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Anti-Quality Factors in Rangeland and Pastureland Forages

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Forward

The goal of this publication is to review major anti-quality factors that influence livestock production on range and pasture lands. Anti-quality components of forages are quite simply any factor inherent in forage that limits the ability of a grazing animal to reach its potential for growth and reproduction. There are a number of frequently encountered effects of anti-quality factors such as bloat, mineral disorders, nitrate toxicity, poisonings from plant toxins such as glycosides or alkaloids, neurological effects, photosensitization, and disorders associated with microorganisms and insects. Lignin, tannins, thorns, and spatial arrangements of plants are also considered anti-quality attributes because they reduce intake or digestibility.

Contemporary livestock production systems have increasingly focused on optimizing the use of forages for economic viability, environmental concerns, animal well being, and quality of life issues. As we place more emphasis on forages for animal production, we need to thoroughly understand the potential limitations to reaching management objectives.

This management bulletin is the outgrowth of a symposium on anti-quality attributes of rangeland and pastureland forages presented at the1999 joint meeting of the American Forage and Grassland Council (AFGC) and the Society for Range Management (SRM). The symposium was sponsored by the USDA-NRCS Grazing Lands Technology Institute and organized by AFGC and SRM members:

Vivien Gore Allen, Texas Tech University
Richard Joost, American Plant Food Corporation
Karen Launchbaugh, University of Idaho
Rosa Muchovej, University of Florida
Arnold Norman, Grazing Lands Technology Institute

The 1999 symposium served as a comprehensive and contemporary review of anti-quality factors in range and pasture plants. The speakers at the symposium were authorities on specific anti-quality attributes. These scientists also prepared papers that were published in Volume 54 of the Journal of Range Management in July 2001.

An important conclusion of this project was to present information on anti-quality attributes in a format useful to livestock and land managers. To accomplish this task, the authors of the 1999 anti-quality symposium worked with graduate students and research technicians at the University of Idaho to convert scientific manuscripts into this management bulletin. Thus, the chapters of this bulletin were created by teams of students and scientists. These teams deserve credit for their efforts to help farmers, ranchers, and land managers understand the complex issues presented by anti-quality factors.

Graduate students from the University of Idaho involved in this anti-quality project were: Jen Ropp, Curtis Yanish, Jeffrey Beck, Robert Garcia, Mitch Thomas, Silvia Lopez, Lance Kennington, Michael Hale, Juley Hankins, and Daniel Patten.

Special thanks to their faculty mentors: F.D. Provenza , L.A. Shipley, J.D. Reed, K. Moore, N. Schneider, J. A. Pfister, F. N. Thompson, W. Majak, H.F. Mayland, and J.B. Campbell

Anti-Quality Components in Forage: Overview, Significance, and Economic Impact[1]

Vivien Gore Allen[2] and Eduardo Segarra[3]

Introduction

Forages have too often been underestimated and undervalued compared with other crops. Perhaps this is due in part to the potential presence of anti-quality factors that can limit animal performance and may cause animal health problems. What is 'forage quality' and 'anti-quality'? Forage quality can be defined as *the degree to which a forage meets the nutritional requirements of a specific kind and class of animal.* An 'anti-quality component' would, therefore, be *any factor that diminishes the degree to which a forage meets the nutritional requirements of a specific kind and class of animal*. Because animals differ in nutritional needs and their ability to handle various toxins, a high quality forage for one animal may be low quality for another. For example, a forage that meets the nutritional needs for dry cows would, thus, be a high quality dry cow feed, but may not meet the requirements for finishing steers and would, therefore, be a low quality finishing diet. Likewise, a chemical toxin or a physical inhibitor to intake for one species or class of animal may have little effect on another species or class of animal. Animal behavior and adaptation are increasingly recognized as important aspects of anti-quality factors. For example, the ability of ruminant animals to detoxify many of the potentially harmful plants has long been recognized. Palatability, rate of passage, digestibility, nutrient density and balance, and intake are all factors determining the degree to which the forage is able to meet the nutritional demands of the animal.

The economic impact of anti-quality factors on individual herds can be devastating but definable. Broadscale economic impacts of anti-quality factors are far more difficult to estimate. Tall fescue toxicity has been estimated to cost the beef industry over $600 million annually. Reproductive and death losses of livestock due to poisonous plants have been estimated at $340 million in the

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[1]Based on: Allen, V.G. and E. Segarra. 2001. Anti-quality components in forage: Overview, significance, and economic impact. Journal of Range Management. 54:409-412.
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17 western states alone. If even a small proportion of these expected losses were eliminated through research, the potential payoff would be very high. This takes on added importance with increased recognition of forage as a feed resource.

Classes and Kinds of Anti-quality Components

Anti-quality in forages is caused by a wide array of factors. These may have evolved as structural components of the plant or as secondary metabolites resulting in plant defense mechanisms. Anti-quality components can result in mineral deficiencies, toxicities, or nutritional imbalances. The origin of anti-quality attributes can be phytochemicals in plant tissues or structural inhibitors in leaf and stem arrangement. Specific chemical inhibitors of quality can result from plant metabolism or from microbes living in plants. Anti-quality factors in forages can furthermore be related to the presence of insects and diseases.

An anti-quality component may reduce dry matter intake, limit dry matter digestibility, or cause nutritional imbalances. Anti-quality factors may also be toxins that shut down vital systems in animals, result in abnormal reproduction, disturb endocrine or neurological function, cause genetic aberrations, or suppress immune function leading to increased death and disease. The study of anti-quality factors is both complex and compelling because of the many and unrelated causes and yet the potential for many interactions and subtle interrelationships.

Economic Impact of Anti-quality Components

The economic impact of anti-quality factors on individual flocks and herds can be devastating when the result is a large loss in production, reproduction, morbidity, or mortality. Economic consequences can also be severe if the loss is but a single animal with high economic value. The economic effect is much less obvious when the result is a subtle decrease in potential performance. The economic impact of anti-quality components on animal health and production are often difficult to estimate. Nevertheless, broadscale estimates are needed to provide perspective and help focus research into areas of high potential economic improvement.

The greatest economic impact of anti-quality factors is diminished forage quality with lowered potential for gain. An example of this can be derived from calculations using a recent beef cattle herd in the U.S. and estimates of expected daily gains. As of January 29, 1999, there were 16.8 million steers and 19.6 million heifers weighing 500 lbs or more in the U.S. The stocker phase of cattle production into which these cattle could be placed, can make efficient use of forage for economic gains. If a 500 lb steer is fed to gain 2 lbs per day that steer will need to consume about 13.1 lbs of dry forage each day to supply the needed nutrition. If the nutritive value of the forage is diminished and intake declines to 12.8 lbs per day, daily gains would be expected to drop to 1.5 lbs per day. This translates into over 18 million lbs per day loss of potential gain for the U.S. If a value of $0.70 per lb is assumed, this results in an approximate cost of over $12 million per day for all stocker cattle in the U.S. or $0.34 per animal per day. This level of loss of potential gain, represents a total economic loss for the 166-day period of over $2 billion. This level of economic loss from lowered forage quality could be considered to be an upper bound of the actual level of loss. That is, it would be expected that if stocker producers were to be aware of the potential reduced weight gain due to the lower diet quality, they might alter their operations to minimize potential losses. However, this strategy would result in higher associated cost of production. If the impediments to quality were identified and eliminated, it might be more cost effective.

The economic impact of mineral imbalances in forages is often poorly understood. However, hypomagnesic grass tetany has been widely researched. This metabolic deficiency of magnesium (Mg) has been estimated to result in the loss of 1 to 3% of the beef cows in the U.S. annually. If 1% of the 42.6 million cows and heifers that calved in the U.S. by January 1, 1999 were lost to grass tetany, the estimated financial loss to producers would be about $150 million assuming an 1100 lb cow worth about $0.35 per lb. Fortunately, Mg supplementation strategies are available that can largely prevent grass tetany but represent an increase in the cost of production.

Tall fescue (*Festuca arundinacea*) is one of the most important cool-season grasses grown in the U.S. occupying over 30 million acres. Widely adapted, this long-lived perennial forms the basis of many forage-livestock systems. However, much of this fescue is infected with the endophyte-fungus *Neotyphodium coenophialum*. Presence of the fungus confers stress tolerance to the plant but production of alkaloids by the plant and the fungus result in a myriad of animal disorders. It has been estimated that the endophyte in tall fescue results in loss of over $600 million annually to the beef cattle industry alone. Recent evidence suggests that this may be an underestimate. It was widely accepted that removal of livestock from infected tall fescue pastures resulted in a fairly rapid recovery from tall fescue toxicosis, but this now appears untrue. It was recently demonstrated that a loss in immune function due to fescue toxicosis is long-lasting, and was measurable throughout the stress of cross country transportation and throughout a 150-day feedlot finishing period. The lowered immunity is likely to contribute to added costs of medications and labor in treating animals that are less-tolerant to stress and disease.

Poisonous plants occur in all types of grazing lands including both rangeland and intensively managed pastureland and are one of the most important economic impediments to profitable livestock production. Based on an estimated 1% death loss in cattle, a 3.5% death loss in sheep, and a 1% decrease in calf and lamb crops due to poisonous plants, the economic impact within the 17 western states has been estimated at $340 million annually.

The potential economic losses discussed above, represent only a few of the areas and issues that anti-quality components can impact. Even if these areas were to be the only ones affected by anti-quality components in forage, the potential associated total economic damage would be over $3 billion each year. This level of damage provides an estimate of the potential payoff of research addressing the anti-quality components in forages. Even if a very small proportion of the expected losses were to be eliminated through research dedicated to minimize the negative impacts of anti-quality components, a relatively large research program could be afforded. It is hoped that such information will highlight the need for further research and the dedication of funding to support this research. After all, forages are the key to economially feasible production of ruminants and horses and are central to the protection of our natural resources. Forages are the most important plants on earth and impediments to their potential as a feed source take on parallel importance.

References for More Information

Ball, D.M., C.S. Hoveland, and G.D. Lacefield. 1991. Southern Forages. Potash & Phosphate Inst. and Foundation for Agronomy Research. Atlanta, Ga.

Fribourg, H.A., K.D. Gwinn, A.B. Chestnut, J.W. Oliver, J.C. Waller, J.H. Reynolds, and B.V. Conger. 1991. Tall fescue and the fungal endophyte. Tennessee Farm Home Science. 160:10-29.

James, L.F., D.B. Nielsen, and K.E. Panter. 1992. Impact of poisonous plants on the livestock industry. Journal of Range Management. 45:3-8.

Mayland, H.F. and P.R. Cheeke. 1995. Forage-induced animal disorders, p. 121-136. *In*: R.F Barnes, D.A. Miller, and C.J. Nelson (ed.). Forages: An Introduction to Grassland Agriculture. Vol. II. Iowa State Univ. Press, Ames, Iowa.

Nielsen, D.B. and L.F. James. 1991. Poisonous Plants - Proceedings of the Third International Symposium. Iowa State University Press, Ames, Iowa.

Steudemann, J.A. and C.S. Hoveland. 1988. Fescue endophyte history and impact on animal agriculture. Journal of Production Agriculture. 1:39-44.

Wood, G.E. 1992. Mycotoxins in foods and feeds in the United States. Journal of Animal Science. 70:3941-3949.

Understanding Herbivore Response to Anti-Quality Factors in Forages[1]

Frederick D. Provenza[2] and Jen Ropp[3]

Introduction

Successful livestock management on rangelands is quite challenging. The nutritional needs of animals change constantly with age, physiological state, and environmental conditions. Animals try to meet these needs by harvesting nutritious forage. This is a difficult task because the quantities of energy, protein, and minerals in plants vary from place to place and throughout the year. Forages also contain "anti-quality" compounds that limit intake or adversely affect animals. The kind and amount of toxins in different plants and plant parts vary as do plant structures such as dead stems or thorns that inhibit foraging. Given these dynamics, livestock managers must constantly track forage value and understand the abilities of herbivores to meet these foraging challenges. In this paper, we will examine how anti-quality plant attributes affect diet selection and intake. We will also examine the behavioral and digestive strategies that animals employ to overcome these anti-quality attributes and gain access to the nutrient and energy resources in plants. Finally, we will suggest management approaches to help animals contend with anti-quality attributes in forages.

How Plant Chemicals Reduce Forage Quality

Plants possess a wide variety of chemical and physical properties that reduce forage value and serve as grazing deterrents. Anti-quality attributes can either reduce the digestibility of forage nutrients, produce toxic effects, or cause illness. It is important to understand how these compounds affect grazing animals to create livestock management strategies for rangeland and pasturelands.

Some plant compounds reduce forage quality because they are nearly indigestible or have chemical effects that limit the digestibility of other plant compounds. For example, lignin, tannins, and resinous compounds can reduce forage digestibility by tying up nutrients. High content of indigestible compounds, such as lignin, silica, or waxes, can also decrease the digestive benefits of a plant and reduce preference. Compounds like gossypol and tannins,

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[1]Based on: Launchbaugh, K.L., F.D. Provenza, and J.A. Pfister. 2001. Herbivore response to anti-quality factors in forages. Journal of Range Management. 54:431-440.

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that bind proteins, can decrease digestibility by deactivating digestive enzymes. Plant compounds, such as essential oils and tannins, have anti-microbial effects that kill microbes in the digestive system, thereby reducing forage digestibility.

Many rangeland and pastureland plants contain compounds that cause a variety of negative neurological and metabolic effects, and are therefore termed "toxic". These poisonous plants can kill animals, or cause maladies such as birth defects, sterility, blindness, or paralysis. Some chemicals do not have overtly toxic symptoms, but cause the animal to feel ill or nauseous. This aversive post-ingestive feedback causes herbivores to decrease intake of foods containing toxins such as alkaloids in larkspur (*Delphinium* spp.) and tall fescue (*Festuca arundinaceae*), condensed tannins in blackbrush (*Coleogyne ramosissima*), essential oils in big sagebrush (*Artemisia tridentata*) and juniper (*Juniperus* spp.), and phytotoxins in mesquite (*Prosopis glandulosa*).

The toxicity or detrimental effects of any plant compounds depends on how much the animal consumes. Even nutrients can cause damage if eaten in high quantities. For example, ruminants often become ill after ingesting large amounts of fruits or grains because of their high content of sugars and starches that degrade quickly in the rumen and cause illness, bloat, or fever. Ruminants eating foods high in rumen-degradable protein can also experience high levels of ruminal ammonia and become ill.

How Animals Contend with Anti-quality Factors

To live a healthy life on rangeland, herbivores must consume nutritious plants and avoid toxic or low quality plants. To meet this challenge, herbivores possess several adaptive behaviors that limit toxins and increase nutrients ingested, and internal systems that detoxify or tolerate consumed phytotoxins.

Selective Grazing

Selective grazing is the herbivore's first line of defense against the negative effects of plants with toxic or anti-quality attributes. Grazing animals are unquestionably sensitive to the quality and anti-quality attributes of plants. For example, animals select diets of higher quality than the average forage available. They also select plants and plant parts of relatively low toxin concentration. Animals accomplish these wise decisions by relating plant flavor to positive or negative digestive consequences. A plant's chemical and structural attributes dictate the potential digestible energy, nutrient yield, or toxicity of a plant. The digestion and detoxification abilities of grazing animals, and their rumen microbes, determine the actual yield of nutrients, energy, or toxins from the plant. The results of these plant and animal interactions determine a forage's palatability. The key to how animals respond to anti-quality factors in plants is therefore centered on the consequences of consumption (Fig. 1).

