



Chapter 21

Plant Toxicities, Defensive Chemical Compounds, and Other Feed Concerns

Derek W. Brake and Adele Harty

SDSU Extension is an equal opportunity provider and employer in accordance with the nondiscrimination policies of South Dakota State University, the South Dakota Board of Regents and the United States Department of Agriculture.

Chapter 21: Plant Toxicities, Defensive Chemical Compounds, and Other Feed Concerns

Introduction

Plants produce various chemical compounds that can be toxic to cattle and other herbivores. The primary biological goal of plants is to survive; however, plants are immobile and unable to escape consumption by herbivores. Thus, plants have adapted strategies to utilize chemical and physical defenses to create aversions among herbivores. This has led to the evolution of many plant defensive chemical compounds.

Not all plant defensive chemicals are toxic to animals. In fact, many defensive compounds (e.g., lignin) simply limit digestibility and selection among grazing animals. Regardless of toxicity to animals, plant defensive chemical compounds often provide no direct benefit to the plant, other than providing protection from consumption by herbivores and resistance to wind, disease, or other environmental factors (Van Soest, 1994). Because the direct benefits to the plant are limited, generally plants do not produce extensive amounts of defensive chemical compounds except under occurrence of stress (e.g., over-grazing, disease, adverse weather; Van Soest, 1994). It is important to note that in addition to large ruminants, herbivores include microbes, insects, birds and other animal species that consume plant tissues (Cheeke, 1995). Thus, stresses to plants that lead to production of defensive chemical compounds and potential toxicities, are not always directly related to grazing pressures from cattle. Therefore, a basic understanding of defensive chemical compounds of some plants is necessary to prevent possible negative effects on performance and in some cases, toxicosis among cattle.

The purpose of this chapter is to discuss plant defensive chemical compounds, potential toxicities and other feed concerns common to South Dakota and the Northern Great Plains at the time of publication. This chapter is not a comprehensive discussion all potential toxicities and plant defensive chemical compounds. Reviews on this topic by Drs. Peter Cheeke (1995) and Peter Van Soest (1994) provide more information. Additionally, the Animal Science Department at Cornell University (Brown, 2014) currently

Key Points

- Plants produce various chemical compounds that can be toxic to cattle and other herbivores.
- Prussic acid is most often associated with forage sorghums, sudangrass, and sorghum-sudangrass hybrids and is most likely to cause toxicity problems after a killing frost.
- Ponderosa pine needles contain isocupressic acid, which is a chemical compound that causes abortions in gestating cows by limiting blood flow to the uterus.
- Nitrates can be a concern regardless of environmental conditions, but the problem is worse in a drought or with early or late frosts. Nitrates can be found throughout the plant, but concentrations will be greatest in the stalks or stems, therefore some management practices can be used in order to decrease the risk.

maintains an updated online reference of plants that are poisonous to livestock. These and other literature cited provide a good starting point for readers seeking further information related to this topic.

General Concepts

Production of defensive chemical compounds toxic to cattle is not common to all plants. Generally, plants have evolved to use one of two broad strategies for survival. One strategy is symbiosis with herbivores whereby plants emphasize growth that provides good nutritive value to herbivores and storage of nutrients to support regrowth after grazing. Plants that have adopted this survival strategy are dependent on herbivores to create a grazing environment, provide nutrients for growth or disperse seeds (Van Soest, 1994). Many forage grasses utilize a strategy of symbiosis with herbivores (Cheeke, 1995). Alternatively, many herbaceous plant species produce defensive chemical compounds that can limit digestion, animal performance or contribute to toxicosis. It is important to note that native and introduced grasses can contain fungal metabolites (e.g., alkaloids) that can have toxic effects on animals. Nonetheless, cattle generally avoid consuming toxic plant material in amounts that will be harmful to them (Rhoades and Cates, 1976). Typically, toxicosis occurs when cattle are forced to consume toxic material (Van Soest, 1994). Examples of situations where cattle can be forced to consume toxic materials include overgrazing of pastures, feeding toxic feeds to cattle in confinement, and grazing of toxic monoculture pastures.

Ruminal fermentation has potential to detoxify some, but not all plant defensive chemical compounds (Allison, 1978; Cheeke, 1988; Van Soest, 1994). This may contribute to grazing behaviors where cattle will often limit intake of amounts of potentially toxic material. We will focus our discussion on plant defensive chemical compounds that cattle have limited to no capability to detoxify via pregastric fermentation that are most commonly found in South Dakota and the Northern Great Plains Region.

Summary of Selected Potential Toxins and Plant Defensive Chemical Compounds

Some potentially toxic plant defensive chemical compounds common to South Dakota and the northern Great Plains region are alkaloids, nitrates, cyanogenic glycosides, and terpenoids. Included is a brief description of each category of toxin.

