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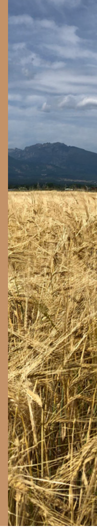

Patrick Mangan

AGRICULTURE AND NATURAL RESOURCES

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Nitrate Toxicity of Montana Forages

By Hayes Goosey, MSU Extension Forage specialist; Wendy Carr, Sanders County MSU Extension agent; Marc King, Sweet Grass County MSU Extension agent; Clain Jones, MSU Extension Soil Fertility specialist; Dan Severson, Pondera County MSU Extension agent

This publication outlines strategies for avoiding nitrate toxicity, including proper management, monitoring forage nitrate levels, and appropriate feeding programs.

FORAGE CROPS CAN ACCUMULATE TOXIC AMOUNTS OF nitrate (NO_3). High nitrate has been reported in cereal grains (oats, rye, wheat, barley, triticale, spelt, etc.), bromegrass, orchardgrass, fescue, sorghum, sudangrass, millet, corn, sweet clover and alfalfa. Several weeds, such as kochia, lambsquarter, pigweed, quackgrass and Russian thistle, can also have high nitrate levels, especially when growing under adverse conditions.

Nitrate poisoning of livestock was reported as early as 1895. Livestock losses occurred for many years before elevated nitrate levels in forage were determined to be the cause of death. The term "oat hay poisoning" was the common explanation for livestock losses in the 1930s, because large acreages of oats were harvested for forage during drought years, and oat accumulates nitrate more than most other cereal forages (Westcott et al., 2012).

Nitrate toxicity

Nitrate itself is not toxic to animals, but at elevated levels, it can cause a noninfectious disease called nitrite poisoning. At normal levels, forage nitrate is broken down by rumen microbes to nitrite (NO_2), and then further to ammonia (NH_3). This ammonia is then converted to protein by the rumen microbes for use by both the host animal and resident rumen microbes.

When an animal consumes excessive levels of nitrate, nitrite accumulates faster than it can be converted to ammonia and microbial protein. The accumulated nitrite passes into the small intestine, where it is absorbed into the bloodstream. Hemoglobin, the oxygen carrying molecule in blood, is converted to methemoglobin by high levels of nitrite. Methemoglobin is unable to supply oxygen to the body.

This low oxygen supply causes many negative effects in the animal (listed below). The intensity of nitrite poisoning is affected by the amount and duration of exposure to high nitrate levels. Chronic toxicity is caused by an animal consuming small amounts of high-nitrate forages over long periods of time, whereas acute toxicity is caused by a large amount of high-nitrate forage being eaten over a short period of time.

Signs of nitrate poisoning

Signs of early or chronic toxicity:

- Watery eyes
- Reduced appetite
- Reduced milk production
- Rough hair, unthrifty appearance
- Weight loss or no weight gain
- Night blindness
- Abortion

Signs of acute toxicity:

- Accelerated pulse rate
- Labored breathing, shortness of breath
- Muscle tremors
- Weakness
- Staggering gait
- Cyanosis (membranes such as the tongue, mouth, vulva and the whites of eyes, turn blue)
- Death

Treatment of chronic nitrate poisoning

The effects of sub-lethal nitrate levels on livestock health and performance are not well-defined. In our region, chronic symptoms such as abortions and poor winter health are of concern because we rely on hay during pregnancy and lactation. Safe and unsafe levels of nitrate in livestock feed have been established. Despite these guidelines, the effects of nitrate vary among individual animals, condition and age of livestock, other feeds in the diet and weather. Chronic nitrate toxicity can only be treated by knowing the N levels of forages and avoiding or diluting the affected feeds.

Treatment of acute nitrate poisoning

Acute nitrate toxicity can occur very rapidly, sometimes within minutes of observing the first signs. Oxygen transport in the blood is sharply reduced, causing the venous blood to become chocolate brown in color.

In these cases, the only way to save an affected animal is an immediate intravenous dose of methylene blue by a veterinarian. Due to the risk and speed of nitrate poisoning, relying on this treatment is not the best management practice to prevent nitrate toxicity death. Rather, producers should be aware of nitrate accumulating species and growing conditions, and use management strategies presented under "Guidelines for feeding livestock" to reduce potential nitrate toxicity.