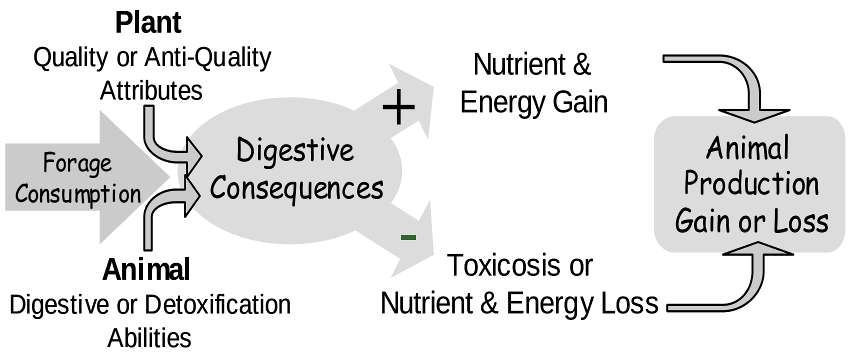

Figure 1. The digestive consequences of forage consumption are determined by plant forage quality and animal digestive and detoxification abilities. This interaction, in turn, affects the nutrients and energy available for animal growth and maintenance.

Learning Through Consequences

When a grazing animal smells and tastes a plant, the flavor is either pleasing or distasteful depending on the animal's previous grazing experiences. When a plant is eaten, it provides feedback during digestion. If consumption of a plant improves the nutrient or energy status of the animal, the plant flavor becomes more desirable or pleasing. If eating of the plant yields illness, the flavor becomes aversive and distasteful (Fig. 2). These flavor-consequence relationships form the basis for dietary likes and dislikes, and the animal then seeks highly palatable foods and avoids aversive foods. The resulting behavior patterns generally lead to increased consumption of nutritious foods and limited consumption of toxic or low quality plants.

This idea that plants become desirable or aversive depending on their digestive consequences is simple. But, how do grazing animals figure out exactly which plants made them feel good or ill? One way herbivores apparently accomplish this task is by regarding unfamiliar plants with caution. Animals associate positive or negative effects of nutrients or toxins with novel foods when offered meals that contain novel and familiar foods. When foraging bouts include several novel plants, plants that dominate the diet are probably 'weighted' more than less-consumed plants, even if the minor foods were primarily responsible for the positive or negative feedback. Furthermore, digestive feedback begins within 10 to 15 minutes of consumption which could help animals attribute digestive benefits or liabilities to specific plants. Finally, livestock grazing on rangelands usually become familiar with the forage resource and may seldom encounter truly novel plants. This allows greater opportunity to 'sort out' feedback from individual or similar groups of plants.

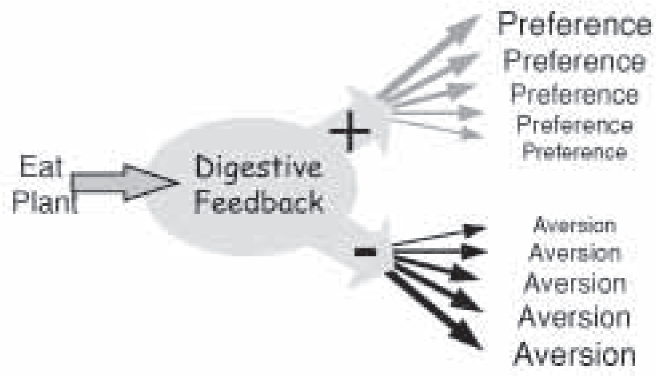

Figure 2. When an animal eats a plant, it receives digestive feedback in the form of energy, nutrients, illness, or toxicosis. If the feedback is positive, preferences are formed to the plant and if the feedback is negative, aversions are formed. The strength of the preference or aversion is determined by the magnitude, nature, and timing of digestive feedback.

Learning From Others

Livestock live in multi-generational groups in which dietary information can be easily passed from experienced to inexperienced animals. Young livestock, therefore, do not require perfect and complete dietary information at birth. Learning from mother may even begin before young herbivores take their first bites. Flavors in uterine fluid and mother's milk can influence food preferences. However, as animals grow older, they are more influenced by their own dietary experiences than by their mother or other social models.

Adaptive Intake Paterns

Successfully navigating the seasonal and spatial variation of forage quality in grazing environments can be accomplished by knowing how much to eat, when to eat, and what else to eat. Grazing animals have a strong natural tendency to select diets composed of several plant species and sample available plants on a regular basis. This behavior may increase the likelihood of ingesting necessary nutrients and reduce the potential of over-ingesting toxins. The toxic effects of a plant are determined largely by the amount eaten, but the ingestion rate may also be important. Grazing animals can avoid toxicosis by limiting their consumption of a specific toxic plant each day to allow sufficient time for detoxification, and to limit potential cumulative effects of specific toxins.

Detoxification and Tolerance After Consumption

Animals possess several mechanisms to negate or restrict the toxic or negative effects of plant compounds once ingested. If a toxin is eaten, it is in the animal's best interest to quickly get rid of it. Sheep, goats, and cattle can and will vomit in response to eating toxins, but it is rarely observed. Horses probably do not vomit except when near death, but commonly experience diarrhea. Diarrhea aids in rapid elimination of toxins from the gut which can reduce absorption. In some episodes of diarrhea, there is a decrease in intestinal motility, further reducing the absorption of toxins.

Chemical reactions during ingestion may provide protection against the effects of some plant toxins. The ruminant's large forestomach is generally well adapted to bind, sequester, degrade, or detoxify plant toxins. The neutral pH of the rumen environment may modify a plant toxin or the toxin may be quickly diluted in the large volume of the rumen (e.g., around 60 gallons for cattle). Of great significance for ingesting toxic plants is the massive number of rumen microbes that transform most phytotoxins into inert or less-detrimental compounds. For example, leucaena (*Leucaena leucocephala*) is a tropical forage legume that contains mimosine, a toxic amino acid. Mimosine is detoxified by a group of rumen microbes and animals susceptible to mimosine toxicity can be cured by receiving a dose of the "mimosine-metabolizing" microbes. Rumen microbes usually reduce the toxic effects of plant compounds. However, in some cases, such as nitrates or cyanogenic glycosides, the rumen microbes convert a harmless compound into a deadly toxin.

Once plant toxins are absorbed from the gut into the blood, they are often transported to the liver. The liver primarily, and secondarily the kidney, intestinal mucosa, lungs, and skin contain enzyme systems that metabolize or alter toxic compounds, rendering them inert. Ability to metabolize or reduce sensitivity to specific phytotoxins varies by herbivore species and individuals. For example, sheep can tolerate and detoxify more pyrrolizidine alkaloids than cattle, therefore it takes five times more tall larkspur (*Delphinium occidentalis*) to poison sheep compared to cattle.

With continued consumption of a plant containing a specific phytotoxin, the animal may gain an ability to overcome its negative effects because enzyme systems in animal tissue can increase their detoxification capacity and efficiency. Rumen microbes may also facilitate the ability of animals to adapt to diets high in phytotoxins. Microbial populations can change rapidly depending on the substrates available for degradation. These "inducible defenses" could explain why herbivores often appear less sensitive to toxic or low quality plants with continued exposure. Nonetheless, adaptation does not develop to all toxins. The effects of many toxins are cumulative and animals may get progressively more poisoned as they continue to ingest plant material containing these toxins.

Management Practices to Help Animals Contend with Anti-quality Attributes

The most common approaches to reduce losses caused by anti-quality factors in forage plants are to change the plant community or grazing management strategy. Poisonous plants have been sprayed and mowed; shrublands with low forage value have been treated with herbicides, mechanically altered, or burned to remove the shrubs in favor of herbaceous forages; and toxin-free forage varieties (e.g., endophyte-free fescue) have been developed and planted. A more contemporary approach is to change the grazing animal, rather than the vegetation, to promote or encourage the animal's natural abilities to combat anti-quality attributes. A first step in creating herds or flocks of animals that can overcome anti-quality attributes is to identify the most significant challenges that specific foraging situations present to herbivores. For example, in sagebrush-dominated communities, selecting or shaping animals with a superior ability to digest and detoxify essential oils in sagebrush could greatly increase the amount of available forage. Once a foraging challenge is identified, management plans can be drafted to help animals meet this challenge.

Select Appropriate Livestock Species and Individuals

A simple approach to improve utilization of a low quality or toxic forages is to select a livestock species that naturally makes good use of the plant of interest. For example, sheep can graze larkspur-infested rangeland more safely than cattle because they are less sensitive to the toxic alkaloids in larkspur. This simple concept is however often difficult for producers to enact because changing the livestock species being raised generally requires substantial changes in fencing, handling equipment, management skills, knowledge, and philosophy. A more acceptable way to assemble groups of animals with desired dietary and digestive attributes might be to select an adapted breed within a species. Research on cattle, sheep, goats, and horses has revealed that breeds differ in the diets they select. Individual variation within a breed may also create a basis for selecting animals to meet specific foraging challenges. Research on the behavioral, metabolic, and production effects of anti-quality factors has consistently revealed that animals vary significantly in their response to toxic or low quality plants. Most toxic plants with acute neurological effects, such as larkspurs, lupines (*Lupinus* spp.), poison hemlock (*Conium maculatum*), broom snakeweed (*Gutierrezia sarothrae*), and pine needles (*Pinus* spp.), exhibit wide variability in dose response when ingested by livestock. In future years, individual animals may be screened for response to anti-quality factors or susceptibility to toxins.

Breed Animals with Desired Attributes

There is significant and growing evidence that the digestive and detoxification abilities of animals are heritable characteristics. Animals that have superior abilities to detoxify specific phytotoxins are able to eat plants containing these toxins and experience less negative feedback. This superior detoxification ability will be passed to their offspring and influence the dietary preferences of succeeding generations. The inheritance of enzyme systems involved in digestion and detoxification is well documented. Given the important role of digestive feedback in directing diet selection, it is not surprising that several studies have revealed significant inheritance values for diet patterns which points clearly to the possibility of breeding animals to overcome the challenges of specific anti-quality attributes.

Offer Animals Proper Early Life Experiences

Attempts to fashion animals with specific dietary attributes could begin at birth because early life experiences strongly affect dietary habits later in life. Young animals forage closely with their mother to learn which plants to eat or avoid. A mother can even influence the plant preference of her offspring through flavors in milk. Exposing animals to potentially troublesome plants in their youth may also improve their ability to harvest, digest, and detoxify these plants when they mature.

Administer Nutritional or Pharmaceutical Products to Aid in Digestion and Detoxification

The examination of anti-quality factors has, in several cases, led to the development of "antidotes" that help herbivores disarm specific phytotoxins or survive their biological assaults. For example, understanding the specific action of fescue alkaloids lead to the development of a compound (i.e., a dopamine antagonist) that blocks metabolic effects of the alkaloid. Simply improving the nutritional state of animals can often lead to increased rates of detoxification and decreased toxic effects, which can reduce risk of damage from some toxic plants such as lupine. Dietary nutrients and energy are also required to maintain the healthy rumen microbial populations important for detoxification of many plant chemicals. Vaccines to inoculate animals against specific plant toxins are becoming a reality. Recent work in Australia and in the U.S. indicates that commercial vaccines against some plant toxins are feasible.

Conclusions

Foraging on rangelands and pasture poses several significant challenges to herbivores. Grazing animals must utilize the nutritional value of plants to evade starvation, gain weight, and produce young while avoiding and negating the anti-quality attributes that are an implicit component of almost all plant communities. Livestock management in these situations can be significantly challenging. Developing grazing plans to minimize the impacts of plant anti-quality attributes requires an understanding of the behavioral and metabolic mechanisms that herbivores employ to extract nutrients from low quality or chemically-defended plants. New frontiers in forage and grazing management therefore lie in understanding the basics of animal behavior, digestion, and metabolism in relation to anti-quality characteristics. Understanding animal response to anti-quality factors in plants will, by necessity, focus on the consequences of consumption; a simple idea with immensely complex implications.

References for Additional Information

Cheeke, P.R. 1998. Natural Toxicants in Feeds, Forages, and Poisonous Plants. Second Edition. Interstate Publ., Inc., Danville, Ill.

Launchbaugh, K.L. 1996. Biochemical aspects of grazing behavior. p. 159-184. *In*: J. Hodgson and A.W. Illius (eds.) The Ecology and Management of Grazing Systems. CAB International, Wallingford, Oxon, U.K.

Provenza, F.D. 1995. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. Journal of Range Management. 48:2-17.

Provenza, F.D., J.A. Pfister, and C.D. Cheney. 1992. Mechanisms of learning in diet selection with reference to phytotoxicosis in herbivores. Journal of Range Management. 45:36-45.

Smith, G.S. 1992. Toxification and detoxification of plant compounds by ruminants: An overview. Journal of Range Management. 45:25-30.

Structural Anti-Quality: The Bones and Gristle of Rangeland Forage[1]

Lisa A. Shipley[2] and Curtis R. Yanish[3]

Introduction

The forage value of a plant is generally considered a result of the nutrients and toxins the plant contains. But, structural and physical traits can profoundly affect a plant's value to grazing animals and profits realized by livestock producers. Most structural anti-quality characteristics of plants affect the rate at which herbivores gather and ingest forages, thereby reducing the total amount of food obtained or increasing the time necessary to obtain food. Structural anti-quality can substantially influence searching time, cropping time (i.e., biting and chewing), and bite size. Physical plant structures also can reduce digestion (e.g., silica), cause injury (e.g., spines, awns, burrs, and calluses), or reduce the value of animal products, such as wool. In this article, we will overview the ways that structural plant characteristics affect grazing animals and suggest a few strategies to mitigate these effects.

Resistance to Biting and Chewing

High fiber content is a seminal attribute of plants that exhibit high structural anti-quality. Forage plants with high fiber content are often difficult for herbivores to bite. In herbaceous plants, resistance to chewing can be considerably greater for stems than for leaves during ingestion and rumination. Any plant compound that increases chewing during ingestion directly reduces intake rate (i.e., amount eaten per minute). For example, cattle grazing legumes and leafy forage achieve greater intake rates than cattle grazing grasses with abundant stem material. Sheep eating perennial ryegrass with high shear strength had a significantly lower intake rate than did those eating ryegrass with low leaf shear strength. Steers grazing grasses with high shear strength sometimes fail to sever the bites of grass and have to release some of the forage before being able to complete the biting motion.

Bite mass of woody plants also is controlled by the force required to sever forage. To obtain sufficiently large bites, browsing animals may need to chomp thicker or multiple twigs. Because the force required to crop a twig increases with twig diameter,

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[1]*Based on: Laca, E.A., L.A. Shipley, and E.D. Reid. 2001. Structural anti-quality characteristics of range and pasture plants. Journal of Range Management. 54:413-419.*
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thick or multiple twigs may restrict bite mass or at least slow cropping rate, particularly for small browsing herbivores. As twig diameter increases, herbivores must switch from using incisors to molars to crop bites, which also slows intake. In this way the structure and composition of woody plants can severely limit the ability of browsing animals to meet intake requirements.

Silica

Silica is an indigestible structural component of most grasses. Silica may affect intake rates in a fashion similar to fibrous compounds. Grasses with higher silica content generally have more rigid leaves and stems with sharper edges that can reduce harvest rates and relative bite mass. Silica can also bind with nutritious compounds in the plant to reduce digestibility. Additionally, high silica content of plant tissues can be detrimental to herbivores by promoting rapid tooth wear. Tooth wear may require culling of otherwise productive animals because they cannot bite and chew enough forage to realize their production potential. Silica content in forages may further reduce animal health by causing urolithiasis, the formation of calculi in the urinary tract.