Alkaloids

Alkaloids are a diverse group of toxins for which the most common occurrence of toxicity to livestock is related to fungi associated with plants; however, some plants do have intrinsic alkaloid production.

Reed canarygrass is common in wet or poorly drained pastures. Cattle display an aversion to reed canarygrass which is most likely related to the presence of alkaloids. Cattle performance is often affected by consumption of reed canarygrass containing greater than 0.2% alkaloid content. Generally, depressed animal performance is associated with greater incidences of diarrhea. Reed canarygrass cultivars that contain small amounts of alkaloid are available and these cultivars support greater animal performance compared to native reed canarygrass. Stress conditions such as heavy grazing can increase the content of alkaloids in reed canarygrass. Harvesting reed canarygrass may decrease alkaloid content; ensiling has no apparent effects on alkaloid concentration (Cheeke, 1995). Consumption of reed canarygrass by cattle is often not fatal; however, other plants similar to reed canarygrass have been associated with lethal toxicoses (e.g., Phalaris aquatica).

English yew, Canada yew and Japanese yew are common ornamental shrubs that contain intrinsic toxic alkaloids. These shrubs are members of the Taxus genus and toxicosis from ingesting these ornamental shrubs is often referred to as Taxus poisoning. Yew shrubs are an introduced plant and are not likely to occur in pastures. Typically, Taxus poisoning occurs when needles from these ornamental shrubs are made available to cattle by depositing in pastures. Cattle do not display an aversion to consumption of yew needles and Taxus poisoning is lethal; ingestion of 0.1% to 1.0% of body weight of yew needles can result in a rapid death of cattle. Endophytic fungi associated with some forages produce toxic alkaloid compounds. Many of these alkaloids act as vasoconstriction agents or neurological agents in cattle. Perennial ryegrass contains fungal metabolites referred to as tremorgens. Tremorgens cause perennial ryegrass staggers. Perennial ryegrass staggers is characterized by neurological disorders that can include head shaking, staggering and collapse. Perennial ryegrass staggers is often temporary, but can put animals in harm by impairing agility. Tremorgens are stored in greatest concentration in the leaf sheathes of perennial ryegrass. Thus most occurrences of perennial ryegrass staggers occur in overgrazed pastures.

Cyanogenic Glycosides (including Prussic Acid)

Hydrogen cyanide, also referred to as prussic acid, is associated with forage sorghums, sudangrass, and sorghum-sudangrass hybrids. Also included in this group of plants are johnsongrass, chokecherry, and black cherry. In normal growing conditions, prussic acid poisoning is not a significant concern, but if plant growth is slowed, development of the cyanogenic glycosides may increase in the plant. When these compounds are intact and bonded, they are not poisonous, but when specific enzymes in the plant break the bond, free cyanide, hydrocyanic acid (HCN) or prussic acid is formed. This conversion is more likely to take place when plant growth has been slowed, specifically during drought or immediately following frost, therefore caution needs to be taken if plans are to graze plants when these conditions are present.

Various plants have different concentrations of prussic acid, with sorghums being much greater than sudangrass and sorghum-sudangrass hybrids. The prussic acid concentrations are greatest in leaves and young plants less than 18" tall. The general recommendation is not to pasture sorghum, except after plants have reached maturity and no new growth is present, as the new growth will contain the greatest concentration of prussic acid. Typically the danger of prussic acid poisoning is greatest in small, immature growth following clipping, drought, frost or grazing. In many of these situations, the primary danger is from regrowth. Under most circumstances, silage and well-cured stalk residue (hay) can be safely fed to cattle. Silage may contain toxic levels of HCN while in storage, but much of the HCN escapes as gas during fermentation and when being moved for feeding. It is recommended that new silage not be fed for at least three weeks after ensiling. The HCN content of hay decreases as much as 75% while curing and is rarely hazardous.

The best management practices for working with prussic acid are to be aware of environmental conditions and the effect they have on the plants. If a killing frost occurs, immediately remove the animals from the field for approximately 10 days. This allows the HCN gas to dissipate from the plants through the broken cell walls. Once the risk has been minimized, the cattle can be returned to the field to continue grazing. However, if the frost was not killing and there is a fall warm-up and new shoots begin to emerge, the cattle must be removed immediately as the resulting small, immature plants will contain extremely large concentrations of prussic acid.

Prussic Acid Poisoning Symptoms

Following consumption of feeds containing large amounts of prussic acid (i.e., HCN), the acid is rapidly absorbed into the bloodstream. Toxicity occurs almost immediately with animals dying within 15 to 20 minutes after consuming the forage. Due to the rapid toxicity, signs of poisoning are rarely seen, but can include increased respiration rate, increase pulse rate, gasping, muscular twitching or nervousness, trembling, foaming at the mouth, blue coloration of the lining of the mouth, and spasms or convulsions. The animals ultimately die from asphyxiation at the cellular level, meaning that the blood is oxygen rich, but the body cells cannot absorb the oxygen. Animals that have died from prussic acid poisoning will have cherry red colored blood.