Nitrate levels in plants

Nitrogen from the soil is taken up by plant roots in the form of nitrate. Plants convert nitrate to nitrite which in turn is converted to ammonia and then to amino acids, the building blocks of protein. Plant tissue accumulates nitrate during the night when photosynthesis is inactive, peaking in the morning. During the day, nitrate is quickly converted to protein when adequate sunlight energy is available. Under normal growing conditions, there is little nitrate buildup; however, in some cases the roots accumulate nitrate faster than the plant can convert nitrate to protein. Nitrate accumulation varies among crop species and varieties, crop management, soil fertility, plant parts and plant maturity **(Table 1)**.

When do toxic levels occur?

Abnormal, or "stressful", growing conditions such as drought, frost, unseasonable or prolonged cool temperatures, hail, shade, disease, insects, high levels of soil nitrate, soil mineral deficiencies or herbicide damage can cause high nitrate accumulation in forages. Crops grown under "stressed" conditions or on soils that have received high applications of manure or nitrogen fertilizer are especially suspect **(Table 1)**.

Mineral deficiencies, phosphorous and potassium in particular, may cause excessive accumulation of nitrates in the plant material. Adequate sulfur may also help to convert nitrate to plant protein, thus decreasing nitrate buildup. It is always important to fertilize according to soil test recommendations to ensure adequate soil and plant nutrient balances. Split nitrogen applications and weed control during the growing season can help manage excessive nitrogen in forages.

Preventative forage management to avoid nitrogen toxicity

- Soil test and apply nitrogen fertilizer in split applications during the growing season
- Control weeds, especially kochia, lambsquarter, and pigweed
- Plant dryland alternative cereal forages with high water use efficiencies, e.g. winter wheat, spring grains, etc.
- Cool-season cereal forages mature earlier and can be harvested prior to hail season, drought or frost.

HARVEST MANAGEMENT

Take precautionary measures prior to harvesting or feeding forage if you suspect high nitrate concentrations. Even under ideal conditions, nitrate accumulation is unpredictable. Elevated nitrate levels are particularly suspect following environmental events such as drought, rain, hail, wind (lodging), frost, etc. Nitrate concentrations can vary among areas of a single field, haystack or silo. Therefore, nitrate testing is advised in many situations. Most MSU Extension Agents can provide the "Nitrate QuikTest," which is a rapid, qualitative test for high nitrate levels (Cash et al., 2005).

Avoid cutting or grazing when nitrate concentrations are at peak levels. Since peak nitrate levels occur in the morning, delay haying or grazing until the afternoon of a sunny day. In high soil nitrate environments or with nitrate-accumulating

Table 1. Nitrate accumulation varies among crops, varieties, plant maturity, with forage treatment and nitrogen fertilization management.

Generality	Example NO_3 (ppm)		
Plant species and varieties vary in nitrate accumulation	Oats contained 1.5 times the nitrate as the average of oat, barley, spelt, spring wheat and triticale. Westford barley accumulated more nitrates than Haybet barley.[1]		
Nitrates decrease as plants mature	Oats at:	Heading	5047
		Flowering	4726
		Soft dough	3027
Plant parts vary in nitrates	Oat with 100 lb N/acre:	Stems[2]	8000
		Leaves	4200
		Heads	1000
Nitrates increase with high N fertilization	Oat stems at boot stage with:	50 lb N/acre[2]	6000
		100 lb N/acre	8000
		150 lb N/acre	12500
Ensiling tends to decrease nitrates once fermentation is complete	Corn with 200 lb N/acre as:	Green forage[3]	2319
		Silage	1468

[1] Westcott et al., 2012; [2] Crawford et al., 1961; [3] Vough et al., 2006

varieties, consider delaying harvest and raise the cutter head to avoid stalk bases. Nitrate concentrations will be highest in the lower third of the plant stalk, and so avoiding this area of the plant material will decrease risk of nitrate toxicity. If high nitrates are found or suspected in cereal forages, delaying harvest from flowering to soft dough stage can significantly decrease nitrate levels **(Table 1)**. Also, toxic levels of nitrate can accumulate in forages immediately after a drought-ending rain or irrigation. If possible, wait about a week before harvesting or grazing after drought-ending moisture (Fjell et al., 1991).

Anticipate and test for nitrates following an environmental event such as rain, hail, wind, disease or insect infestation, drought, overcast weather, etc.

If possible, harvest forage immediately after an environmental event and prior to shoot regrowth which is high in nitrogen.

Crimp hay to accelerate dry down and volatize nitrogen (denitrification).

