because animals cannot sense high nitrates in feed, intake will be controlled by other factors such as palatability and digestibility.

Adaptation. Because the ability of ruminal microorganisms to detoxify nitrate/nitrite is an inducible process, prior exposure to nitrate can help to protect animals from nitrate toxicity. Exposure to nontoxic levels of nitrates (< 6,000 ppm) for three to ten days is required to induce the nitrate detoxifying ability of ruminal microorganisms. This exposure must be continuous, however, until the animals are fed the high nitrate feed because the ability to detoxify nitrate can be lost as rapidly as it is developed.

In addition to the microbial adaptation to nitrate, the physiological processes of the animal also adapt. For example, animals exposed to a continuous source of nitrate have increased hemoglobin, hematocrit and blood volume (Jainudeen et al., 1964). Increased hemoglobin helps the animal compensate for the proportion of methemoglobin created by nitrite in the blood. Increased blood volume is an adaptive response to the vasodilation and resulting low blood pressure associated with increased blood nitrite concentrations. With these adaptations, the animals can adapt to, and tolerate, some blood nitrite.

Diet. Feeds that are high in energy, such as the starchy cereal grains, will stimulate ruminal microorganisms to convert nitrate to nontoxic nitrogen compounds at a faster rate. Burrows et al. (1987) showed a dose-related response to level of corn fed to cows dosed with nitrate (Table 5). Approximately 0.8% of body weight of corn reduced ruminal nitrite by 75% and blood nitrite and methemoglobin by approximately 50%. Thus, previous feeding of cereal grains such as corn or milo have the dual benefit of diluting the intake of high nitrate feed and stimulating the utilization of nitrate by ruminal microorganisms.

Table 5. The effect of corn supplementation on rumen and blood nitrite concentrations.

	Corn, % body weight		
	0	0.4	0.8
Rumen nitrite, ug/ml	1.89	1.45	0.5
Blood nitrite, ug/ml	0.07	0.07	0.04
Methemoglobin, %	25.3	23.7	12.4

Forage form. Differences in the toxicity of different types of forage may also affect potential nitrate toxicity. For example, the plant cells in dry hays become more permeable during dehydration. When consumed by ruminants, ruminal fluid rapidly saturates these cells and quickly releases nitrate into the ruminal environment (up to 80% of cellular nitrate can be released into ruminal fluid within 20 minutes). In contrast, green, growing forages are composed of intact plant cells. Although a portion of these cells are ruptured during chewing and swallowing, many plant cells reach the rumen intact. In the rumen, intact plant cells release their cell contents, including nitrate, more slowly which may help to minimize the potential toxicity (only 30% of cellular nitrate released within 20 minutes). Thus, dry hays are potentially more toxic to livestock than lush, green forages (Geurink et al., 1979).

Baling method may also affect potential toxicity. For example, the potential for toxicity may be greater when forage is harvested in large, round bales. The reason for this is that nitrate concentrations vary significantly across a given field. Thus, "hot spots" of increased nitrate concentration exist. With large, round bales, there is more potential to concentrate a large quantity of high nitrate forage into a single feeding unit (Edwards and McCoy, 1980).

Ruminal environment. Characteristics such as ruminal pH may affect a potential toxicity. The pH optimum for nitrate reductase is 6.5 while the optimum for nitrite reductase is 5.6 (Tillman et al., 1965). Because most forage diets create a ruminal environment with a pH from 6.2 to 6.5, nitrate reduction to nitrite is favored. Nitrite reduction, however, may be retarded. Consequently, normal ruminal pH may increase the likelihood of nitrite accumulation. Dietary alterations to reduce ruminal pH such as feeding cereal grains may help activate nitrite reductase.

Because ammonia is one of the normal end products of nitrite reduction, excessive ruminal ammonia concentrations may reduce nitrite reduction because of negative feedback mechanisms. Thus, forages high in protein or feeds high in nonprotein nitrogen sources such as urea may exacerbate the nitrite problem.

Sources of nitrates

Livestock consume nitrates from a variety of sources. The most common source is from forage with cultivars from the sorghum family (sorghum, sudan, pearl millet and their crosses) being particularly high accumulators of nitrate. Under certain conditions, a wide variety of plants can accumulate potentially toxic quantities of nitrate (Table 6). In addition to common livestock feeds, certain weeds that commonly inhabit pastures or crop fields can also accumulate nitrates. Cereal grains and protein concentrates rarely contain appreciable nitrate concentrations.