Spinescence

Spines influence harvesting rate by reducing bite mass and decreasing biting and chewing rates. Spines make it difficult for animals to strip leaves off stems, which forces animals to crop individual leaves. Spines also slow chewing rate by requiring herbivores to carefully manipulate plants in their mouths to avoid pain and injury. Hooked thorns especially catch on lips, tongues, and ears.

The influence of thorns on ingestion depends on the size of the foraging animal. Smaller animals can maneuver their mouths more easily among thorns to pluck small leaves, and therefore, thorns may be less effective in reducing cropping rates. Most browsing animals have lips and tongues that are very agile and can more easily select leaves and avoid thorns. This explains why goats are more effective browsers then cattle or sheep.

Plant spinescence can also physically block animals from feeding by causing injury and pain so that animals refuse to eat the plant. Some injuries from spines cause chronic, rather than immediate pain and injury. Scratches and scar tissue can be found in the digestive tracts of kudus and domestic goats feeding in acacia woodlands. Thorns may injure and scar mouth or throat tissue making animals more susceptible to infection and disease.

Awns, Burrs, and Calluses

Many plant species have evolved mechanisms of seed dispersal that are detrimental to herbivores. Grass seeds with long awns or sharp calluses, such as needle-and-threadgrass (*Stipa comata*), bottlebrush squirreltail (*Sitanion hystrix*), and foxtail barley (*Hordeum judatum*) are noxious to livestock because they are bristly or scabrous, bearing stiff hairs arranged like harpoons. These structures can work their way into soft tissues (e.g., eyes, mouth, nostrils, and ears), causing distress and infections. Sheep and other fiber-producing livestock are also susceptible to injury in any area of the skin, because their hide is thinner and more delicate than cattle. Such lesions cause distress, reduce productivity, may contaminate the carcass, and reduce the quality of the hides. Fruiting structures with thorns and hooks, such as those produced by burr clover (*Medicago polymorpha*), and seeds from several grasses, may contaminate and reduce the value of fleece.

Steminess

Cured seed stalks in bunchgrasses can effectively deter grazing by cattle, particularly when plants are young. For example crested wheatgrass (*Agropyron cristatum*) plants are less likely to be grazed and severely defoliated if they have a few old seed stalks. "Wolf plants" are bunchgrasses that contain many old stems and are often completely avoided by herbivores.

Canopy Structure

The way that leaves and stems are arranged in space determines the size and arrangement of bites. Bite mass is one of the main determinants of short-term intake rate by herbivores. In grasslands, bite mass is often limited by the canopy arrangement of the grasses and forbs, especially height and bulk density of plants. Herbaceous plants that yield small bites tend to be avoided, and plants that offer large bites of good quality forage tend to be preferred. Thus, sward structure has a pronounced effect on selective grazing patterns.

As grasses mature, the proportion of more fibrous stems and older leaves increases, resulting in large variation in nutritional quality within a plant or sward. To compensate for the decline in quality as grasses mature, herbivores seek higher quality plant parts. However, increased selectivity requires more time and often yields smaller bites. At some point, adjacent plants that allow higher intake rates become preferred. How well herbivores can compensate for changes in nutritional quality depends on the animal's size and mouth shape. Because of large mouth parts, larger herbivores are generally less able to select small, more nutritious plant parts than smaller herbivores.

Browsing herbivores tend to prefer woody plant species and portions of plants that provide larger leaves and current-season's twigs. However, small, thin stems branching at wide angles may deter herbivory by spatially separating bites. As twigs age, they become thicker and more lignified which reduces their nutritive value. Large thick twigs may have lower nutrient content, but they generally allow animals to harvest more grams per minute than slender twigs. Because large herbivores require a greater intake rate than smaller herbivores to meet their nutritional requirements, plants with smaller leaves and twigs are less profitable and provide a greater defense against large browsing herbivores, like cattle or bison.

Conclusions and Management Implications

A number of anti-quality traits affect herbivores by making it hard for them to bite, handle, and chew forages. However, the ability of herbivores to deal with different canopy structures, stems, and spines improves with experience and learning. Therefore, livestock managers need to ensure that herbivores have sufficient grazing experience to reduce the impacts of structural anti-quality attributes of plants on herbivores.

Structural anti-quality factors tend to limit forage intake over the long-term by constraining ingestion. Therefore, management recommendations follow general grazing management guidelines to ensure that herbivores achieve sufficient quality and quantity of forage. It is, however, important to acknowledge positive aspects of anti-quality factors on grazed ecosystems. By preventing complete defoliation, or by providing refuges for highly desirable forages, structural anti-quality traits may promote sustainability of the system. Thus, these management guidelines must be considered as components of integrated grazing management plans that incorporate effects on animal productivity and plant communities. The following management recommendations should be included in an overall grazing management plan.

Guidelines for Management

- Carefully select livestock species and type to match the forage characteristics of specific plant communities.

- Ensure pastures have forage that optimizes grazing efficiency for specific herbivores. For example, shorter and prostrate growth forms of forage are more efficiently used by small ruminants, like sheep.

- Periodically "clean" grasslands to remove old stems and standing dead forage by mowing, burning, or grazing with very high animal densities for a short time. When using animals as the cleaning tool, use animals with low physiological demands and good teeth, like horses, whethers, or mature dry cows.

- Determine the abundance of plants with high silica in different paddocks and assess their impact on tooth wear. Paddocks with high silica content should be used by livestock with good teeth whose longevity in the herd is not an issue, such as steers.

- Determine which pastures and seasons have an abundance of plants with awns, calluses, burrs, and other structures that cause injuries and reduce the quality of fiber, hides, and carcasses. Plan grazing management such that susceptible livestock are not in those areas when seeds mature and noxious plant structures become abundant.

• In areas where challenging forage structure is to be consumed, use animals that have experience with the forages, or gradually introduce livestock to the new forages. This is best accomplished by placing naive animals with experienced ones at times when their productivity and survival does not depend on structurally defended forages. Also, ensure that animals are exposed to structural challenges when young because young animals acquire foraging skills more readily than older animals.

References for Additional Information

Arnold, G.W. 1987. Influence of the biomass, botanical composition and sward height of annual pastures on foraging behaviour by sheep. Journal of Applied Ecology. 24:759-772.

Belovsky, G.E. and O.J. Schmitz. 1991. Mammalian herbivore optimal foraging and the role of plant defenses, pp. 1-28. *In*: R. T. Palo and C. T. Robbins (eds.), Plant Defenses Against Mammalian Herbivory. CRC Press Inc., Boca Raton, Fla.

Briske, D.D. 1996. Strategies of plant survival in grazed systems: a functional interpretation, pp. 37-67. *In*: J. G. Hodgson and A. W. Illius (eds.), The Ecology and Management of Grazing Systems. CAB International, Wallingford, Oxon, UK.

Cooper, S.M. and N. Owen-Smith. 1986. Effects of plant spinescence on large mammalian herbivores. Oecologia. 68:446-455.

Gali-Muhtasib, H.U., C.C. Smith, and J.J. Higgins. 1992. The effect of silica in grasses on the feeding behavior of the prairie vole, *Microtus ochrogaster*. Ecology. 73:1724-1729.

Shipley, L.A. and D.E. Spalinger. 1995. Influence of size and density of browse patches on intake rates and foraging decisions of young moose and white-tailed deer. Oecologia. 104:112-121.

Van der Wal, R., N. Madan, S. van Lieshout, C. Dormann, R. Langvatn, and S. P. Albon. 2000. Trading forage quality for quantity? Plant phenology and patch choice by Svalbard reindeer. Oecologia. 123:108-115.

Tannins: Anti-Quality Effects on Forage Protein and Fiber Digestion[1]

Jeffrey L. Beck[2] and Jess D. Reed[3]

Introduction

Tannins are naturally occurring plant compounds mainly found in woody species that have a large influence on the nutritive value of forages. Tannins are widespread among forbs, shrubs, and trees but are uncommon in grasses. More specifically, about 17% of annual plants, 14% of herbaceous perennials, 79% of deciduous woody plants, and 87% of evergreens contain tannins. The word tannin was coined from the ability of many of these plant chemicals to tan animal skins into leather, by forming insoluble complexes with protein that stabilize hides against decomposition. When eaten, tannins produce bitter or astringent tastes that result from binding with salivary proteins in the mouth. An example, familiar to many, is the astringent "pucker" of red wines caused by tannins in red grape skins. Although humans may value this taste, tannins in red grape skins are thought to deter insect herbivory.

Tannins form strong chemical complexes with proteins, sugars, and starches that are stable over a pH range from the neutral environment of the rumen (pH 7.0) to acidic conditions in the stomach (pH 3.5). In plants, the ability of tannins to form insoluble complexes with proteins and polysaccharides (e.g., sugars and starches) can effectively reduce herbivory from mammals, birds, reptiles, and insects. When herbivores forage on tannin-rich plants, tannin–protein complexes can reduce the digestion of forage protein. Tannins directly affect digestibility of plant cell walls by binding with microbial enzymes in the rumen. Tannins may further reduce digestibility of cell wall carbohydrates by forming indigestible complexes with cellulose and hemicellulose. Reduced digestibility of cell wall compounds restricts the digestible energy that animals gain from forage plants.

Tannins in Plants

The amount of tannin present in plants depends on a plant's developmental stage and environmental conditions under which plants grow. Tannins are secondary products not involved in plant growth or reproduction; therefore, there are no minimum requirements for tannins in plants. In other words,

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tannins are not used by the plants that produce them, but, rather are by-products of plant chemical reactions. Domestication of tanniniferous forage plants led to selection of plants with lower tannin concentrations to improve palatability. Thus, tannin levels in food and forage crops are usually lower than in rangeland species.

Several important forage legumes contain significant levels of tannins, including lespedeza (*Lespedeza* spp.), trefoil (*Lotus* spp.), sainfoin (*Onobrychis viciifolia*), crown vetch (*Coronilla coronata*), and sulla (*Hedysarum coronarium*). Sorghum (*Sorghum vulgare*) contains tannins and thus, animals provisioned with this forage grain can experience reduced digestibility of protein and fiber. On rangelands, foraging herbivores usually encounter tannins in browse species. North American rangeland browse species containing tannins include acacia (*Acacia* spp.), blackbrush (*Coleogyne ramosissima*), ceanothus (*Ceanothus* spp.), oak (*Quercus* spp.), red elderberry (*Sambucus racemosa*), huckleberry (*Gaylussacia* spp.), salmonberry (*Rubus spectabilis*), and willow (*Salix* spp.). Fireweed (*Epilobium angustifolium*), mulesears (*Wyethia amplexicaulis*), and swordfern (*Polystichum munitum*) are examples of herbaceous rangeland plants containing tannins.

Chemical Nature of Tannins

Tannins can be chemically categorized as hydrolyzable or condensed. Hydrolyzable tannins occur in oak leaves in temperate regions, and in acacia shrubs in tropical areas. Acacia is an important source of browse forage in Africa, Australia, and the southwestern United States. Hydrolyzable tannins do not affect forage digestibility in ruminants, but can be metabolized into compounds that cause liver damage.

In general, the terms proanthocyanidins and condensed tannins are synonyms. Plant chemists prefer the term proanthocyanidin because it is more closely related to their chemical structure. Most nutritionists use the term condensed tannins, because these tannins are water-soluble compounds that precipitate or condense proteins (i.e., cause them to separate from solution and form solid compounds). We will hereafter not distinguish between insoluble and soluble tannins, but will instead refer to this class of forage anti-quality chemicals as tannins.

Research on how tannins affect nutritive value is complicated by inadequate laboratory procedures for determining the kind and amount of tannins in forage. It is beyond the scope of this paper to review this problem but, in essence, it is important to understand the limitations of chemical tannin analysis to make sense of the potential effects of tannins on fiber and protein digestion.

How Tannins Affect Herbivores

The ability of tannins to bind proteins and convert them into useless inert compounds can have several negative effects on animal nutrition. When tannins are eaten, they can bind dietary protein in the rumen or stomach, which reduces the amount of protein the animal can metabolize and use. These ingested tannins can also bind proteins and cell tissues in rumen microbes, which kills them and reduces the efficiency of fiber fermentation in the rumen. Furthermore, tannins can bind and kill the cells along the digestive tract of animals causing digestive disorders. Tannins are rarely so toxic that they cause death, but rather, reduced digestive efficiency and protein availability can cause significant weight loss in wildlife and livestock.

Tannins in forages have both negative and positive effects on nutritive value. In high concentrations, they reduce intake and digestibility of protein and carbohydrates, which leads to reduced animal performance. Leaves of woody browse plants often contain enough tannins to reduce protein digestibility by 50%. In low to moderate concentrations, tannins can prevent bloat by binding with cellular complexes produced during mastication. In the rumen, tannins eliminate foaming properties of legume forage proteins and reduce the rate of gas production during fermentation. Tannins can also increase the flow of protein compounds through the rumen to the small intestine thereby escaping microbial fermentation (i.e., bypass protein). This is important because problems associated with extensive breakdown of proteins and amino acids in the rumen reduce protein quality and limits livestock production in modern feeding systems. Tannins eaten by animals can also protect them against infestations or diseases caused by parasitic worms. For example, lambs grazing sulla, a legume forage that contains tannins, had lower fecal parasite egg counts and worm burdens than lambs grazing alfalfa (*Medicago sativa*), which does not contain tannins. This reduction in worm burdens led to higher average daily gains for lambs ingesting tannins.

Some tannins can be quite toxic if eaten in excess. Oak poisoning has occurred in cattle in many parts of North America and Europe usually through ingestion of oak buds and leaves in spring and acorns during fall. Tannins in oak such as tannic acid and gallic acid are the chemicals that cause oak poisoning. Oak poisoning can be fatal. Initial symptoms include anorexia, depression, clear watery nasal discharge, rumen stasis, excessive thirst, and frequent urination. Constipation is followed by excretion of dark, thin, mucus-like, and often bloody feces. Ultimately, oak poisoning causes kidney, liver, and gastrointestinal lesions.

Animal Response to Tannins

Most herbivores forage selectively and consume plants of relatively low tannin concentration. For example, goats browsing blackbrush prefer previous year's growth to current year's growth apparently because it has lower tannin content, even though the current year's growth contains more nutrients. Studies of browsing herbivores like beaver, domestic goats, moose, mule deer, and white-tailed deer have revealed these herbivores counteract the negative effects of tannins by secreting tannin-binding salivary proteins (e.g., proline) from enlarged salivary glands. When browsing animals eat tannin-containing plants these salivary compounds bind with the tannins, making them inactive. These tannin–salivary protein complexes thus provide browsing animals the ability to maintain greater digestion of fiber and protein when ingesting tannin-rich forages, than grazing herbivores like cattle and sheep.

Some herbivores can degrade and absorb some condensed tannins. Deer and sheep in one study were fed alfalfa pellets mixed with quebracho tannins (a commercial tannin extract used in leather tanning). Sheep excreted about 40% of the ingested tannins, suggesting about 60% was absorbed and metabolized, while deer feces contained all of the quebracho tannins, suggesting deer absorbed none.

Management Implications

Because tannins are rare in most grasses, management of animals browsing on tannin-rich woody plants and forbs is a key concern for managers. A better understanding of the relationship between tannin structure and function is necessary to manipulate tannins in forages through breeding and selection or through genetic engineering. The interaction between tannins and fiber and digestion is an important component of this research. There is a fine line between the potentially positive effects of tannins and their negative effects on intake, digestion, and performance. Research is needed to define the chemical structure of tannins in grasses, herbs, browse, and seed coats to determine tannin reactivity with proteins and enzymes, and to suggest optimal kinds and amounts of tannins for ruminant diets. The effect of tannins on the nutritive value and selection of rangeland species in the diets of ruminant herbivores is another important research topic. Specific management considerations include:

- Products are being developed to enhance the ability of foraging ruminants to overcome the negative effects of tannins and related polyphenolic compounds on rangelands. These products are currently used in South Africa, Australia, and Zimbabwe, and may someday be available in the United States. These products are designed to complex and deactivate tannins during digestion. For example, polyethylene glycol is a tannin-binding polymer that improves animal performance by preventing adverse effects of tannins on protein digestibility and digestive enzyme activity.