Nitrate toxicity is most likely to occur when livestock are pastured or fed green-chop, followed by hay. Silage is the least hazardous feed. Ensiling forage usually lowers the nitrate level 10 to 60 percent, as the fermenting microbes are able to consume the nitrates present in the forage. The nitrate level in hay usually remains constant or declines slightly in storage; however, this should not be expected.

Producers should never assume their forage levels are safe if they know a crop was exposed to any adverse growing conditions that increase nitrate accumulation.

SAMPLING PLANTS OR FEEDS FOR NITRATE

Forage sampling is essential to ensure livestock meet their nutritional requirements and to identify forages high in nitrates (NO_3). Forages are sampled in multiple ways depending on the forage type. Following proper sampling procedures, outlined in the MontGuide *Collecting a Forage or Feed Sample for Analysis*, (MT201610AG) will guarantee an accurate representation of the forage being sampled.

To prepare the sample for a quantitative NO_3- test, forages must be dried and ground prior to testing. This can be done using a microwave to dry the forages and a coffee grinder to grind the forages. The main disadvantage of the microwave technique is that the sample drying process is labor-intensive. The steps and activities performed to dry forages with a microwave need to be done every two to three minutes. If the recommended steps are not followed, there is a risk the sample will not be completely dried or be charred.

As an alternative a residential air fryer could be used to dry the forages. An air fryer is a small convection oven that uses forced air like the ovens used in laboratories, to dry the forage sample. Air circulates around the forage placed in the fry basket. Since an air fryer uses air for sample drying, it is recommended to place wire cloth cut in the shape of the basket, on top of the sample. The wire cloth traps the small sample particles keeping them from escaping out the exhaust vent.

This drying option does not have to be watched because there is no way to accidentally start a fire. After you have collected a forage sample, cut the sample into 1–2-inch lengths.

Add the cut sample to the basket. Set the fryer temperature to 250˚F and set the timer for 30 minutes. After time has expired, you may proceed to grind the sample and follow the instructions for performing a quantitative NO_3- test. Periodic testing may be necessary to assure that the nitrate level has declined.

If high nitrates are detected and growing conditions are normal, delay harvest for several days, which will usually reduce nitrate levels rapidly. Use the quantitative test for forages suspected of having elevated levels of nitrate. The test results can be interpreted using **Table 4**.

Sampling hay or haylage (low moisture silage) for nitrate requires collection and testing of appropriate samples. An accurate measurement of forage nitrate is not possible unless the sample analyzed in the laboratory is representative of the forage lot in question. Poor sampling techniques or an inadequate number of subsamples are the main sources of error in analysis. Hay or haylage from different 'lots', that is harvested at different times (more than 48 hours apart) or from different fields, should each make up their own sample to be analyzed. Each 'lot' sample should be a composite of random subsamples taken from 20 bales or representing 10 percent for the stored forage.

At least one pound of forage is necessary for an adequate sample. Keep silage samples frozen until analysis to prevent nitrogen losses from volatilization or chemical changes. Seal hay and silage samples in plastic bags and ship to the laboratory in dry ice or insulated container for testing as soon as possible. See your Extension agent for a list of laboratories that provide forage nitrate testing. For forage sampling protocol, refer to MontGuide MT201610AG *(Collecting a Forage or Feed Sample for Analysis).*

Nitrate laboratory reports

Results of nitrate analysis may be confusing because of the variation in reporting methods. Further confusion and questions exist because of varying guidelines on what levels of nitrate can be fed safely. In the chemical analysis for nitrate, the actual element determined is the oxidized nitrogen. However, values may be reported as percent nitrate or nitrate-nitrogen (NO_3-N). Efforts have been made to have nitrate analysis and tolerances for safety uniformly reported as nitrate-nitrogen on a 100 percent dry matter basis. However, at present, reports may be given as nitrate or nitrate-nitrogen reported as either percent or as parts per million **(Table 2)**.

Table 2. Converting one form of nitrate to another.

Generality	Example NO_3 (ppm)	
	To convert reported data to one of these, multiply by:	
Reported as	**NO_3–N**	**NO_3**
Nitrate-nitrogen (NO_3–N)	(1)	4.4
Nitrate (NO_3)	0.23	(1)

Examples:

0.1% NO_3–N = 0.44% NO_3 (0.1 x 4.4);

0.44% NO_3 = 0.1% NO_3–N (0.44 x 0.23)

0.1% = 1000 ppm (move decimal point four places to the right)

750ppm = 0.075% (move decimal point four places to the left)

Nitrate in water

In addition to forages and other feeds, drinking water can significantly contribute to nitrate toxicity. Nitrate in water can pose a greater risk than forage nitrate (Hibbard et al. 1998). Therefore, threshold hazard levels are lower for water than those for feeds **(Table 3)**.