Table 6. Feeds known to accumulate nitrate under certain circumstances.

Barley forage	Alfalfa	Dock
Beet pulp	Annual brome	Goldenrod
Corn forage	Clovers	Jimson weed
Kale	Fescue	Johnsongrass
Molasses	Kikuyugrass	Kochia (Fireweed)
Oat forage	Orchardgrass	Lamb's quarter
Rape	Pearl millet	Nightshade
Turnips	Sorghum	Pigweed
Wheat forage	Sunflower	
	Sweetclover	
	Switchgrass	
	Timothy	
	Wheatgrasses	
	Wild rye	
	Witchgrass	

Nitrates also tend to be concentrated in certain parts of plants. For example, nitrates are typically higher in stems, lower in leaves (more nitrate reductase activity) and extremely low in grain (Fjell et al., 1991; Pfister, 1988). In pearl millet, stems contained three times more nitrate than leaves (Krejsa et al., 1987).

Forage maturity plays an important role in that nitrates are typically higher in young growth (or regrowth) but lower in mature plants (Pfister, 1988; Fjell et al., 1991). Sunlight is also important because nitrate reductase activity is low during shade or dark (Pfister, 1988). Thus, hay should be cut or animals released in the afternoon of a sunny day.

Soil moisture affects uptake and utilization of nitrates by plants. In contrast to popular belief, however, short or moderate drought creates more nitrate accumulation than extended drought. This is because moderately drought-stressed plants continue to take up nitrate but have reduced nitrate reductase activity because leaves are stressed (Pfister, 1988).

From the standpoint of drought, a greater concern is the nitrate uptake that occurs after a drought-ending rain. For example, Krejsa et al. (1987) and Pfister (1988) reported large accumulations of nitrate in plants shortly after a severe drought. Stem nitrate

concentrations in pearl millet increased from approximately 5,000 ppm to 9,000 ppm within two days after eliminating drought stress by irrigation (Krejsa et al., 1987). In addition, seven to 14 days are required for nitrate levels to return to normal after a drought-ending rain (Fjell et al., 1991)

Other factors such as soil mineral content and herbicide treatment also affect nitrate accumulation (Pfister, 1988).

The contribution of nitrates in drinking water is sometimes overlooked. Either we don't analyze the nitrate content of water resources or we fail to recognize its significance. Nitrates in water are more toxic than plant nitrates because they are immediately available in the rumen while plant nitrates must be released from the plant cell. Consequently, toxic levels for water nitrate are lower (150-200 mg/lb body weight) than toxic levels for forage nitrate (450 mg/lb body weight).

Across Oklahoma, the nitrate content of water ranges from 0.5 to 26.5 ppm (Judy Duncan, State Environmental Laboratory, personal communication). Although these nitrate levels may not seem very high, they can contribute to total nitrate intake and may aggravate a diet that already contains moderate levels of nitrate. The combination of daily water intake and water nitrate content have a significant effect on the quantity of nitrate actually consumed by the animal (Table 7).

Table 7. Effect of water intake and nitrate content (ppm) on total nitrate intake (g nitrate/day).

Water	Water nitrate, ppm						
intake (gal)	10	25	50	100	200	400	800
	g nitrate/day						
0.5	0.02	0.04	0.08	0.16	0.32	0.64	1.27
1.0	0.03	0.08	0.16	0.32	0.64	1.27	2.54
2.0	0.06	0.16	0.32	0.64	1.27	2.54	5.09
5.0	0.16	0.40	0.80	1.59	3.18	6.36	12.71
10.0	0.32	0.80	1.59	3.18	6.36	12.71	25.42
20.0	0.64	1.59	3.18	6.36	12.71	25.42	50.85
40.0	1.28	3.18	6.36	12.71	25.42	50.85	101.70

To produce 100 lb of milk per day, a 1,500 lb Holstein consumes approximately 40 gallons of water. If her drinking water contains 25 ppm nitrate, her nitrate intake from water alone would represent 2 mg/lb body weight. This represents 10% of the quantity of nitrate that could cause reproductive problems (Table 3). Drinking water containing 100 ppm nitrate (common in California) would contribute 8 mg nitrate/lb body weight which is 40% of the quantity of nitrate that could cause reproductive problems. Based on these calculations, water containing 235 ppm nitrate could cause reproductive problems in dairy cows. Although this level of nitrate in water would be unusual in Oklahoma, cows with access to water contaminated by feedlot effluent or runoff from heavily fertilized fields, septic tanks or manure piles could be exposed to high levels of water nitrate.