- Manipulating rangeland vegetation to reduce plants with high tannin concentrations is very difficult because many dominant woody species contain high tannin levels. However, forages with low concentrations of tannins can be selected for pasture settings.

- Caution should be used when interpreting forage quality lab reports for high-tannin forages. Actual protein and fiber digestibilities my be higher than reported values because of negative effects of tannins in laboratory procedures.

- Animals ingesting substantial quantities of tannin-rich browse, may require protein supplements to account for reduced forage protein digestibility. This practice may be especially necessary when animals are lactating because of higher protein requirements.

- Livestock grazing oak woodlands should be checked frequently for signs of oak poisoning. Managers should move affected animals to oak-free areas and consult a veterinarian if symptoms persist. A preventative measure against oak poisoning is to supplement the diet with a feed mixture containing calcium hydroxide.

References for More Information

Mueller-Harvey, I. and A.B. McAllan. 1992. Tannins: Their biochemistry and nutritional properties. Advances in Plant Cell Biochemistry and Biotechnology. 1:151–217.

Reed, J.D. 1995. Nutritional toxicology of tannins and related polyphenols in forage legumes. Invited Paper. Pharmacology/Toxicology Symposium on Toxic Legumes. Journal of Animal Science. 73:1516–1528.

Waghorn, G.C., J.D. Reed, and L.R. Ndlovu. 1999. Condensed tannins and herbivore nutrition, p. 153. *In*: Proceedings of the XVIII International Grassland Congress. Volume III- Association Management Centre, Calgary.

Role, Impacts, and Management of Plant Lignin[1]

Kenneth Moore[2] and Roberto Garcia[3]

Introduction

The first step in overcoming any obstacle in life is understanding it. No less is true of addressing a plant anti-quality component such as lignin. Our path to understanding lignin is hindered because science has not yet drawn a complete and clear picture of lignin.

We know that lignin is an integral component of plant cell walls. Lignin is deposited in the cell wall as part of maturation after cell elongation has ceased. Scientists conclude that lignin is chemically linked to carbohydrates and possibly proteins in the cell wall to form large macromolecules. Consequently, lignin provides a rigid framework for the plant, thereby allowing it simply to stand up. Lignin also protects the plant from water loss and disease organisms.

Lignin Levels and Distribution in Plants

The chemical structure of lignin has not yet been conclusively determined. How lignin is assembled within the plant cell wall is also a mystery. Consequently, lignin's exact role in plant growth and development is not fully understood. However, there is hope! It is certain that lignin is practically indigestible. Furthermore, lignin inhibits digestion of potentially digestible fibrous compounds such as cellulose and hemicellulose. It is a common belief that lignin essentially affects fiber digestion, and little else.

Grasses have a higher fiber concentration than legumes. Lignin's impact on overall digestible energy is, therefore, greater in grasses. A primary distinction among grasses is that warm-season species generally have higher fiber than cool-season and higher lignin concentrations at comparable growth stages. Legumes ferment faster than grasses at the same stage of growth. This occurs because legumes contain less fiber and a greater concentration of readily fermentable substrates.

Lignin concentration varies between 3 and 20% of dry matter depending on the forage's stage of maturity. Lignin concentration increases with maturity in both

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grasses and legumes. In grasses, lignin concentrations more than double as plants develop from vegetative to reproductive growth stages. The increase is somewhat less dramatic in legumes. With increasing age, a greater proportion of plant biomass is made of stems compared to leaves. Plant stems contain more lignified structural tissues than leaves and, as a result, are much less digestible.

It is known that forage lignin concentration varies depending on environmental conditions. Warm temperatures tend to increase lignin concentrations in tropical and temperate plants. Lignification can decrease with both high and low moisture levels. Lignification tends to decrease under low light conditions. Scientists suspect that this occurs because under limited light, plant development is delayed. Plant development is also delayed as a result of nutrient deficiency. Therefore, low soil fertility will generally decrease lignification. However, the response of plant lignification to soil fertility is not well established and predictable; it depends on the plant species and the environment in which it is grown. Likewise, sulfur fertilization has been reported to decrease lignification and improve fiber digestibility in sorghum (*Sorghum vulgare*), but did not affect either lignin concentration or fiber digestibility in tall fescue (*Festuca arundinacea*) or orchardgrass (*Dactylis glomerata*).

Lignin Structure

Scientists have identified several types of lignin in plants. The two most recognized types of lignin are guaiacyl-, which typically comprises >95% of the lignin found in gymnosperms (e.g., coniferous trees), and syringyl-type lignin which, in addition to guaiacyl-type lignin, is deposited in angiosperms (e.g., flowering plants including grasses). These lignin compounds are arranged in a web-type structure that is central to lignin's true identity and function. It is also determined that guaiacyl-type lignin exhibits a cross-linking nature, while syringyl groups cannot. Guaiacyl-type lignin would therefore be expected to more adversely affect digestibility. However, the type of lignin present may be unimportant in highly lignified woody tissues where physical surface features such as thorns or bark are more inhibiting to ingestion and digestion.

Advancements have been made, through biotechnological manipulations, increasing the digestion of forage by either reducing the amount or by altering the types of lignin compounds in the plant. Studies have revealed that reducing the lignin concentration of plants may create non-reproducing plants. Research with tobacco plants revealed that when the guaiacyl-type concentrations were reduced, digestion increased though total lignin concentration was not altered.

It has been determined that lignin is also connected to specific parts of the plant cell wall through a process known as ferulate cross-linking. This refers to the ferulic acid molecules that connect lignin to specific compounds in the plant cell wall. Some suspect that the degree of ferulate cross-linking within the plant cell directly affects the ability of lignin to inhibit digestion. In studies where ferulate cross-linking was reduced, digestibility increased slightly in big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), and corn (*Zea mays*).

Lignin vs Animal

Any limitation of fiber digestion will directly reduce digestible energy gained by the animal. Lignin also limits the daily amount of dry matter that an animal can consume. Microbes in the animal's gut are inhibited from breaking down cellulose and hemicellulose, thus causing a delay in digestion. Energy derived from soluble polysacharides (i.e., starch) is also limited. This digestion resistance creates a sort of "log-jam" in the animal's gut. The logs (plant cells) cannot pass from the rumen because microbes in the rumen have difficulty breaking up lignin-bound compounds. Overall, this contributes to a "fill effect" in the animal that decreases the amount of forage it can consume.

It is safe to say that an animal consuming forages containing lignin compounds will not produce overt symptoms like lesions, bloody noses, or death. Animals simply reduce their intake of forage. The effects of lignin ingestion may, therefore, be inconspicuous. However, measures of production and weight gain will indicate that animals may not be reaching their full potential.

Management Opportunities

Research results have suggested several management strategies that may reduce lignin's impact on digestibility. Several approaches may be found useful and practical. The goal of management is not necessarily to minimize lignin concentration, but rather to minimize its impact on fiber digestion under varying environmental conditions. Defoliation management is probably the most powerful tool available to producers for managing forage quality. Timing of harvest and grazing events such that forages are maintained in a vegetative stage is the most effective and straightforward approach to managing the decline in forage quality associated with plant maturity. However, decisions regarding defoliation management need to be weighed against factors such as yield and effects on plant persistence. In addition to defoliation management, maturation of forages may also be controlled by clipping, burning, and application of plant growth regulators.

Species and variety selection are also extremely useful tools for managing forage quality within the constraints of an ecosystem. Altering species composition, either by seeding or vegetation manipulation, can greatly enhance the yield of available nutrients and productivity of forage-livestock systems, thus resulting in increased economic returns. Estimates in the value of increased production realized from improvements in forage quality range from $125 to $213 per acre per year.

There are several post-harvest treatments that can improve the digestibility of fiber in highly lignified forages. These include alkaline hydrolysis, ammonia treatments, enzymatic hydrolysis, oxidation, and microbial treatments. Of these, alkaline hydrolysis is by far the most common and practical. Alkaline treatments such as sodium hydroxide have been demonstrated to improve the digestibility of grasses, but not legumes. Nitrogen-enhancement treatments are accomplished using anhydrous ammonia applied in gaseous form or by incorporating urea with the forage. In nitrogen-deficient rumen conditions, the extra N supplied by ammonia or urea can improve the health and abundance of rumen microbes which increases fermentation of fiber. Ammonia costs approximately $0.26 per lb. Costs will vary depending on the rate of application.

Sodium hydroxide treatment, however, generally results in greater increases in fiber digestibility than ammoniation. The extent to which sodium hydroxide increases digestibility depends on the proportion of lignin-carbohydrate bonds that are broken and the resistance of lignocellulosic residue to breakdown. A pH of 8 must also be achieved for delignification to occur. Furthermore, with alkaline treatments, the potential digestion rate of carbohydrates may be reduced as they become chemically altered during treatment. In all cases, chemical treatments used to enhance fiber digestion result in greater improvements when applied to poor-quality roughages, such as mature grasses and cereal crop residues, than when applied to higher quality forages.

Conclusions

Certainly, there are more life-threatening situations than an animal ingesting lignin. However, repeated lignin ingestion can result in significant economic losses. Future research will continue to develop cost-effective and practical ways to reduce the effects of lignin. Currently, the most effective management practices for overcoming lignin include:

- Manipulating of the plant community such that it contains less lignified, more digestible and desirable plants.

- Using harvest and grazing management to maintain plants in a vegetative growth stage.

- Applying post-harvest treatments to improve the digestibility of low-quality harvested forages.

References for More Information

Akin, D.E. 1989. Histological and physical factors affecting digestibility of forages. Agronomy Journal. 81:17-25.

Boudet, A.M. 1998. A new view of lignification. Trends in Plant Science. 3:67-71.

Buxton, D.R. and S.L. Fales. 1994. Plant environment and quality. p. 155-199. *In*: G.C. Fahey, Jr., M. Collins, D.R. Mertens, and L.E. Moser (eds.) Forage Quality, Evaluation, and Utilization. ASA, CSSA, and SSA, Madison, WI.

Hattfield, R.D., J. Ralph, and J.H. Grabber. 1999. Cell wall structural foundations: Molecular basis for improving forage digestibilities. Crop Science. 39:27-37.

Klopfenstein, T. 1978. Chemical treatment of crop residues. Journal of Animal Science. 49:841-848.

Vogel, K.P. and D.A. Sleper. 1994. Alterations of plants via genetics and plant breeding. p. 891-921. *In*: G.C. Fahey, Jr. M. Collins, D.R. Mertens, and L.E. Moser (eds.) Forage Quality Evaluation and Utilization. ASA, CSSA, and SSA, Madison, WS.

Nitrate Toxicosis: How it Works and How to Cope with it

Mitch Thomas[1] and Norman Schneider[2]

Introduction

Nitrogen is a basic building block of proteins and an essential nutrient for animal and plant growth. However, nitrogen in the form of nitrate (NO_3) and in excessive amounts can cause livestock to eat less, loose weight, abort fetuses, or even die. Nearly all plants are capable of accumulating toxic levels of nitrate. However, excessive nitrate concentrations usually only occur when plants are growing in moist nitrogen-rich soils or in cloudy overcast weather. Some plants are more likely to accumulate nitrates than others. The key to reducing livestock risk of nitrate toxicity is to understand the conditions that lead to nitrate accumulation in plants.

Nitrate poisoning occurs most often in tame pasture, harvested hays, and ensiled forages. A "tame" pasture is grazing land planted with introduced forage species that usually receives periodic agronomic treatments such as renovation, fertilization, or weed control. Nitrogen fertilizer applied to improve forage yield can lead to high levels of nitrates in plants under some conditions. Plants sprayed with the herbicide 2,4-D may also accumulate nitrate and simultaneously become more palatable to animals. Nitrate toxicosis rarely occurs in animals grazing rangeland. However, plants growing under drought conditions tend to have higher nitrate content. High temperatures, insects, and low light conditions can also contribute to nitrate accumulation in plants.

Crops that are grazed, or used to make hay or silage, that are high in nitrates are corn, oats, wheat, alfalfa, soybeans, sweet clover, sorghum, turnip or beet tops, and canola plants. Weedy plants such as Russian thistle (*Salsola iberica*), lambs quarters (*Chenopodium album*), pigweed (*Amaranthus* spp.), ragweed (*Ambrosia spp.*), field bindweed (*Convolvulus arvensis*), erect knotweed (*Polygonum erectum*), wild mustards (*Brassica* spp.), and Johnsongrass (*Sorghum halepense*) may also accumulate toxic levels of nitrate.

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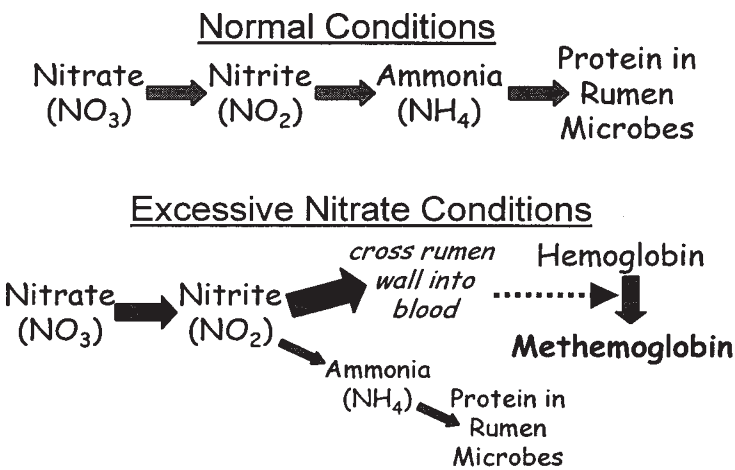
Mechanisms

Nitrates are very toxic to ruminants and somewhat toxic to non-ruminants. When an animal consumes forage high in nitrates, the rumen microbes convert nitrate (NO_3) to nitrite (NO_2). The nitrite is normally converted to ammonia and used to synthesize protein by rumen microbes. These microbial proteins become an important protein source for the grazing animal when they are digested and absorbed in the small intestines. If the rumen microbes are overwhelmed by large amounts of nitrate, the intermediate and toxic compound, nitrite, may begin to accumulate. High nitrite concentrations can promote absorption of nitrate across the rumen wall into the bloodstream. When nitrite reaches the bloodstream, it oxidizes hemoglobin into methemoglobin, a brownish pigment incapable of transporting oxygen. This reduced ability of the blood to carry oxygen is the source of ailments that constitute nitrate toxicosis. Monogastrics, like horses and rabbits, are also susceptible to nitrate poisoning. The cecum of horses provides an environment conducive for bacteria to convert nitrate to nitrite.



Occurrence

There have been many documented case studies of nitrate toxicity in livestock. The earliest documented case of nitrate toxicity occurred in Kansas in 1895 when 10 of 34 cattle died from consuming corn stalks high in nitrates. Oat hay high in nitrates also caused livestock losses in Wyoming in 1939. Other cases of nitrate poisoning are widespread and result from many different causes. Severe drought conditions in western Australia caused 130 out of 400 head of cattle to die from nitrate toxicity when exposed to a nitrate-accumulating weed. Excess nitrates in dairy feeding trials have caused abortion, decreased conception, and even death. Nitrates added to a feedlot rations have not been shown to reduce growth of cattle, but can reduce intake. Hungarian swine farmers lost hogs that ate cocklebur seedlings (*Xanthium* spp.) which contained 4 to 5 g/kg of potassium nitrate and drank well water that had nitrate levels from 517 to 1,360 parts per million (PPM), exceeding the recommended maximum of 100 PPM for drinking water.