Nitrate applied to or produced in the soil may leach into groundwater or run-off into surface water. It is more concentrated below or near areas of animal and human fecal accumulation or disposal (e.g. feedlots, septic tank drain fields). High nitrate is more likely to be found in groundwater under low areas and waterways. Water from shallow, dug, bored and driven wells more frequently contains high nitrate than water from deep drilled wells. Test water from wells immediately following a wet period when levels tend to be highest (Undersander et al., 1999).

Portable meters are available to field test water nitrate levels before turning stock onto a pasture. If the water quality is questionable, get the water tested by a laboratory; your Extension agent or county health department can help with this.

Guidelines for feeding livestock

Due to the variations in plants, water sources, and livestock, it is difficult to develop specific guidelines that fit all conditions. If there is a potential nitrate problem, growers should first have an accurate laboratory analysis of the suspect forage nitrate concentration. The nitrate concentrations and risks listed in **Table 3** assume that high-nitrate forages comprise the entire diet, rather than a portion of the ration, and do not account for differences in animal size. For example, a 500-pound

Table 3. Guidelines for use of drinking water with known nitrate content[1].

NO_3–N (ppm)	NO_3 (ppm)	Comment
< 10	< 44	Generally regarded as safe for all animals and humans.
10 – 20	44 – 88	Questionable or risky for humans, especially young children and pregnant women. Safe for live- stock unless feed also has high levels. Animals drinking 10 pounds of water per 100 pounds of body weight would have intake of less than 0.1 gram NO_3–N per hundred pounds of weight if water contains 20 ppm NO_3–N.
20 – 40	88 – 176	Considered unsafe for humans; may cause problems for livestock. If ration contains more than 1000 ppm NO_3–N and the water contains over 20 ppm, the total NO_3–N is likely to exceed safe levels.
40 – 100	176 – 440	Unsafe for humans and risky for livestock. Be sure that feed is low in nitrate and a well-balanced ration is fed. Fortify ration with extra vitamin A.
100 – 200	440 – 880	Dangerous and should not be used. General or non-specific symptoms such as poor appetite are likely to develop. Water may also be contaminated with other foreign substances. When allowed free choice to cows on a good ration, acute toxicity not likely.
> 200	> 880	**DO NOT USE.** Acute toxicity and some death losses might occur in swine. Probably too much total intake for ruminants on usual feeds.

[1] *Source: Undersander et al., 1999.*

Table 4. Effect of nitrate concentration on livestock[1]. These guidelines are more conservative than some others published.

Reported on 100% dry matter basis[2] as:

NO_3–N (ppm)	NO_3 (ppm)	Comment
< 350	< 1,500	Generally safe for all conditions and livestock.
350 – 1,130	1,500 – 5,000	Generally safe for nonpregnant livestock. Potential early-term abortions or reduced breeding performance. Limit use to bred animals to 50% of the total ration.
1,130 – 2,260	5,000 – 10,000	Limit feed to 25–50% of ration for nonpregnant livestock. **DO NOT FEED TO PREGNANT ANIMALS** – may cause abortions, weak calves and reduced milk production.
> 2,260	> 10,000	**DO NOT FEED.** Acute symptoms and death.

[1] *Source: Hibbard et al., 1998;* [2] *If nitrate content of a feed is reported on an "as is" basis, convert to 100% dry matter basis to compare it to levels in this table. For example, silage at 40% moisture that contains 600 ppm NO_3–N on an "as is" basis contains 600 ppm/0.6 = 1000 ppm on 100% dry basis; thus it fits the second group in this table.*

steer may have nitrate toxicity after consuming 15 pounds (3% of body weight) of barley hay that contains 8,000 ppm nitrate. However, if the steer weighs 1000 pounds or hay intake is limited to six pounds per day, no problems may occur. Therefore, the potential nitrate risk is better expressed as total nitrate consumption on a bodyweight basis **(Table 5)**.

The following guidelines were developed conservatively to help assure animal safety. Reasonable animal health, feeding and care is assumed. Safe levels of nitrate are not specifically known for all various livestock feeding conditions.