Management strategies - proactive vs reactive

Nitrate toxicity can be managed in either of two ways. The first method involves the release of livestock onto a forage of unknown nitrate content. If the animals survive, we breath easier and go about our business. If some of the animals die, we call the veterinarian to confirm the cause of death and then lament our misfortune. This approach is a "reactive" method that involves some degree of risk. An example of a reactive nitrate management program is when 390 beef cattle were released onto high nitrate forage in Nebraska and 226 (58%) died (Hibbs et al., 1978).

The risk associated with a "reactive" management approach could be minimized if producers had immediate access to methylene blue, the antidote for nitrate intoxication. Unfortunately, most producers don't have methylene blue on hand.

The second method is a proactive approach to nitrate management. The specifics of a proactive nitrate management system are outlined below. Basically, a proactive approach involves: a) using our knowledge of varietal, environmental and harvesting strategies to minimize the production of high nitrate forage, b) analyzing the nitrate content of the forage to assess risk, and c) implementing a cattle management program to minimize the effects of nitrate consumption on livestock productivity and health.

What are the possibilities of producing a high nitrate forage?

Production of high nitrate forages should be minimized by recognizing and managing the factors that potentially create situations where nitrates accumulate. For example, some types of forage (sorghum vs millet) and some varieties within type accumulate more nitrate than others (Selk, 1993). Nitrogen fertilization is highly correlated with forage nitrate (Selk, 1993). Planting date can be adjusted so that grazing and haying do not occur during commonly droughty times. At the time of harvesting, weather can be monitored and cattle turnout or haying timed to minimize forage nitrate content. Harvesting can be delayed until 4 to 7 days have elapsed after a drought-ending rain. Harvesting height can be increased to minimize the quantity of high nitrate stems in hay and ensiling can be used to reduce forage nitrate content by microbiological action.

Recognition and management of these factors should minimize the nitrate content and the quantity of high nitrate forage produced. If we successfully reduce forage nitrate concentrations, then livestock management is simplified. Unfortunately, it is virtually impossible to eliminate the nitrate problem. Good forage management, however, should help to minimize nitrate problems.

What is potential nitrate intake?

Before proactive nitrate management strategies can be implemented, the magnitude of the potential nitrate problem must be determined with an estimate of potential nitrate intake. To determine nitrate intake (g nitrate/day or mg nitrate/lb body weight), the nitrate content of the feed must be combined with the projected intake of that feed which is then divided by the body weight of the animal (Table 8).

Table 8. Calculation of nitrate intake assuming a 1,200 lb beef cow consumes 10 lb (4,540 g) of a 10,000 ppm nitrate hay.

Nitrate intake (g/day) = Forage intake (g/day) X nitrate concentration (ppm)

= 4,540 g/day X 0.01 (ppm converted to decimal)

= 45.4 g nitrate/day

Nitrate intake (mg/lb body weight) = 45.4 g/day X 1,000 mg/g / 1,200 lb

= 37.8 mg nitrate/lb body weight

In this example, a 1,200 lb beef cow consuming 10 lb of a 10,000 ppm nitrate hay would consume 38 mg nitrate/lb body weight. Using the nitrate concentration column of Table 1, we might conclude that this cow is at risk. The high nitrate hay, however, only represents a portion (10 lb) of her total daily intake. Thus, her actual nitrate intake (38 mg/lb BW; see Table 3) is within the safe range for nonpregnant cattle although she may be a candidate for early term abortion.

Nitrate content of feeds is determined by accurate sampling of those feeds and accurate analysis of nitrate concentration. Forage samples must be obtained so that they represent the variation in nitrate concentrations in the feed. With dry hay, this sampling involves collection of individual core samples from 20 to 40% of the bales. Although this is a labor intensive process, the results will help us determine the most appropriate management strategy.