If questionable feeds are to be utilized through grazing, samples should be sent to a laboratory for analysis. Table 1 shows the toxicity levels for HCN. For more tips on grazing forages containing prussic acid, see Prussic Acid Poisoning of Livestock: Causes and Prevention (Harty, 2015).

Table 1: Generalized interpretation	for forage HCN test
-------------------------------------	---------------------

Toxicity Levels for HCN				
ppm HCN (dry matter basis)	% HCN	Interpretation		
0-250	0-0.025%	Slight-safe to graze		
250-500	0.025-0.05%	Small-safe to graze		
500-750	0.05-0.075%	Intermediate- exercise caution to graze		
750-1000	0.075-0.1%	Large-dangerous to graze		
>1000	>0.1%	Very large-very dangerous to graze		

Isocupressic Acid (Pine Needle Abortion)

Ponderosa pine trees are prevalent in the central and western United States. Ponderosa pine needles contain isocupressic acid; a chemical compound that causes abortions in gestating cows by limiting blood flow to the uterus. Historically, incidences of pine needle abortion have been broadly reported in the Black Hills (Cogswell, 1974, Lacey et al., 1988, Pfister et al., 1998). Abortions can occur in the final trimester; thus, contributing to substantial economic loss.

Intake of pine needles by cattle is related to availability of forages other than pine needles. Generally, greater snow cover and decreased availability of grasses for grazing increase intake of pine needles (Pfister et al., 1998). Susceptibility of pine needle abortion increases with increasing stage of gestation. In the final trimester, cattle that consume about 3 to 5 pounds of needles for several days will often experience abortion (Short et al., 1997). Management strategies have been evaluated to limit effects of pine needles on gestating cattle. Early parturition (i.e., early birthing) can be blocked by feeding melengesterol acetate (MGA) or aspirin (a prostaglandin inhibitor; Short et al., 1997), but these substances will not increase blood flow to the uterus and calves can still die in utero (Short et al., 1997). Feeding cattle more than 25% corn silage can limit intake of pine needles (Short et al., 1997). Unfortunately, it is often difficult or not feasible for producers to provide large amounts of corn silage to cattle that can consume large amounts of pine needles.

Nitrates

Nitrates can be a concern regardless of environmental conditions, but the problem is worse in a drought or with early or late frosts. In the process of normal ruminal digestion, nitrate (NO_3) is rapidly converted into nitrite (NO_2) , the NO_2 to ammonia (NH_3) , NH_3 to amino acids and protein. When too much nitrate enters the system too rapidly, it is rapidly converted to nitrite, but the conversion to ammonia is a much slower process, which can result in poisoning of the animal.

This results from nitrite being absorbed in the bloodstream with potential detrimental effects, including abortion, reduced milk production, weight loss, muscle tremors, and death. The death of these animals is the result of the blood being unable to transport oxygen for the animal and will be characterized by a chocolate brown color. The degree of severity of these symptoms is dependent on the concentration of nitrate in the feed and water. Table 2 provides a guide for levels of nitrate in feeds for mature cattle.

Nitrates can be found throughout the plant, but concentrations will be greatest in the stalks or stems, followed in order by leaves and grain in decreasing amounts. The greatest concentration will be in the lower 1/3 of the stem, therefore some management practices can be used in order to decrease the risk. This can include increasing the cutting height so that the greater concentrate nitrate feed is left in the field. This residue should not be used for grazing purposes. Alternatively, animals can be allowed to graze for a few hours a day and then moved to a feed source that does not have nitrates.

Nitrate Accumulators

Specific plants are known to be nitrate accumulators, so necessary precautions should be taken prior to feeding these forages specifically. The process of building proteins in plants is similar to the process outlined above. The plant takes nitrogen from the soil as nitrate, which is rapidly converted to nitrite, slowly converted to ammonia, then to amino acids and proteins. When this process is slowed down or stopped suddenly in the plant, large levels of nitrates will remain, unless the plant begins to grow again. Below is a list of forages that accumulate nitrates, with those at the top of the list having the greatest Table 2: Guide for nitrate levels in mature cattle. Nitrate Poisoning of Livestock Causes and Prevention, iGrow.