Clinical Signs

The symptoms of nitrate toxicity result from low blood oxygen levels. The first recognizable symptom is a brownish discoloration of the skin and mucous membranes because of the chocolate-brown color of methemoglobin in the blood. In livestock with naturally dark pigment, like Black Angus cattle, this characteristic is difficult to distinguish. One may be able to detect pigment discoloration in the mouth, but the most reliable field examination is checking the vulva (i.e., the opening below the anus) of cows for a blue-gray discoloration versus a normal pinkish color. Advanced symptoms of nitrate toxicity include: a staggering gait, rapid pulse, diarrhea, frequent urination, labored breathing, followed by collapse. Convulsions and coma will often follow collapse and death is eminent in 1 to 3 hours after the symptoms become apparent. Pregnant animals that have survived a nearly fatal bout of methemoglobinemia may abort within a few days.

Nitrate toxicity can be easily confused with prussic acid poisoning because the two afflictions share many of the same symptoms. However, the blood is bright red in prussic acid poisoning versus chocolate brown in nitrate toxicity. Proper diagnosis is very important because the treatment for nitrate toxicosis can cause death in animals suffering from prussic acid poisoning.

Treatment

An intravenous injection of 2 mg methylene blue per 500 pounds of body weight in a 1 to 4% aqueous solution has been effective in saving animals suffering from nitrate toxicity. Methylene blue will return the blood flow to normal and regenerate the oxygen-carrying capacity of blood by converting methemoglobin to hemoglobin. Another treatment for excessive nitrate consumption is to flush the animal's rumen and purge the rumen of nitrate-containing digesta. This crude operation can be achieved with cold water delivered to the rumen with a flexible tube placed down the esophagus. To be effective the rumen contents should be sucked out through the tube. However, simply flushing the rumen with cold water may slow rumen fermentation and reduce nitrite accumulation.

Management Opportunities

• Adding engery supplements like molasses to the diet can decrease the effects of nitrate toxicosis. Readily available energy can also be obtained from grains like corn, wheat, or barley. Offering animals high energy feeds can reduce the concentration of nitrite in the rumen because grains are relatively low in nitrogen and these energy sources can encourage the growth and vigor of rumen microbes that convert nitrite to ammonia.

• Vitamins and minerals should also be provided to livestock grazing forage potentially high in nitrates. Supplementing livestock with vitamin A and iodine is also recommended when animals are consuming feeds high in nitrates, because nitrates interfere with vitamin A and iodine uptake. Supplementing cattle with 2 grams of sodium tungstate per day has reduced the occurrence of nitrate toxicosis. Making sure livestock have sufficient minerals, such as molybdenum, copper, iron, magnesium, and manganese, is also important because they are necessary for the conversion of nitrate to ammonia in the rumen.

• Forage and fecal testing can be used to detect nitrate levels and balance a ration for optimizing production. Forage samples from a haystack should be taken throughout the entire stack because the top bales can leach considerable amounts of nitrate into the lower bales over the winter. Corn stalks can be tested in the field with a dye to determine if they are high in nitrates. Testing results can be interpreted by the following table:

	% Nitrate	% Nitrate Nitrogen	% Potassium Nitrate
Generally Safe	< 0.5	< 0.12	< 0.81
Caution Some subclinical symptoms may appear	0.5 to 1.0	0.12 to 0.23	0.81 to 1.63
High Risk Death loss and abortions can occur	> 1.0	> 0.23	> 1.63

• Water should also be tested if nitrate problems are suspected. Water containing less than 100 PPM of nitrate is considered safe for livestock; 100-200 PPM of nitrate is risky with possible sub-clinical signs resulting; and, more than 200 PPM of nitrate should not be used. It is also important to know the history of tanks used for livestock drinking water. Tanks previously used to transport nitrogen fertilizer can continue to add nitrogen to the hauled water for several years. It is especially important to know water nitrate levels when feeding forages potentially high in nitrate. Thus, it may be prudent to test livestock water for nitrate concentrations because it is a relatively inexpensive laboratory test that can generally be arranged through county health offices.

• Altering management of pastures and crops can help minimize susceptibility of livestock to nitrate toxicosis. For example, graze turnips in the summer rather than the fall because nitrate accumulation tends to occur in the fall. Grazing instead of mechanically harvesting plants can also reduce nitrate toxicity problems because nitrates tend to accumulate in plant stems and the stem is commonly avoided by grazing livestock.

• Forage harvesting procedures can also minimize the risk of nitrate toxicity. Leaving drought-damaged forage in the field as long as practical will lower nitrate content as the plant matures. Cutting forages high in nitrates with a longer stubble height will reduce nitrate toxicity because nitrates tend to accumulate in the lower portion of the stalk. Drought-stressed plants should not be harvested for 3 to 5 days following a rain to reduce nitrate levels.

• Nitrate accumulation in plants can be related to the amount of nitrogen in the soil, though it is rarely a result of proper fertilization. Because of the high cost of fertilizer, it is always advisable to test soil for plant needs before fertilizer applications. This will minimize fertilizer costs and reduce the risk of nitrate accumulation. Using ammonia rather than nitrate fertilizer can reduce plant nitrate accumulations.

• Use caution when feeding forage plants that can accumulate nitrates. Introduce suspect feeds over 7 to 10 days so rumen microbes can adapt to higher nitrate levels. Feed rations several times per day rather than free-choice or once a day. Mix low nitrogen-feeds with feeds potentially high in nitrates.

Conclusion

Nitrate toxicosis is quite variable and dangerous but can be addressed with careful forage and grazing management. A manager must be able to recognize environmental conditions that cause plants to accumulate high levels of nitrate. A manager can manage plants high in nitrates and take precautions when introducing these feedstuffs to livestock. Forage-livestock systems that reduce the risk of nitrate toxicity can increase livestock productivity and improve profitability.

References

Cowley, G.D. and D.F. Collings. 1977. Nitrate poisoning. Veterinary Record. 101:305-306.

Deeb, B.S. and K.D. Sloan. 1975. Nitrates, Nitrites, and Health. University of Illinois. Illinois Agricultural Experiment Station. Bulletin 750. Urbana-Champaign, Illinois.

Guillard, K. and D.W. Allinson. 1989. Seasonal variation in chemical composition of forage Brassicas. 2. Mineral imbalances and antiquality constituents. Agronomy Journal. 81: 881-886.

Toxicity and Management of Alkaloid-Containing Range Plants[1]

James Pfister[2] and Silvia Lopez[3]

Introduction

Alkaloids constitute the largest class of plant secondary compounds, occurring in 20 to 30% of perennial herbaceous species in North America. Alkaloids are a diverse group of basic organic compounds containing nitrogen. Alkaloid-containing plants are of interest because alkaloids may kill, injure, or reduce productivity of livestock, and have the potential to directly or indirectly alter diet selection. Range plants that contain alkaloids poison more livestock worldwide than any other class of toxic compounds. In this article we review the major groups of rangeland plants that contain alkaloids in North America and suggest management strategies to reduce the risk of livestock losses from these plants (Table 1).

Locoweed

Locoweed species (*Astragalus* and *Oxytropis* spp.) occur throughout much of the western U.S., centering about the Great Basin and Colorado Plateau. About 10 *Astragalus* and 2 *Oxytropis* species have been found to contain the toxic alkaloid swainsonine. Animals eating locoweed suffer from lost body weight, erratic behavior, and abortions. Swainsonine usually occurs at very low concentrations in locoweeds (0.01 to 0.3% of dry weight), with much of the toxin found in the seeds. Livestock producers should not over-stock nor over-utilize locoweed-infested ranges, and should manage for sufficient desirable forage so that grazing pressure does not compel livestock to begin eating locoweed. When animals become overtly intoxicated, the most economical solution may be to remove them from pasture, and allow them to recover before selling them.

Whitepoint locoweed (*Oxytropis sericea*) begins to grow in late winter and early spring on shortgrass prairie rangelands. The green leaves are often more palatable than dormant grasses. Livestock readily consume green locoweed leaves during the spring when cool-season grasses are just beginning growth, and warm-season grasses are dormant. Grazing of whitepoint locoweed may cease when warm season grasses begin active growth in early summer, or

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[1]*Based on: J.A. Pfister, K.E. Panter, D.R. Gardner, B.L. Stegelmeier, M.H. Ralphs, R.J. Molyneux, and S.T. Lee. 2001. Alkaloids as anti-quality factors in plants on western U.S. rangelands. Journal of Range Management. 54:447-461.*

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livestock may switch to other green locoweeds (e.g., *Oxytropis lambertii*), if available. On mountain rangelands, cattle prefer immature seed pods of whitepoint locoweed, but may also eat mature pods and green leaves later in the summer, particularly if grazing pressure is excessive. In contrast to shortgrass prairie rangelands, whitepoint locoweed on high elevation rangelands is grazed during summer even though other forage is also green and actively growing. Simple changes in grazing management can significantly reduce losses to whitepoint locoweed. Reductions in cattle losses from over 20% to less than 3% annually have been reported from changes in grazing practices that reduce stocking density or avoid pastures containing locoweed in seasons when the risk of toxicity is greatest.

The likelihood of animals eating specklepod locoweed (*Astragalus lentiginosus* var. *diphysus)* increases greatly during spring when animals begin to search avidly for newly growing cool-season grasses (i.e., "chasing green"). Cattle prefer dormant grasses to specklepod locoweed during much of the spring, but once cattle begin eagerly selecting green grass, they also begin eating still-green, but drying, locoweed. During winter, cattle will even eat toxic black stems from previous growing seasons. During spring, horses intensely search for green grass, and consequently select green locoweed. Once horses begin to eat locoweed, consumption may continue until they become very intoxicated.

Woolly locoweed (*Astragalus mollissimus*) is not very palatable to grazing cattle, and probably is not selected by livestock unless grazing pressure is excessive. Consumption of woolly locoweed generally ceases when growth of warm-season grasses begins.

When some animals begin to eat locoweed, they can influence other grazing animals, including nursing calves, to begin eating locoweed through social facilitation. In most situations, ranchers should remove animals that eat locoweed to eliminate social influences, and to prevent progressive intoxication. Some producers in New Mexico with locoweed-infested pastures have reduced their locoweed losses by systematically, over several years, removing any cow from their herds seen eating locoweed, before the animal either becomes intoxicated or influences her calf or companions to eat locoweed.

Grazing animals may be conditioned (i.e., averted) so that they will avoid toxic plants, including locoweed, in future encounters. In this procedure, animals are given a taste of the plant in a corral, then dosed via stomach pump with a solution of lithium chloride (LiCl) at 200 mg/kg body weight. The LiCl-induced illness is associated with the taste of the toxic plant, and animals avoid eating the target species. Averted animals must not be allowed to graze with companions, not averted to locoweed, as social facilitation can quickly extinguish the aversion.

Producers should, if possible, provide a locoweed-free pasture for spring or fall grazing when animals are most likely to eat locoweed. Herbicidal control of locoweed in some pastures can provide a relatively "loco-free" pasture for critical times. Herbicidal treatment for this specific purpose is often economical, even though general spraying to eliminate locoweed on a ranch-wide basis is usually not economical.

Larkspur

Larkspurs (*Delphinium* spp.) are divided into three general categories based primarily on mature plant height and distribution: low, tall, and plains. All of the 17 western states contain some of the species of larkspur. Most research has focused on tall larkspur (*D. barbeyi* and *D. occidentale)*. Larkspurs contain many (>18) alkaloids of which the most important is methyllycaconitine (MLA).

Larkspurs cause cattle to die from acute respiratory failure. Cattle eat little or no tall larkspur before the plant has elongated flowering stems. Cattle generally begin consuming tall larkspur after flowering stems are elongated, and consumption increases as larkspur matures. Consumption usually peaks during the pod stage of growth in late summer, when cattle may eat large quantities (25 to 60% of the diet).

The period of greatest risk on tall larkspur ranges extends from the flower stage into the pod stage. Many ranchers defer grazing on tall larkspur-infested ranges until after the flower stage to avoid death losses. This approach wastes valuable forage, and often places cattle into larkspur-infested pastures when risk of losses is high. An additional 4 to 6 weeks of grazing may be obtained by grazing these ranges early, before larkspur elongates flowering stems. The risk of losing cattle is low when grazing before flowering even though larkspur is very toxic, because consumption of tall larkspur is very low. Once pods are mature and begin to shatter, larkspur ranges can usually be grazed with little risk because pod toxicity declines rapidly, and leaf toxicity is low.

Consumption of low larkspur (*D. nuttallianum*) by cattle appears to increase once low larkspur has flowered. High grazing pressure will often increase the amount of low larkspur eaten by grazing animals. Spring grazing of low larkspur-infested ranges can be a problem, as there may not be sufficient forage growth to graze these ranges before larkspur flowers, but risk appears to increase once flowering occurs. Fortunately, in most years low larkspurs are short-lived, so producers must avoid heavily infested areas only for about 4 weeks during peak toxicity.

Cattle can be trained to avoid eating tall larkspur through aversive conditioning, as previously noted with locoweed. Social facilitation, whereby one animal influences another to eat a particular plant, will quickly extinguish the aversion. Therefore, averted cattle must be grazed separately from non-averted cattle. Animals experienced in eating larkspur can be successfully averted, although the aversion is initially more difficult to induce and may be more fragile and less persistent than for naive animals.

On tall larkspur-infested ranges where larkspur grows as discrete patches, sheep can be herded into or bedded on the patches to reduce larkspur availability or acceptability to cattle. In areas where larkspur is uniformly distributed over a pasture, sheep must eat immature larkspur and leave sufficient feed for cattle. This has been successfully accomplished but may be difficult because early growth tall larkspur may not be palatable to sheep.

Larkspur losses can be economically reduced if dense larkspur populations are controlled by herbicides. Picloram, metsulfuron, and glyphosate have proven to be effective in killing tall larkspurs when applied at specific growth stages.

These herbicides do not reduce toxic alkaloid concentrations in treated larkspur plants, and metsulfuron may increase toxicity. Therefore, sprayed areas should not be grazed until larkspur has withered and decomposed.

Senecio and Houndstongue

Senecio or groundsel species (*Senecio* spp.) and houndstongue (*Cynoglossum officinale*) contain highly toxic pyrrolizidine alkaloids. These alkaloids are potent liver toxins that cause wasting and photosensitization. Senecios and houndstongue occur on many western U.S. rangelands. Only seven of more than 112 senecio species are known to be toxic so correct identification is essential. Managing rangelands so that plant communities are in good condition and adequate forage is available is crucial to reduce losses to senecio. Generally, senecios are not very palatable, and are avoided by grazing livestock if other forage is available. Drought stress and overgrazing can increase populations of threadlleaf groundsel, as the plant is an aggressive invader. Drought is an especially dangerous time because other forage may be lacking and the toxic alkaloid concentration in senecio plants increases during drought, so grazing animals may ingest higher quantities of more toxic forage. Senecio species are also most toxic when plants are reproducing, thus avoiding pastures when these plants are in bud, flower, or seed is prudent. Proper grazing management must consider stocking rates, as excessive stocking may increase the amount of toxic plant consumed when alternative forages become limited. Excessive stocking may lead to degradation of the desirable plant community allowing senecio species to increase. Herbicidal control may alleviate some problems if incorporated into an overall management program.