Sampling a field is more difficult. On June 30, 1992, we obtained 48 forage samples from a five acre area of a sorghum/sudan pasture that had received 80 lb actual N/acre plus had rainfall within the previous three days. The nitrate content of these samples ranged from 7,930 to 43,600 ppm (Figure 1). Because the nitrate content of standing forage varies significantly, it is difficult to determine the average nitrate content of a pasture.

Nitrate Map (5 acres)

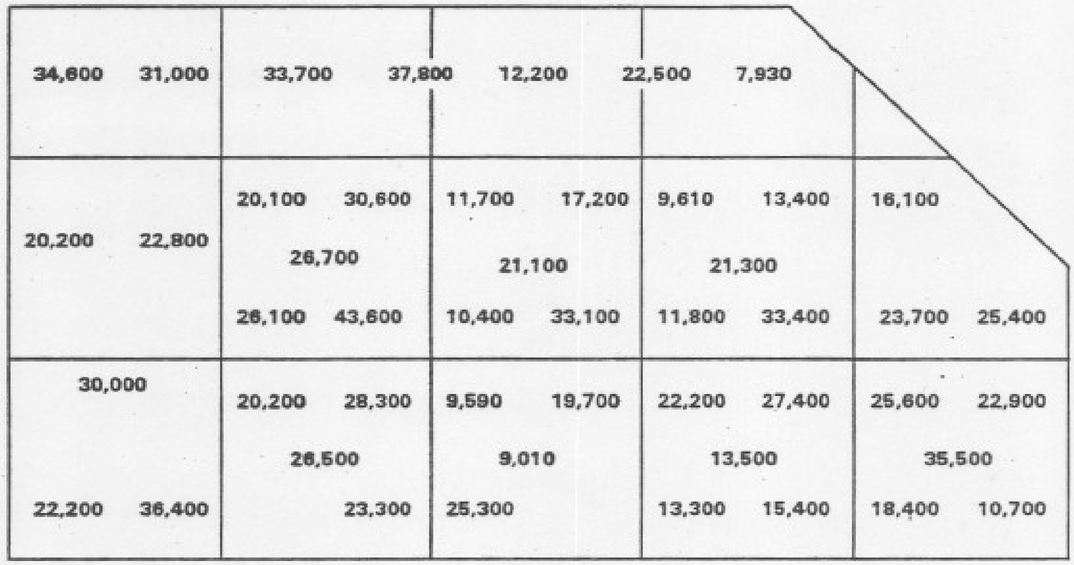

Figure 1. The variation in nitrate concentration of samples collected from a 5 acre sorghum/sudan pasture.

Haliburton and Edwards (1978) also noted that nitrate tends to accumulate unevenly across a field with "hot spots" that potentially contain an extremely high concentration of nitrate. One of the major problems with these "hot spots" is that hay packaged in large round bales from these fields may have large quantities of nitrate concentrated in a few bales. When these bales are then fed, the potential for nitrate toxicity is very high even though hay from the same field may have been fed for some period of time with no detrimental effects.

The second step in this process is to determine the actual nitrate content of the feed samples. The diphenylamine blue "drop" test has been the standard screening tool for many years. Recent evidence (Selk, 1993) helps to validate the "drop" test as an indicator of nitrate content because high nitrate forages tend to turn blue or black. The major concern is the number of false negatives determined with this method. False negatives are samples that contain high levels of nitrate but are declared low nitrate because the "drop" test didn't change color. Approximately 5% of samples in excess of 10,000 ppm nitrate did not react with diphenylamine (false negative) while 61% of the low nitrate forages showed a positive reaction (false positive). A false negative reading can be dangerous to the livestock.

Most commercial labs perform nitrate testing with an ion specific electrode or a nitrate meter. The cost of these tests ranges from $5-8/sample. Care must be taken to determine the method of expressing nitrate content of feeds. In this paper, nitrate concentration has been expressed as the actual nitrate ion. Certain labs may report nitrate-N, potassium nitrate or % nitrate. For conversion factors, see Kilgore (1993).