Forages with sub-lethal nitrate levels can be fed to healthy livestock with appropriate precautions:

- feed hungry livestock tested dry hay prior to exposure to decrease likelihood of rapid overconsumption,
- graze or cut forages in the afternoon when nitrate levels are lowest
- stock lightly so animals can select leaves, the lowest nitrate-containing portion of plants
- adapt livestock gradually to increasing levels of the suspect forage, see Strickland et al., 2003, for details
- feed grain with the hay to stimulate rumen microbes to convert nitrate to nontoxic amino acids and proteins at a faster rate, and
- blend with low-nitrate feeds.

Never turn hungry animals onto pasture with heavy dew or after irrigation.

High-nitrate feeds can be diluted with low-nitrate feeds to reduce the nitrate hazard of the ration using the following equation:

WL = (WH) (%H - %B) / (%B - %L), where
WL = weight of safe, low-nitrate hay required,
WH = weight of high-nitrate hay,
%H = nitrate concentration of high-nitrate hay,
%B = nitrate concentration desired in final blend,
%L = nitrate concentration of low-nitrate hay required for blending.

For example, a producer with 10 tons of hay tested at 0.6 percent (6000 ppm) nitrate, could blend 15 tons of hay tested at 0.1 percent (1000 ppm) to produce 25 tons of feed with 0.3 percent (3000 ppm) nitrate. The two hay lots should be processed and mixed thoroughly in a tub grinder to provide the proper dilution. The contribution of nitrates in drinking water towards total nitrate intake must be considered when calculating 'safe' feed blends. Also, if urea supplement is available in addition to high nitrate feed, it can exacerbate the rumen's high nitrate induced ammonia imbalance and lead to additional neurotoxic symptoms (urea toxicity) caused by excessive ammonia.

Boluses or feed additives containing the rumen bacteria Propionibacterium acidipropionici strain P5 (the active ingredient in Bova-Pro®) reduce the probability of nitrate toxicity. Boluses should be fed once, 10 days before exposure to high-nitrate feed, while the feed additive needs to be fed daily for 10 days prior to feeding high-nitrate feed (Highfill, 2011). The additive must also be ingested daily in order to ensure microbial survival and effectiveness. This supplement does not provide instant protection or heal affected animals and should be used in combination with other preventive measures.

In addition to the variations in plant and environmental factors that contribute to nitrate toxicity, there can be extreme variability among livestock for predisposal to nitrate toxicity. In feeding trials where toxic doses of nitrate were administered to

Table 5. Determining feed and water nitrate uptake per pound of animal weight.

Nitrate from feed (mg/lb body weight) = [concentration of NO_3–N (ppm) x dry forage consumed per day (lb)]/body weight (lb)
Using 3% dry matter intake (DMI), this equation simplifies to: concentration of NO_3–N(ppm) x 0.03
Nitrate from water (mg/lb body weight) = [concentration of NO_3–N (ppm) x gallons consumed per day x 8.3 (lb/gallon)]/body weight (lb)
Total nitrate intake (mg/lb body weight) = nitrate from feed + nitrate from water

Toxicity of total daily nitrate intake in milligrams (mg) per pound of body weight[1].

NO_3–N	NO_3	Comment
< 5	< 20	Generally safe for all conditions and livestock.
5 – 14	20 – 60	Generally safe for nonpregnant livestock. Potential early-term abortions or reduced breeding performance. Limit use to bred animals and to 50% of the total ration.
14 – 28	60 – 120	Limit feed to 25–50% of ration for nonpregnant livestock. **DO NOT FEED TO PREGNANT ANIMALS** – may cause abortions, weak calves and reduced milk production.
> 28	> 120	**DO NOT FEED.** Acute symptoms and death.

[1] *Hibbard et al., 1998*

a uniform group of beef cattle, there were three- fold differences among animals in the rate of blood methemoglobin formation (Hibbard et al., 1998). Diet and the rumen environment can significantly impact nitrate tolerance by individuals. Livestock that are thin or suffer from respiratory infections are more prone to nitrate toxicity.

Consult with your local Extension Agent for specific questions regarding sampling of forage suspected of containing dangerous levels of nitrate and your veterinarian about nitrate poisoning.

Summary

- There are many factors that can increase nitrate levels in forage.
- Soil test and apply appropriate nutrients.
- Select forage types and crop rotations to avoid toxic nitrogen buildup.
- Control high nitrogen accumulator weeds within forage stands.
- Time harvest and grazing to minimize risk of nitrate toxicity.
- Monitor crop nitrate levels, especially immediately prior to harvest.
- Test your forages and water if there is potential for nitrate toxicity.
- Dilute any high-nitrate forages with low-nitrate forages to create a safe ration for livestock.

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