Houndstongue (*Cynoglossum officinale*) is not only a toxic plant that contains alkaloids, but also a noxious weed that is increasing over much of North America. The plant spreads from bur-like seeds that cling to wildlife, livestock and humans, and invades disturbed areas. Houndstongue is generally unpalatable when growing on rangelands, but lactating cows and horses may eat green houndstongue at times. When houndstongue contaminates hay, it is readily eaten by cattle and horses, and is quite toxic.

Lupine

Lupines (*Lupinus* spp.) are widely distributed throughout the western U.S. Cattle eating lupine may have deformed or "crooked" calves, and sheep may be poisoned outright by lupine. Livestock losses from lupine poisoning can largely be prevented by understanding two interrelated aspects. First, the highest concentrations of toxic alkaloids tend to occur in immature lupine plants and seed pods. Second, pregnant cattle are susceptible to the effects of alkaloids that cause birth defects during a window from 40 to 70 days of gestation, occasionally extending to 100 days. Birth defects in cattle can be prevented by using breeding or grazing programs that avoid placing pregnant cattle in lupine-dominated pastures in the first trimester of gestation. Alternatively, risk can be reduced by allowing only short-term access to lupines by pregnant cattle in some form of rotational grazing scheme. Herbicidal control of lupines is feasible, but is usually more expensive than altering a grazing management program.

Acute toxicity problems are less common now, but large sheep losses occurred frequently 100 years ago. Deaths occur when livestock, usually sheep, ingest a large amount of seed pods in a short time. This can occur from contaminated hay or from hungry animals gaining access to lupine-dominated forage, and can be prevented by using lupine-free hay and avoiding lupine-dominated ranges when other forage is scarce. During some years, lupine populations may temporarily increase on rangelands not normally problematic. Livestock producers need to be aware of lupine populations and be sufficiently alert to alter grazing or breeding programs when these eruptions occur. Lupine populations increased dramatically during 1997 in Washington, Oregon, Idaho, and Montana, causing severe losses. For example, producers in Adams County, Washington lost over 30% of their calves (>4000 calves) from lupine-caused birth defects.

Poison Hemlock

Poison hemlock (*Conium maculatum*) grows throughout the United States in areas with abundant moisture (i.e., creeks, ditches etc.). Animals eating poison hemlock die from acute respiratory failure or have deformed offspring. The most critical season to avoid poison hemlock is spring because the plant often appears before other forage has emerged. Green seed pods may be eaten in mid-to-late summer. Furthermore, poison hemlock may regrow in fall after seeds shatter. Ingestion during fall may coincide with birth defects in pregnant cattle, if they are in the first trimester of gestation (days 30-75). If poison hemlock invades hay fields, the contaminated hay can poison livestock. Even though toxicity decreases upon drying, sufficient toxins may be retained to poison livestock. Cattle appear to be particularly susceptible because of their acceptance of the plant and their sensitivity to the alkaloids that cause birth defects. Poison hemlock can be easily controlled with phenoxy herbicides.

False Hellebore and Death Camas

False hellebore (*Veratrum* spp.) is found in moist habitats in the Pacific Northwest and Rocky Mountain states. It is grazed by sheep and goats and causes birth defects (i.e., monkey-faced lambs). Livestock management to avoid losses to false hellebore is relatively simple because the window of toxicity when false hellebore poisons the fetus is relatively narrow (i.e., 14 to 33 days gestation). Pregnant animals, particularly sheep, should not be allowed access to veratrum-infested pastures during this period. Cattle rarely eat the plant, therefore no special management is needed. For sheep, false hellebore is quite palatable, and herders must keep bred sheep from ingesting false hellebore for about one month after the rams are removed. This is not difficult to accomplish because false hellebore is limited in distribution to moist mountain habitats and grows in easy to identify dense patches. Although effective herbicidal control is available, it may not be practical because the major populations grow in

National Forests and most problems can be solved by grazing management.

Death camas (*Zigadenus* spp.) grows on foothill ranges in much of the Rocky Mountain area. Animals eating death camas die from reduced blood pressure and heart failure. Death camas is one of the first plants available during spring, and animals may graze the plant if other forage is lacking. Generally, recognizing the presence of death camas and understanding the acutely toxic nature of the plant will aid in avoiding problems. Hungry animals should not be driven through a death camas-infested pasture. Sheep in particular should not be bedded near large patches of death camas, and sheep herders should avoid stressing sheep by rapidly driving them if they do eat death camas. Death camas can be controlled by phenoxy herbicides.

General Management Guidelines to Reduce Risk of Toxicity

Alkaloid-containing plants exact a heavy economic toll on livestock production in rangelands of western North America. Losses to these plants can be reduced or eliminated by recognizing plants containing alkaloids, understanding when livestock graze specific toxic plants, and knowing signs of potential toxicity. Grazing schemes can then be developed based on knowledge of the temporal and spatial dynamics of alkaloid concentration and consumption by livestock. Losses can be reduced by ensuring that livestock are not exposed or have limited exposure during periods of greatest risk (i.e., highest toxin concentration) or when livestock are most likely to eat toxic plants in sufficient amounts to produce toxicity.

Table 1. Summary of effects and symptoms of major alkaloid-containing plants and management practices to reduce losses.

Plant	Affected Species	Body System(s) Affected
Locoweeds	Horses, cattle, sheep	Digestive; reproductive; nervous system
Tall Larkspur	Cattle	Skeletal muscles; respiration
Senecios and Hound's-tongue	Cattle, horses	Liver
Lupine	Cattle, sheep	Nervous system; respiratory;reproductive
Poison Hemlock	Cattle, sheep, horses, pigs	Nervous system; skeletal muscles; respiratory; reproductive
False Hellebore	Sheep	Reproductive
Death Camas	Sheep	Digestive tract; nervous system

Symptoms	Management Practices
Depression; weight loss; incoordination; nervousness	Do not overstock loco-infested ranges; remove "loco-eaters"; aversive conditioning; keep animal density low
Muscular weakness, collapse; rapid breathing; bloat	Graze before flowering and after pod shatter; aversive conditioning; graze sheep before cattle
Photosensitization; weight loss; depression	Proper range management especially during drought; avoid excessive stocking rates
Depression, muscular weakness; respiratory failure; birth defects	Avoid grazing when plant is immature; keep pregnant cattle from eating lupine during days 40 to 70 of gestation
Muscle weakness; respiratory failure; birth defects	Avoid grazing in infested areas in spring and fall
Birth defects	Avoid grazing pregnant ewes from days 14 to 33 of gestation
Excess salivation; muscular weakness; lung congestion	Avoid grazing hungry animals in death camas areas; do not stress affected animals; ensure adequate forage is available

Anti-Quality Factors Associated with Alkaloids in Eastern Grasslands[1]

Frederick N. Thompson[2] and Lance R. Kennington[3]

Introduction

Most forage grasses are relatively free of toxic compounds that are dangerous to livestock. However, there are a few grasses such as tall fescue (*Festuca arundinacea*), perennial ryegrass (*Lolium perenne*) and reed canary grass (*Phalaris arundinaceae*) that produce alkaloids through a mutualistic relationship with an endophytic fungus ('endo', meaning within, and 'phyte', meaning plant). Mutualism is an interaction existing between two organisms that is beneficial to both organisms. In this relationship, the endophytic fungus resides between the plant cells and gains soluble nutrients from photosynthesis by the plant. The plant derives many benefits from this mutualistic relationship with endophytic fungus, such as enhanced drought tolerance, increased growth (which may be related to drought tolerance), and resistance to grazing. The fungus appears to be transmitted by the seed only. Endophyte-infected temperate grasses appear to have negative effects on beef cattle and sheep performance, resulting in large economic losses to producers. The main reason for these negative effects appears to be alkaloids produced by endophytic fungi associated with these plants. The negative effects include heat intolerance, fat necrosis, fescue foot, decreased weight gains, ryegrass staggers, and death. In this review, we will discuss the potential production problems associated with alkaloids in forage grasses and suggest a few management strategies for counteracting the alkaloids.

Tall Fescue

When land managers think of an important grass for pastures in eastern temperate grasslands, tall fescue usually appears at the top of the list. Tall fescue is a predominant cool-season, perennial grass introduced into North and South America from Europe in the mid-1800's. Tall fescue is an important turf and forage crop, cultivated on 29 to 35 million acres, and is mainly used in the midwest and southern United States. As a cool-season grass, tall fescue is used in conjunction with warm-season grasses to supply forage to livestock during the cool times of the year. In 1993, 21 states were found to use tall fescue for hay

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[1]*Based on: F.N. Thompson, J.A. Stuedmann, and N.S. Hill. 2001. Anti-quality factors associated with alkaloids in eastern temperate pasture. Journal of Range Management. 54:474-489.*

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and pasture, with an estimated 8.5 million cattle and 688,000 horses grazing tall fescue pastures. Tall fescue provides cattle with a good nutrient source in comparison to other grasses, providing 16% crude protein, 63% neutral detergent fiber, 6% ether extract (i.e., fats and oils) and 10% ash. However, tall fescue also contains an endophytic fungus that can have various adverse effects on cattle including inhibition of digestion, heat intolerance, fat necrosis, fescue foot, and decreased performance.

Mutualistic Relationship with Endophytic Fungus

Why does tall fescue demonstrate grazing resistance? Researchers have concluded that resistance exists because of the production of toxic alkaloids. Alkaloids are nitrogenous compounds produced by some organisms as a defense mechanism. The alkaloids in tall fescue are produced by an endophytic fungus and by the tall fescue plant.

Ergot Alkaloids

Alkaloids produced by fungus are termed ergot alkaloids. Ergot alkaloids produced by endophytic fungi include ergovaline, ergotamine, ergovine, lysergamine, and possibly others yet to be identified. All ergot alkaloids have similar effects on cattle but differ in their potency, with ergovaline being the most potent alkaloid identified in tall fescue. Ergot alkaloids have many adverse pharmacological effects on cattle, which are commonly termed "fescue toxicosis". Signs of fescue toxicosis include heat intolerance, fat necrosis, lameness, and associated decreased performance. Fescue toxicosis costs the U.S. beef industry about $609 million in losses each year. Therefore, finding solutions to eliminate or reduce this problem should be a high priority.

Tall Fescue Alkaloids

Tall fescue also produces alkaloids independent of the endophytic fungus that include perloline and perlolidine. Researchers have suggested that fescue alkaloids decrease the number of endophytes by inhibiting their growth. Others have suggested ruminal microorganisms might also be inhibited. Fescue alkaloids have also been implicated in decreasing palatability and intake because of bitterness. Voluntary intake of tall fescue increases with advancing maturity, which may be related to decreasing concentrations of fescue alkaloids with increased plant maturity. However, compared to ergot alkaloids, fescue alkaloids have mild effects on beef cattle.

Fescue Toxicosis Symptoms

The negative effects of fescue alkaloids can be severe but management strategies can be implemented to lessen their effects. The first step to mitigating the problems caused by endophyte-infected tall fescue is an understanding of the symptoms of fescue toxicosis.

Symptom #1: Heat Intolerance. Heat intolerance is the inability of animals to adjust to increased ambient temperatures. Outward signs of heat intolerance in cattle include standing in water, excessive use of shade, and rough hair coats. Heat intolerance affects the majority of the herd when temperatures exceed 86° F. The primary cause of heat intolerance appears to be vasoconstriction (blood vessel constriction) by ergot alkaloids. This vasoconstriction causes decreased blood flow to peripheral tissues, body core and brain. As a result, the animal loses its ability to dissipate heat through the skin and ears. Increased respiration rates are often observed as animals seek alternative methods to dissipate heat. In addition, cortisol, a hormone produced in response to stress, also increases in the blood with increased intake of endophyte-infected tall fescue.

Symptom #2: Fat Necrosis. Fat necrosis occurs when fat hardens and dies. Fat lesions are a deep yellow color compared to normal fat and often contain chalky white or orange colored areas. Fat necrosis occurs when blood flow to the body core decreases. Normal adipose cells fill with fat evenly but necrotic adipose cells show uneven filling of cells. Dead cells are usually found interspersed with healthy cells in necrotic fat lesions. These hard, necrotic lesions can cause constriction of intestines, reproductive problems, and kidney failure in cattle.

Symptom #3: Fescue Foot. Probably the most well known negative effect associated with grazing endophyte-infected tall fescue is a condition known as "fescue foot". Researchers estimate 20% of a herd grazing endophyte-infected tall fescue will be affected with this condition. Early clinical signs of fescue foot may appear 3 to 7 days after cattle graze endophyte-infected fescue. These signs include a red line forming at the coronary band of the hind feet and skin discoloration and swelling, which will worsen if animals are allowed to remain grazing endophyte-infected tall fescue. Death of peripheral tissues can occur as a result of vasoconstriction and subsequent inadequate blood flow to the periphery. Fescue foot occurs more commonly in cool periods because cattle have normal vasoconstriction to conserve body heat compounded with vasoconstriction by ergot alkaloids. When lameness is first observed, cattle must be immediately removed from endophyte-infected tall fescue and fed an alternative feed.

Symptom #4: Decreased Production. Decreased production is the most costly adverse effect caused by endophyte-infected tall fescue. Decreased production can result in significant economic losses to the livestock producer, because of lower cow and calf weights at the end of the grazing season. In 1983, Dr. Carl Hoveland, at the University of Georgia, and coworkers studied the effect of endophyte-free versus endophyte-containing tall fescue on performance of beef steers. Results showed grazing days were increased by 175 days when grazing endophyte-containing compared to endophyte-free tall fescue (768 and 593 days, respectively). However, they also found average daily gains and beef gain per acre were increased by grazing endophyte-free compared to endophyte- infected tall fescue. The authors concluded endophyte-free tall fescue provided superior feed for beef steers compared to endophyte-infected tall fescue. Other researchers have confirmed these results and further noted that endophyte-free fescue can be expected to yield cattle production similar to other popular forage grasses like orchardgrass (*Dactylis glomerata*).

Decreased calf weights have also been reported for calves grazing endophyte-infected compared to endophyte-free tall fescue and other forage grasses. Decreased weaning weights are caused in part by decreased milk consumption because cows grazing endophyte-infected fescue experience reduced milk production. Prolactin is a hormone secreted by the animal to initiate lactation by filling the mammary glands with milk and decreased milk production appears to be a result of decreased prolactin secretion in cows grazing endophyte-infected tall fescue.

Other Endophyte Infected Grasses

Tall fescue is by far the most important forage grass afflicted with endophytic fungi. However, several other grasses also produce alkaloids. These include perennial ryegrass, annual ryegrass, and reed canary grass.

Perennial ryegrass produces the same alkaloids found in tall fescue and additional alkaloids associated with a mutualistic endophyte. The endophyte of perennial ryegrass has been shown to increase growth, density, and insect resistance compared to endophyte-free ryegrass varieties. The alkaloids in perennial ryegrass produce involuntary convulsing when animals are excited or disturbed, a condition known as 'ryegrass staggers'. Ryegrass staggers are more common in warm, drought conditions in heavily grazed pastures. Severe outbreaks have resulted in substantial livestock losses with the greatest loss in young lambs as a result of depressed lactation. Heat stress, depressed weight gains, and reduced serum prolactin have been observed in sheep grazing endophyte-infected perennial ryegrass.