A special note of caution. Even during "normal" Oklahoma summers, many forage samples contain high nitrate concentrations. Consequently, all susceptible forage should be considered toxic unless proven otherwise by a reputable analytical laboratory.

The next step is to estimate the quantity of high nitrate feed that the animals can be expected to consume. As general guidelines, young animals (500 lb) will consume approximately 2.5% of their body weight (dry matter intake) of a green, succulent forage (Table 9). This amounts to 12 to 15 lb of dry forage.

Table 9. The effect of forage quality on intake.

Forage type	DM intake (% BW)
Low quality forage	1.5
- dormant grass	
- wheat straw	
Average quality forage	2.0 - 2.5
- native grass	
- bermuda in late summer	
High quality forage	2.5 - 3.0
- alfalfa	
- wheat pasture	

To calculate actual nitrate intake, feed nitrate concentration is multiplied by feed intake (Table 8). This result can be divided by body weight to determine the mg nitrate/lb body weight. This number can be compared to the values in Table 3 to determine the risk of nitrate toxicity. If nitrate effects on livestock appear imminent, proactive nitrate management strategies should be implemented to minimize the impact of nitrate consumption.

The relationship between nitrate content of the diet, daily intake and total nitrate intake is presented in Table 10. A cow fed 10 lb of a 5,000 ppm nitrate hay would have a nitrate intake of 22.7 g/day which is equivalent to 22.7 mg nitrate/lb body weight. Values in excess of 20 mg/lb body weight could affect rebreeding performance (Table 3). Thus, even low intake of a hay with moderate nitrate content could present problems.

Table 10. Relationship between nitrate concentration (ppm), hay intake (lb/day) and total nitrate intake (g nitrate/day).

Feed intake, lb/d	Forage nitrate, ppm				
	1,000	5,000	10,000	20,000	50,000
	g nitrate/day				
5	2.27	11.35	22.7	45.4	113.5
10	4.54	22.7	45.4	90.8	227
15	6.81	34.05	68.1	136.2	340.5
20	9.08	45.4	90.8	181.6	454
25	11.35	56.75	113.5	227	567.5

What steps can be taken prior to, or during, preliminary exposure to nitrate?

1. Fill hungry cattle prior to release. If cattle are hungry, take the time (1-3 days) to make sure they are consuming a significant quantity of a bulky forage such as good quality grass hay. Then, release the cattle in the afternoon when they are not as hungry.

2. Adapt cattle to nitrate. The objective is to give the ruminal microorganisms the opportunity to adapt to high nitrate intake. With high nitrate hay, this can be accomplished by blending with low nitrate feeds such as grass hay or concentrates. Grain feeding has the additional benefit of providing ruminal energy to stimulate the conversion of nitrate to nontoxic nitrogen compounds. With grazed high nitrate forages, palatable, low nitrate hay or concentrates can be used. Another alternative with grazed forage is to limit graze for the first 6 to 8 days by increasing the grazing time each day. For example, cattle might be allowed to graze high nitrate forage for 2 hours on day 1 and increase by 2 hours each day through day 6 after which cattle could be released full time onto the high nitrate forage. Another strategy with grazed forage would be to feed the animals several times per day (3-5x/day) to disrupt grazing periods and provide ruminal fill to decrease the rate and extent of consumption of the high nitrate forage.

3. Dilute high nitrate feeds with low nitrate feeds. Dilution is one method that can be used to help ruminal microorganisms adapt to high nitrate feeds. But, it may also be the only practical method that can be used to feed extremely high nitrate forage (>20,000 ppm). Dilution is most effective when the low nitrate feed can be blended or mixed directly with the high nitrate feed.

4. Utilize propionibacteria. Some strains of propionibacteria are capable of rapidly reducing nitrite to nontoxic nitrogen compounds. These bacteria can be established in the rumen by feeding them for a minimum of eight days prior to a nitrate challenge. Once established, they have the capability of reducing ruminal and blood nitrite concentrations by 40 to 50%. Although the propionibacteria can effectively reduce the probability of nitrate toxicity, other methods of nitrate management should also be employed to minimize nitrate exposure.

5. Release cattle in afternoon when night-time nitrate accumulations have subsided. In addition, avoid release shortly after a drought-ending rain.