Percentage of	Content of nitrate-nitrogen (dry matter basis)			
nitrate ion (NO ₃) (dry matter basis)	Percentage	ppm²	Comments ¹	
Less than 0.44	0.0-0.10	0-1,000	Safe to feed if adequate feed and water are available	
0.44-0.66	0.1-0.15	1,000-1,500	Safe for nonpregnant animals. Limit to 50% of total ration dry matter for pregnant animals; animals may go off feed, have a slow drop in production, some abortions are possible.	
0.66-0.88	0.15-0.20	1,500-2,000	Limit to 50% of total ration dry matter for all animals; may experience some symptoms, possibly death.	
0.88-1.54	0.20-0.35	2,000-3,500	Limit to 35 to 40% total ration dry matter. Do not feed to pregnant animals.	
1.54-1.76	0.35-0.40	3,500-4,000	Limit to 25% total ration dry matter. Do not feed to pregnant animals.	
greater than 1.76	greater than 0.4	greater than 4,000	Toxic. DO NOT FEED.	
¹ Total ration dry matter refers to total dry matter being consumed as forages and concentrates.				

² ppm = parts per million

probability of nitrate levels that cause toxicity.

- 1. Small grains, especially oats
- 2. Corn, sudangrass, sorghum, millet
- 3. Bromegrass, orchardgrass, fescue
- 4. Sweetclover, alfalfa
- 5. WEEDS: wild oats, quackgrass, pigweed, lambsquarter, kochia, Russian thistle, etc.

Multiple factors influence the level of nitrate accumulation including level of nitrogen fertilizer, stage of growth, time of day, stressors including drought and frost, and variability across a field. For example, a field that has received a large amount of nitrogen fertilizer is more likely to contain large concentrations of nitrates compared to a field that did not have additional nitrogen fertilizer applied. This becomes a bigger concern if precipitation is below average as the plant is not able to complete the process of converting the nitrogen into proteins. Also, more immature plants will have greater nitrate levels. As the plant matures, the nitrate is converted to protein in the seed. Therefore, time of cutting is critical to minimizing nitrate levels in plants to ensure safety for feeding. Due to availability of soil nitrogen from different soil types there will also be variability in plant nitrate levels across a field. Thus, it is critical to sample throughout the field to get a

representative sample of the plants to determine risk.

A key point with nitrates is to understand that once the plant has been harvested or matured, the nitrate level will not change. For instance, if oat hay has been harvested and it contains 2100 ppm NO₃⁻N (nitrate-nitrogen), that feed can only be used for non-pregnant cattle and only make up 35 to 40% of the ration (Table 2).

Nitrate Quick Test

The nitrate quick test is a tool used by many University Extension staff and other trained individuals to assess the presence of nitrate in standing forage prior to harvest. The results of the test are based on color, and indicate presence of nitrate, but do not quantify the nitrate levels. The test uses a solution of diphenylamine and concentrated sulfuric acid as an indicator of nitrates. The solution is placed on the lowest nodes of the plant and if a blue color change occurs, nitrates are present, and additional testing needs to be completed prior to harvest and/or feeding. If there is no color change, nitrates are not present and the feed is safe to harvest and feed to cattle. Training is available from University personnel for producers and others to learn how to conduct these tests.

References

- Allison, M. J. 1978. The role of ruminal microbes in the metabolism of toxic constituents from plants. In: Effects of Poisonous Plants on Livestock. R. F. Keeler, K. R. Van Kampen, and L. F. James, eds. Academic Press, New York.
- Brown, D. 2014. Plants Poisonous to Livestock. Cornell University. <u>http://www.ansci.cornell.edu/plants/index.</u> <u>html</u>. (Accessed 14 July 2014.)
- Cheeke, P. R. 1995. Endogenous toxins and mycotoxins in forage grasses and their effects on livestock. J. Anim. Sci. 73:909-918.
- Cheeke, P. R. 1988. Toxicity and metabolism of pyrolizidine alkaloids. J. Anim. Sci. 66:2343-2350.
- Cogswell, C. A. 1974. Pine needle (Pinus ponderosa) abortive factor and its biological determination. PhD Diss., South Dakota State Univ., Brookings, SD.
- Harty, A. (Review and Revision), L.R. Vough and E.K. Cassel. 2015. Prussic Acid Poisoning of Livestock: Causes and Prevention. iGrow (submitted)
- Lacey, J. R., L. F. James, and R. E. Short. 1988. Ponderosa pine: economic impact. p. 95-106. In: L. F. James, M. H. Ralphs, and D. B. Nielsen (eds.). The ecology and economic impact of poisonous plants on livestock production. Westview Press, Boulder, Colo.
- Pfister, J. A., K. E. Panter, and D. R. Gardner. 1998. Pine needle consumption by cattle during winter in South Dakota. J. Range Manage. 51:551-556.
- Rusche, W., E. Kim Cassel, L. R. Vough, S.M. Barao. 2012. Nitrate Poisoning of Livestock Causes and Prevention. iGrow Resources.
- Short, R. E., S. L. Kronberg, E. E. Grings, J. P. Rosazza, and S. P. Ford. 1997. Reproductive toxicology: Pine needles and plant estrogens. Range Beef Cow Symp. Paper 148.
- Van Soest, P. J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell Univ. Press, Ithaca, NY.