Alkaloids are also produced in association with an endophytic fungus residing in annual ryegrass, however toxicosis is only seen in annual ryegrass parasitized by a nematode. The toxins are produced by a bacterium associated with the nematode that yields a yellow slime on the seed heads. Toxicosis may appear as soon as 2 days or as late as 12 weeks after grazing the toxic forage. Signs of toxicosis in sheep include a high stepping gait, lack of coordination, and convulsions. Signs are similar to ryegrass staggers but more death loss is associated with annual ryegrass toxicosis. Annual ryegrass staggers have also been reported in horses. Supplementing with cobalt sulfate appears to have some protective effects.

Reed canarygrass is a grass well suited to poorly drained or flooded areas and low-lying areas where spring melting snows or streambanks provide moist habitats. Alkaloids associated with reed canarygrass reduce grazing, can cause diarrhea, and reduce average daily gains. In sheep, these alkaloids can cause a nervous syndrome and sudden collapse. Affected animals appear frightened when approached. Signs have occurred within 4 hours of turnout, but usually are seen between 12 and 72 hours after exposure. The nervous syndrome usually occurs 2-3 weeks after turnout. Addition of cobalt to iodized salt appears to be a preventive measure. Signs of toxicosis in cattle include hock stiffness, dragging the hind feet, and tongue and lip incoordination which results in eating difficulty.

Management Options to Overcome or Reduce Fescue Toxicosis

Pasture and Animal Management

- Feed fescue in combination with other forages including Bermudagrass *(Cynodon dactylon*) or clovers (*Trifolium* spp.). The major problem associated with dilution with clovers is that the opportunity for utilizing clover varies greatly among regions. Clovers are sensitive to viruses and other diseases and they are comparatively shallow rooted and consequently subject to summer drought stress.

- Although research is limited, it appears that increased stocking rates on endophyte-infected tall fescue may improve animal performance and production. Increased stocking rates may decrease the formation of seedheads, which is where the majority of the endophytes reside.

- Friendly endophytes. In the near future, endophyte-infected cultivars containing non-toxic endophytes will be commercially available. Limited research suggests they will improve animal productivity; however, effects on stand persistence are unknown.

- Withdraw pregnant mares from endophyte-infected tall fescue pastures at least 30 to 60 days before their expected foaling date to reduce foaling problems.

Hay Treatment and Dietary Additives

- Ammoniation of fescue hay has resulted in consistent improvement in animal performance.

- Energy supplementation with concentrated feedstuffs like grains and molasses-based feeds may overcome some of the negative effects of alkaloid containing grass forages.

- Mineral supplementation with selenium, copper, or cobalt have improved animal resistance to alkaloids in some cases but not given consistent results.

- Ensiling has been proposed as a way to mitigate the negative effects of fescue alkaloids, but limited research suggests it is not effective.

- Other treatments such as thiamine supplementation, zeranol, aluminosiliates and activated charcoal have either given negative results, inconsistent results, or have not been well researched.

Pharmacologic Compounds

- Ivermectin, a treatment for internal parasites, appears to have some positive effect for animals grazing alkaloid-containing grasses. The specific mode of action and method of administration have not been fully researched.

- Domperidone, a dopamine agonist, appears to be an effective treatment for fescue toxicosis in horses and may soon be commercially available.

References

Corah, L.R., T.G. Dunn, and C.C. Kaltenbach. 1975. Influence of prepartum nutrition on the reproductive performance of beef females and the performance of their progeny. Journal of Animal Science. 41:819.

Emile, J.C., S. Bony, and M. Ghesquiere. 2000. Influence of consumption of endophyte-infested tall fescue hay on performance of heifers and lambs. Journal of Animal Science. 78:358-364.

Hoveland C.S., S.P. Schmidt, C.C. King, Jr., J.W. Odom, E.M. Clark, J.A. McGuire, L.A. Smith, H.W. Grimes, and J.L. Holliman. 1983. Steer performance and association of *Acremonium coenophialum* on tall fescue pasture. Agronomy Journal. 75: 821-824.

Marten, G.C., R.M. Jordan, and A.W. Hovin. 1976. Biological significance of reed canarygrass alkaloids and associated palatability variation to grazing sheep and cattle. Agronomy Journal. 68:909-914.

Paterson J.A., C. Forcherio, B. Larson, M. Samford, and M.S. Kerley. 1995. The effects of fescue toxicosis on beef cattle productivity. Journal of Animal Science. 73:889-898.

Peters, C.W., K.N. Grigsby, C.G. Aldrich, J.A. Paterson, R.J. Lipsey, M.S. Kerley, and G.B. Garner. 1992. Performance, forage utilization, and ergovaline consumption by beef cows grazing endophyte fungus-infected tall fescue, endophyte fungus-free tall fescue, or orchardgrass pastures. Journal of Animal Science. 70:1550-1561.

Toxic Glycosides in Rangeland and Pasture Forages: What They Are and What They Do[1]

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Introduction

Glycosides are naturally occurring compounds found in many rangeland plants and forages. These compounds can serve an important function in the life cycle of certain plants by attracting pollinators or seed dispersers or repelling herbivores and microorganisms, but they can also be highly toxic to grazing animals. Understanding which forages contain toxic glycosides and recognizing the symptoms of glycoside poisoning can help livestock producers minimize losses. This review covers the distribution of toxic glycosides in forage species, how they affect ruminants, and strategies for preventing and treating glycoside poisoning.

Glycosides are a chemically diverse group of compounds that bear little resemblance to each other and they can form toxic compounds upon hydrolysis. The variations on this chemical theme yield a variety of powerful toxic effects when animals eat plants containing glycosides. These toxic effects can be observed as restlessness, uncontrolled bleeding, convulsions, or rapid death. Some glycosides are so powerful that they have been harvested by humans and used to kill pests or treat diseases. In this article, we will review 10 classes of toxic glycosides and discuss the plants that contain them and their effects on herbivores.

Nitro-containing Glycosides

Glycosides containing a toxic nitro-group (NO_2) are found in several species of legumes. Miserotoxin has been identified in species of milk vetch (*Astragalus* spp.) and is responsible for stock losses on western rangelands. Karakin, a glycoside-like compound, is found in several legumes *(Astragalus, Coronilla, Indigofera,* and *Lotus*) and has been implicated in neural degeneration in mammals.

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[1]Based on: Majak, W., J.W. Hall, and T.A. McAllister. 2001. Practical measures for reducing risk of alfalfa bloat in cattle. Journal of Range Management. 54:490-493.
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Acute clinical signs of toxicosis caused by nitro-containing glycosides include incoordination, distress, labored breathing, bluish skin or tongue, muscular weakness, and collapse. Death may occur within a few hours after ingestion of the toxin. In chronic poisoning, animals lose weight and develop respiratory distress, a poor hair coat, hind limb paralysis, and nasal discharge. During early stages of poisoning cattle may become unresponsive and show frothy salivation, diarrhea, and labored breathing. When forced to move they will act uncoordinated and lag behind the herd. No specific antidote is available. However, protein supplementation can enhance the activity of unique rumen bacteria capable of detoxifying this group of glycosides. These bacteria reduce the nitro group to the much less toxic amino group.

Cyanogenic Glycosides

Some plants, such as white clover (*Trifolium repens*), choke cherry (*Prunus virginiana*), serviceberry (*Amelanchier alnifolia*), and arrowgrass (*Triglochin* spp.) possess cyanide-containing glycosides that can be extremely toxic. Cyanogenic glycosides have even been extracted and used at high doses to kill rats and other household pests. Hydrocyanic acid (HCN), is released from plant cells when the cell walls are disrupted during chewing and digestion. Cattle should be least susceptible to cyanide poisoning during active feeding when rumen fermentation of forage depresses the pH of rumen fluid and most susceptible after a 24-hour fast. The cyanide is extremely toxic because it blocks the vital cellular process of aerobic respiration, which yields energy for cell and tissue function. Clinical signs of poisoning develop slowly because of the slow release of HCN from the glycoside. The delayed release of HCN permits a greater opportunity for livestock managers to identify and limit the toxic effects. Clinical signs of subacute and acute poisoning in cattle include rapid heart rate, rapid breathing, recumbency, increased pinkness of the mucous membranes around the eyes and mouth, and convulsive contractions. Administration of nitrite-thiosulfate is the preferred treatment, especially if it is supplemented with oxygen. This generally requires the aid of a veterinarian.

Cardiac Glycosides

Cardiac glycosides have a long history as medicines and poisons because of their powerful effect on the heart. Most famous in the western world is digitalis, an extract of foxglove (*Digitalis purpurea*), for the treatment of heart disease. Similar usage of squill or sea onion (*Urginea maritim)* dates back to ancient civilizations. Other forms of cardiac glycosides are found in milkweeds (*Apocynaceae* spp.), dogbanes (*Asclepiadaceae*), and lilies (*Lillaceae*).

Membrane bound proteins in the heart are the major receptors for cardiac glycosides. The presence of these glycosides results in more forceful contractions of the heart. Medicinal doses or cardiac glycosides have been used for treatment of congestive heart failure in humans. They are toxic to herbivores when consumed at naturally occuring concentrations. Sub-acute to acute signs of poisoning in cattle and sheep include restlessness, labored breathing, frequent urination and defecation, and irregular or rapid heartbeat. All cardiac glycosides may be regarded as highly toxic.

A veterinarian should be consulted immediately if cardiac glycoside poisoning is suspected. Treatments include administering activated charcoal, potassium chloride, atropine, digoxin-specific antibodies, beta-adrenergic blocking agents, procainamide and phenytoin.

Saponins

Saponins are complex glycosides that are widely distributed throughout the plant kingdom. Historically, alfalfa (*Medicago sativa*) and yams (*Dioscorea* spp.) have been recognized as rich in saponins which bind with nutrients and reduce forage value. Saponins are noted for their ability to destroy red blood cells, even at low concentrations. Because of their low degree of absorption from the gastrointestinal tract, only a few species containing saponins yield toxic effects. A growing list of saponin-containing forages cause photosensitization which is observed as intense sunburn especially around the eyes, ears, nose, and udder of livestock and can cause death in severe cases.

Toxic saponin effects usually begin in the mouth and throat, causing permeability changes or loss of membrane-bound enzymes in mucosal membranes. These effects can result in intestinal lesions and severe inflammation of the digestive tract. Under these conditions, saponins may be absorbed from the stomach and intestines and produce liver damage, respiratory failure, violent convulsions, and coma. The adverse effects of saponins can be reversed by the addition of dietary cholesterol, presumably because saponins form insoluble complexes with cholesterol.

Glucosinolates

The glucosinolates, precursors of mustard oils, are mainly found in the mustard family (*Brassicaceae*), but they are also found in other families of tropical plants. Some glucosinolates are degraded into compounds that cause enlargement of the thyroid gland (i.e., goiters). Two types of goitrogens are derived from glucosinolates and they affect the thyroid gland in different ways. One compound, the thiocyanate ion, inhibits uptake of inorganic iodine by the thyroid gland and the inhibition can be reversed with iodide supplements. The other type of goitrous compound, cyclic thiouracils, cause enlargement of the thyroid, which cannot be reversed. Several drugs are available to treat these thyroid effects including, methimazole, propylthiouracil, amphenone, and chlorpromazine.

Ingestion of mustard (*Brassica* spp.) seeds by cattle can result in lesions in the gastrointestinal tract including profuse edema of the rumen, death of mucous tissue, and intestinal bleeding. During digestion of stinkweed (*Thlaspi arvense*), allylthiocyanate is formed and the irritant oil may cause severe stomach distress. The digestion of several *Brassica* species and other mustards can cause toxic effects in the pancreas and kidney.

Diterpenoid Glycosides

The 1970's saw the isolation and characterization of compounds from species of the sunflower family (*Asteraceae*), such as cocklebur (*Xanthium strumarium*), thistle (*Atractylis* spp.), and yellow daisy (*Wedelia* spp.), that can block the body's energy-carrier system and cause cellular dysfunction. Clinical signs of poisoning in livestock include acute depression, weakness, and convulsions, and the accompanying pathologic changes include kidney dysfunction, stomach irritation, liver damage and low blood sugar.

Bracken Glycosides

Poisoning of cattle by bracken fern (*Pteridium aquilinum*) was suspected for many years, but the first report of lesions in experimental animals on a diet including bracken fern did not appear until 1965 when rats were found to develop cancers. After another 18 years, the carcinogenic agent was isolated and identified as ptaquiloside. Ptaquiloside and several analogues have since been isolated from other ferns. The prominent feature of bracken poisoning in cattle is depressed bone marrow activity. Depressed bone marrow activity results in a lower than normal level of white blood cells and platelets that can result in bleeding in the bladder evidenced by blood in the urine. Ptaquiloside is apparently transferred in cows' milk, and could pose a human health hazard on rare occasions. Bracken fern also contains the enzyme thiaminase, which can induce brain polio (polioencephalomalacia) in monogastric animals and ruminants.

Calcinogenic Glycosides

Calcinosis refers to the deposition of calcium salts in soft tissues. The ingestion of nightshade (*Solanum glaucophyllum*, and *S. malacoxylon*) was long suspected for the incidence of a calcinotic disease of livestock in Argentina and Brazil. Likewise, jasmine (*Cestrum diurnum*) in Florida and yellow oat (*Trisetum flavescens*) in the European alps, have been blamed as the cause of calcinosis. Under conditions of calcium deprivation, activated dietary vitamin D_3 is required to synthesize calcium carrier proteins. Consumption of this form of dietary D_3 results in excess absorption of calcium and phosphate from the intestine leading to calcification of soft tissues.

Phenolic Glycosides

A very large number of phenolic glycosides have been isolated from plants, and may provide a defense against herbivorous insects, but only a few are regarded as dangerously toxic to mammals. Classic examples found in subterranean clover (*Trifolium subterraneum*) and alfalfa (*Medicago sativa*) are known to induce abortions in sheep. Reproductive problems were first encountered over 50 years ago with the establishment of subterranean clover on pastures in western Australia when a dramatic decrease in the fertility of sheep was noted. Signs of reproductive disorders diminished with the introduction of cultivars of clover that were low in formononetin, an estrogen-like plant compound, but a temporary infertility still prevails among ewes exposed to phytoestrogen-containing pastures. Reproductive disorders on alfalfa pasture are usually associated with increases in coumestrol concentrations resulting from fungal infections. Coumestrol decreases ovulation rates in ewes. There is no satisfactory explanation for why cattle are less susceptible than sheep to the effects of phytoestrogen-containing pastures. Vaccinations have been partially successful for preventing phytoestrogenic disorders under experimental and field conditions.

High concentrations of coumarin are found in sweet clover (*Melilotus* spp.). Sweet clover poisoning is associated with moldy hay or silage where enzymes of fungal origin metabolize coumarin to dicoumarol, a potent anticoagulant that prohibits blood clotting. Signs of poisoning in cattle include lethargy, anemia, and the development of swelling below the skin in response to internal bleeding which causes death. The induced deficiency can be counteracted with vitamin K_1 given intramuscularly. Low-coumarin cultivars of sweet clover are available but "high-coumarin" sweet clover persists in pastures and as a weed.

Ranunculin

Ranunculin has been obtained from several species of the buttercup family (*Ranunculaceae*). Ingestion of buttercup can cause irritation of the digestive tract, abdominal pain, and diarrhea. When bur buttercup (*Ranunculus testiculatus*) was given to sheep, clinical signs of poisoning included weakness, depression, rapid heart rate, labored breathing, anorexia, diarrhea and sometimes fever.