6. Stock lightly so animals can choose lower nitrate leaves over higher nitrate stems (Fjell et al., 1991)

7. Provide large quantities of fresh drinking water. Water dilutes nitrate concentrations in the rumen and reduces the potential of toxicity (Fjell et al., 1991).

Nitrate management scenarios

The objective of this section is to present five scenarios selected to illustrate the major concerns relative to a specific situation and the types of management that could be applied to minimize the effects of nitrate consumption.

Scenario #1: High nitrate hay as an emergency feed for beef cows

Sorghum/sudan hay harvested in August is to be used as an emergency feed source for some spring-calving beef cows during winter.

Concerns:

What is the stage of production (month relative to calving date)?

- If cows are in early gestation even low nitrate levels could cause abortions.
- If cows are in late gestation, excess nitrate intake could kill or weaken the fetus so that calves may die at, or shortly after, birth (Broadmeadow et al., 1984).
- If cows are in early lactation, abortions are not a concern so attention must be focused on the effects of nitrate on the cow.

What is the nitrate content of the hay?

- To determine the nitrate content of the hay, representative samples must be collected and analyzed. During sampling, bales should be identified so that "hot" bales can be sorted.

How much hay will the cows eat?

- If snow or ice cover, cows can consume an extremely large quantity of hay (25-35 lb/cow).
- If hay is fed during cold, open weather, intake will likely be less (8-15 lb/cow) and dependent on feeding rate.

Management:

Determine susceptibility of cows based on stage of production.

Calculate potential nitrate intake from hay nitrate analysis and projected hay intake.

Sort bales by nitrate content:

- Feed low to moderate nitrate bales (<10,000 ppm) as emergency feeds.
- Feed higher nitrate bales (>10,000 ppm) as a supplemental feed (4-8 lb/cow/day).
- Consider discarding extremely high nitrate bales (>20,000 ppm)

Consider some combination of the following:

Watch weather and start feeding low to moderate nitrate hay prior to inclement weather to adapt ruminal microorganisms to nitrate. Slowly increase feeding level so that cows are adapted by the time the storm arrives.
Feed high energy grain cubes to dilute nitrate intake and provide energy to stimulate microbial detoxification of nitrate.
Establish propionibacteria (feed for 8 days) prior to nitrate exposure to minimize the effects of nitrate intake.

Scenario #2: High nitrate hay as a supplemental feed for wintering beef cows

Sorghum/sudan hay harvested in August is to be used through the winter as a supplemental feed source for spring-calving beef cows.

Concerns:

What is the nitrate content of the hay?

To determine the nitrate content of the hay, representative samples must be collected and analyzed. During sampling, bales should be identified so that "hot" bales can be sorted.

How much hay do the cows need to eat?

Consider stage of production, forage quality and forage quantity to determine appropriate feeding rate. Based on this feeding rate and the nitrate content of the hay, what is the nitrate exposure?

Management:

Determine the potential nitrate exposure based on hay intake and forage nitrate concentrations.

Sort bales by nitrate content:
- Feed low to moderate nitrate bales (<10,000 ppm) as emergency feeds.
- Feed high nitrate bales (>10,000 ppm) as a supplemental feed (4-8 lb/cow/day).
- Discard extremely high nitrate (>20,000 ppm).

Consider some combination of the following:
- Adapt cattle with low to moderate nitrate hay by slowly increasing the feeding level.
- Feed high energy grain cubes to dilute nitrate intake and provide energy to stimulate microbial detoxification of nitrate.
- Establish propionibacteria (feed for 8 days) to minimize the effects of nitrate intake.

Scenario #3: Summer grazing of sorghum/sudan by beef stockers

Beef stockers (4-600 lb) will be released onto sorghum/sudan in mid summer (July 1).

Concerns:

What is the nitrate potential?

Although it is difficult to determine the actual nitrate content of a field, a thorough knowledge of the circumstances or factors that promote nitrate accumulation in plants should help us predict when nitrates could be a problem. For example, fertilization rates, rainfall, variety, etc. can all affect the potential for nitrate accumulation. If nitrate accumulation is likely, take extra management precautions to minimize nitrate intoxication.

Have cattle recovered from shipping stress?

Stressed, hungry cattle should not be released directly on to potentially toxic forage. Use the opportunity to put the cattle through a recovery program so that ruminal function and health status are normal. Then release the cattle.

Management:

Evaluate the potential nitrate exposure based on environmental conditions and previous management decisions. If necessary, delay release.

Consider some combination of the following:

- Adapt cattle to nitrate:
  - Use increasing levels of high nitrate feeds harvested in previous years.
  - Adapt cattle to sorghum/sudan forage by limit grazing for increasing hours for 5-7 days.
- Feed a high energy receiving ration to stimulate ruminal recovery and increase ruminal energy prior to release.
- Feed frequently to disrupt grazing patterns and provide fill.
- Establish propionibacteria (feed for 8 days) to minimize the effects of nitrate intake.
- Consider releasing in the afternoon when cattle are full and appetite is low.

Scenario #4: High nitrate forages in receiving programs

Newly received beef calves (4-800 lb) are fed sorghum/sudan-based receiving rations.

Concerns:

What is the nitrate potential?

Nitrate analysis of sorghum/sudan hay is essential. Bales should be sampled and identified to allow sorting into low and high nitrate groups. Design concentrate portion of diet so that nitrate is diluted adequately and energy is available to stimulate nitrate utilization by ruminal microorganisms.

How stressed are the cattle?

Moderately stressed cattle may consume large quantities of high nitrate hay because they are hungry and sorghum/sudan hay can be very palatable.

Heavily stressed cattle may not be hungry and their microbial activity may be low so they should not be as susceptible to nitrate upon arrival. As they recover from the stress and increase intake, nitrates may become more of a concern.

Management:

Minimize initial nitrate exposure for newly received cattle by using low nitrate hay first.

Consider some combination of the following:

Use increasing levels of high nitrate feeds to slowly adapt cattle to nitrate.

Feed a high energy receiving ration to stimulate ruminal recovery and increase ruminal energy.

Establish propionibacteria (feed for 8 days) to minimize the effects of nitrate intake.

Scenario #5: Dairy cows exposed to multiple sources of nitrate

Dairy cows are fed a diet that contains 20% corn silage (DM basis) harvested during a dry summer and consume water that is known to be high in nitrate.

Concerns:

What is the nitrate content of the corn silage?

The silage must be representatively sampled and analyzed for nitrate content. Nitrate analysis shows 8,000 ppm.

What is the nitrate content of the water?

Water nitrate must be determined to evaluate its contribution to nitrate intake. Nitrate analysis shows 200 ppm.

Management:

Calculate total nitrate intake to evaluate risk.

A 1,500 lb Holstein producing 100 lb milk/day will consume 58 lb dry feed and 40 gallons of water.

58 lb DM X 20% silage X 8,000 ppm =>	42.1 g nitrate/day
40 gal X 7 lb/gal X 100 ppm =>	<u>12.7 g</u> nitrate/day
Total nitrate intake	54.8 g nitrate/day

54.8 g nitrate X 1,000 mg/g /1,500 lb cow = 36 mg nitrate/lb BW

This quantity of nitrate (36 mg/lb BW) is within the range where rebreeding performance may be reduced and early term abortions may occur (Table 3). Acute toxicity, however, is not a concern.

Evaluate alternative roughage sources. To completely compensate for water nitrate, silage intake must be reduced to 2 lb DM/cow/day or 3.4% of diet DM. This level of corn silage may not be worth the trouble. Perhaps other, low nitrate, forages should be purchased for use with the high producing cows. The higher nitrate corn silage could be used with dry cows or other less productive animals.

Evaluate alternative water sources. If wells are the water source, consider drilling a deeper well to potentially draw lower nitrate water. Also evaluate other water

sources such as rural or city water. If surface water is used, determine the source of the nitrates (manure runoff, excess fertilizer, etc) and attempt to control the nitrate source.

Establish propionibacteria (feed for 8 days) to reduce nitrate effects in the rumen. Caution: Propionibacteria do not have a demonstrated effect on subacute nitrate toxicity.

Identify nitrate sensitive cows and cull. Some individuals are less able to physiologically manage nitrates and thus, are more susceptible to nitrate intake. These animals might be identified by blood nitrite or methemoglobin concentrations when they are first exposed to high nitrate diets. These animals should probably be culled.

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