Summary and Management Implications

Bioactivation and toxicity of the glycosides mainly depends on the: 1) rate of digestion and hydrolysis by rumen microbes; 2) rate of detoxification; and, 3) degree of absorption from the gastrointestinal tract. Plant enzymes may also be involved in the mode of action of toxic glycosides. Livestock management to reduce the risk of glycoside toxicosis is difficult because of the immense variety of glycoside compounds and the toxic effects they produce. However, wise grazing management of range and pastureland containing glycosidic plants should be based on:

• Knowledge of plants containing toxic glycosides. It is important that a livestock manager recognize the glycoside-containing plants that can cause toxic effects in livestock. It is also wise to carefully observe use of plants that contain glycosides and monitor for toxic signs in grazing animals.

• Know the life cycle of potentially toxic plants and adjust the timing of grazing when the plants are least toxic.

• Provide animals the opportunity to select a diverse diet. This can allow the foraging animal to be selective in choosing the diet that best meets its needs. A mixed diet can decrease the toxic effect of one plant by the ingestion of another that may have an ameliorating or diluting effect.

• Maintain animals with healthy rumen populations. The microbes in an herbivore's gut are the first line of defense against ingested toxins. Ruminants often graze or browse lightly on toxic plants, and rumen organisms may adapt to detoxify many toxins.

• Carefully select plants for pasture planting. Varieties of forage plants that naturally contain glycosides have been bred to minimize incidences of toxicosis. This should be considered, especially when selecting leguminous forages.

References for Additional Information

Alstad, A.D., H.H. Caspar, and L.J. Johnson. 1985. Vitamin K treatment of sweet clover poisoning in calves. Journal of American Veterinary Medical Association. 187:729-731.

Cheeke, P. R. 1998. Natural Toxicants in Feeds, Forages, and Poisonous Plants. Second Edition. Interstate Publishers Inc., Danville, Ill.

Fenwick, G.R., R.K. Heaney, and R. Mawson. 1989. Glucosinolates, p. 1-41. *In:* P.R. Cheeke (ed.), Toxicants of Plant Origin, Vol. II, Glycosides. CRC Press Inc., Boca Raton, Fla.

Kingsbury, J.M. 1964. Poisonous Plants of the United States and Canada. Prentice Hall Inc., Englewood Cliffs, N.J.

Majak, W. and M.A. Pass. 1989. Aliphatic nitrocompounds, p. 143-159. *In:* P.R. Cheeke (ed.), Toxicants of Plant Origin, Vol. II, Glycosides. CRC Press, Boca Raton, Fla.

Weissenberg, M. 1989. Calcinogenic glycosides, p. 201-238. *In:* P.R. Cheeke (ed.), Toxicants of Plant Origin, Vol. II, Glycosides. CRC Press Inc., Boca Raton, Fla.

Mineral Imbalances and Animal Health: A Management Puzzle[1]

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Introduction

All animals, including humans, need nutrients, vitamins, minerals, and water to survive. Some of us, knowing that we do not get proper amounts of nutrients in our foods, take multivitamins to complete our diets and meet our vitamin and mineral needs. Livestock producers generally provide mineral supplements to meet the dietary requirements of their stock. We know that deficiencies in certain minerals can cause health problems. For example, low calcium intake causes thin and brittle bones. But, what if a person who consumed adequate amounts of calcium was also ingesting something else that "tied up" that calcium? The result would be brittle bones and would place an unaware person at risk. As livestock owners, would we know if there were mineral imbalances in what we feed our animals?

Key to Mineral Abbreviations

B	boron
Ca	calcium
Cl	chlorine
Co	cobalt
Cr	chromium
Cu	copper
Fe	iron
I	iodine
K	potassium
Li	lithium
Mg	magnesium
Mn	manganese
Mo	molybdenum
N	nitrogen
Na	sodium
Ni	nickel
P	phosphorus
S	sulfur
Se	selenium
Si	silicon
Zn	zinc

Plants and animals need proper amounts of minerals to achieve maximum health and production. Knowledge of mineral requirements of forage plants and grazing animals is essential to understand the complex interactions that one element may have on another. Deficiency or excess of dietary mineral elements may cause animal production and health concerns. The study of simple mineral deficiencies in animal diets is not new. However, the interactions among minerals and their subsequent imbalances are relatively new areas of study in animal nutrition. In addition, when minerals are out of

[1]Based on Mayland, H.F. and G.E. Shewmaker. 2001. Animal health problems caused by silicon and other mineral imbalances. Journal of Range Management. 54:441-446.

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balance they can directly or indirectly affect bioavailability of other minerals. This means that an animal may show signs of a mineral deficiency even though it is getting the "required amount" of that mineral.

Grazing animals require 8 macronutrients. This list includes the 6 needed by plants (N, K, Ca, Mg, P, and S) plus Na and Cl. Animals require some of the same micronutrients as plants (Cu, Fe, Mn, Mo, and Zn) plus Co, I, and Se. Animals may also require ultratrace quantities of Cr, Li, and Ni. Often grass and forb diets will contain nutrient levels considered adequate, but the bioavailability of some minerals may be reduced because of interactions like K x Mg, Mo x Cu x S, and S x Se. Mineral management for livestock production requires a general idea of mineral requirements and concentrations found in forage plants (Table 1).

Grasses may not provide sufficient macronutrients (N, Ca, Mg, P, and S), micronutrients (Cl, Cu, or Zn), or other elements (I, Na or Se) and, thus, fail to meet the animal's nutritional needs. Pastures of cool-season grasses are often fertilized with N and K. If N-fixing legumes are grown then P may be applied and N fertilization will be minimized or even omitted. Grazing animals are generally supplemented with salt (NaCl) and may receive additional amounts of I, Se, Zn, and Co trace mineral to supplement their forage diets. Ruminants may also receive supplementary Mg where there is risk of grass tetany.

Forages in some geographic areas may contain sufficient mineral nutrients to maintain herbage growth, but insufficient amounts of Cu, Mg, S, Se, or Zn to meet animal requirements. For example, tall fescue is well adapted to many areas of the U.S. Soils in these areas contain little plant-available Se and research shows that plants growing in these areas may not take up sufficient Se to meet animal requirements. Management programs that allow for direct or indirect supplementation of these nutrients to the animals should be considered.

Magnesium, Potassium, Calcium and Their Interactions

Grass tetany (hypomagnesemia), induced by a Mg deficiency, may be the most important health problem in ruminants caused by mineral imbalances. Although forage containing 0.2% Mg (2 g Mg/kg DM) is adequate to meet Mg requirements in most situations, cows and ewes near parturition and continuing into lactation may need extra Mg (10 to 30 g Mg/cow/day, 2 to 3 g Mg/ewe/day). Magnesium absorption by herbivores is negatively affected by K, and forms the basis for the K/(Mg+Ca) index in forages that indicate risk level. Calcium is included in the index because it counters some of the effects of K on Mg absorption. The risk of grass tetany increases exponentially when the herbage K/(Ca+Mg) index increases above 4.4 when expressed on a mass basis (g/g or percentage by weight). Other factors that reduce Mg availability to ruminants include high concentrations of N and low concentrations of soluble carbohydrate (e.g., sugars and starches).

Table 1. Nutrient element concentrations normally found in cool-season grasses and legumes and their requirement by sheep and cattle.

	Concentrations in Forages		Dietary Requirements	
Element	Grasses	Legumes	Sheep	Cattle
	Macronutrients (g/kg)			
Calcium, Ca	3 - 6	3 - 14	3 - 4	3 - 4
Chlorine, Cl	1 - 5	1 - 5	1	2
Magnesium, Mg	1 - 3	2 - 5	1	2
Nitrogen, N	10 - 40	10 - 50	10 - 15	10 - 15
Phosphorus, P	2 - 4	3 - 5	2	2
Potassium, K	10 - 30	20 - 40	3	8
Silicon, Si[1]	10 - 40	0.5 - 1.5	requirement not established	
Sodium, Na[1]	0.1 - 3.0	0.1 - 2	1	2
Sulfur, S	1 - 4	2 - 5	1 - 2	1 - 2
	Micronutrients (mg/kg)			
Boron, B	3 - 40	30 - 80	requirement not established	
Copper, Cu	3 - 15	3 - 30	5 - 6	7 - 10
Fluorine, F[1]	2 - 20	2 - 20	1 - 2	1 - 2
Iron, Fe	50 - 250	50 - 250	40	40
Manganese, Mn	20 - 200	20 - 200	25	25
Molybdenum, Mo	1 - 5	1 - 10	<0.1	<0.1
Zinc, Zn	10 - 50	15 - 70	25 - 40	25 - 40
	Trace elements (micro-g/kg)			
Cobalt, Co[1]	50 - 300	200 - 300	100	60
Chromium, Cr[1]	200 - 1000	200 - 1000	Trace	Trace
Iodine, I[1]	40 - 800	40 - 800	500	500
Nickel, Ni	200 - 1000	200 - 1000	60 - 70	60 - 70
Selenium, Se[1]	50 - 200	50 - 200	30 - 200	40 - 300

[1]Required by animals but not by grasses or legumes.

Dietary requirements are for growing sheep and lactating beef cattle. Requirements may be different for other animal classes.

Grass tetany mainly affects older lactating cows grazing fertilized cool-season grasses in the early spring, about 2-4 weeks after turnout. Sheep are also susceptible, especially lactating ewes with twins. The signs of grass tetany in cattle include reduced intake of feed, reduced milk production, and nervousness or muscle twitching around the face, head or shoulders. As tetany progresses, the cow will stagger and fall, throw her head back, salivate and grind her teeth, and may paddle her feet. Convulsions, coma, and death soon follow. Sheep show similar symptoms, except initially they may simply hang their heads, separate from the flock, and try not to move. Symptoms may be detectable for less than 4 hours.

Severity of economic livestock losses can be reduced by delaying early spring use of grass pastures, grazing with stocker or dry cows, and supplementing animals with soluble Mg. The Mg may be provided in drinking water (using water soluble magnesium sulfate or magnesium acetate), licks, salt, or perhaps as a dust on the forage. On acid soils, liming with Ca-Mg limestone (dolomite) rather than calcium limestone (calcite) would increase Mg availability to plants and likely to grazing animals.

Prudent use of N and K fertilizers can minimize risk of grass tetany. Split applications of K fertilizer, where used, will minimize the impact of high K levels on Mg availability to the plant and subsequent grazing animals. Aluminum in acid soil solutions may also reduce Ca and Mg uptake by cool-season grasses and increase susceptibility to grass tetany. Restoring available soil P to concentrations adequate for good plant growth can also elevate Mg and Ca concentrations in grass leaves.

Assessments of mineral concentration must also keep an eye on K levels in dry-mature or winter grass (standing or harvested), as they may be inadequate for cattle requirements. This may occur because of weathering and leaching of K from the curing forage. Minimum critical levels for cattle are in the range of 0.5 to 1% of forage (5 to 10 g/kg). During summer, forage with 2% K (20 g K/kg DM) may be desired to reduce heat stress in cattle. Prudent applications of K fertilizer are required to meet plant growth requirements, and not aggravate the risk of lowered Mg and Ca uptake by plants and absorption by animals.

An alternative to fertilization or direct supplementation may be to increase Mg in forage through plant breeding. Scientists have made progress with Italian ryegrass *(Lolium multiflorum),* perennial ryegrass *(Lolium perenne),* and tall fescue *(Festuca arundinacea).* The new cultivars have resulted in reduced values of K/(Mg+Ca) in forage, increased blood Mg levels of grazing animals, and in high risk situations these high Mg cultivars have reduced the incidence of grass tetany and death losses in grazing animals.

Calcium and Phosphorus

Milk fever (parturient paresis, or calving fever) is a condition that mainly affects older dairy cows during early lactation. It occurs when the cow cannot replace the Ca in her body used by the initial production of milk, and is characterized by low blood Ca. The symptoms ensue relatively quickly, normally within 12 hours after calving. Early symptoms include depressed appetite, listlessness, cold ears, or dry muzzle. The clinical onset of milk fever and its symptoms can progress through three stages: 1) the cow is still standing, but shaky and uncoordinated; 2) the cow is laying down on her chest and her muscles are weak; and, 3) the cow is on her side, comatose and unresponsive, with very weak muscles. Animals must be treated with Ca for several days, but it must be administered by injection, not orally, because milk fever also halts digestive activity. Milk fever can occur even when herbage contains more the 0.4% Ca (4.4 g Ca/kg DM).

It is more important to balance the dietary Ca and P than to focus on Ca intake alone. A Ca:P ratio of 2:1 (wt:wt) is ideal, but as high as 8:1 has been tolerated. In situations where the Ca:P ratio is very high, cattle and sheep may be observed chewing on bones. This behavior may be indicative of a P deficiency. Male sheep or cattle may be more prone to kidney stones when the dietary Ca:P is less than 2:1. Supplementing Ca will reduce the incidence of this problem if the stones are analyzed as containing high concentrations of P. Knowing the approximate Ca:P ratios of feedstuffs and giving animals balanced amounts of Ca and P is another way to avoid the problems of Ca or P imbalances.

Selenium

Selenium is needed for animal health in low concentrations but is toxic at high concentrations. This is a challenging dilemma because in some regions of North America, plant Se occurs in high, potentially toxic concentrations, while in other areas, Se concentrations may be inadequate for animal requirements. Dietary Se requirements range from 0.03 to as much as 1.0 mg Se/kg DM. Selenium deficiency causes white muscle disease, ill thrift, reduced fertility, and retained placenta in animals. White muscle disease is a condition often affecting young animals where the buildup of white connective tissue in the muscles causes degeneration of the heart and skeletal muscles. Alkali disease and acute Se toxicosis (selenosis) may occur when animals ingest excess Se (> 5 mg/kg). It is characterized by hoof sloughing and malformations, loss of hair, stiff joints, and anemia, and in some cases, death. This can occur when animals are grazed in areas with high soil Se and the forage plants uptake toxic amounts of Se. Selenosis occurs when animals eat Se accumulator plants growing on Se-rich soils. Se-rich soils are often found where coal and petroleum production occurs. Seleniferous areas can often be grazed for a few weeks and then animals must be moved to areas that have reduced concentrations of Se.

The amount needed for selenium toxicosis or deficiency is dependent on the class of animal and levels of other vitamins or minerals in the diet. High levels of dietary S will counter the availability of Se to ruminants. A deficiency in vitamin E can cause the same symptoms as a selenium deficiency. Often when these symptoms are detected, both selenium and vitamin E are administered. When the symptoms of toxicosis are present, providing a feed source known to be low in Se or grown on Se-deficient soils can counter the symptoms. Another way to counteract excess Se is to increase sulfur intake or to add S to fertilizers used on Se-rich pastures.

Sulfur and Selenium Interactions

Sulfur toxicity may occur if ruminants ingest excess sulfate sulfur. The symptoms are caused when sulfate is reduced to the toxic H_2S form in the rumen, which kills rumen microflora. Symptoms include weight loss, anorexia, and possibly liver damage or breathing problems. Research indicates sulfate in drinking water should be considered suspect in these cases. Interactions of S x Se may occur when S fertilization results in forage crop yield response. This can lead to reduced Se intake or Se deficiency in the animals eating these plants.

The S x Se interaction is real, but the most important relationship is one of mistaken identity. In the early days of experimentation on toxicosis of Se accumulator plants, experimenters drenched several calves with water later identified as rich in both Glauber's salt (sodium sulfate), and Epsom salt (magnesium sulfate). One of the calves became blind and the experimenters associated the blindness with the excess Se in the plant. Since the 1990's others have shown that the "blind staggers" is caused by high levels of sulfate-sulfur in feed and especially in water. Blind staggers are often observed in animals restricted to poor quality water because of enriched levels of sulfate salts.

In some high elevation alfalfa fields, and perhaps in other situations, S may be deficient and prevent successful inoculation of the legume with N-fixing microbes. In these situations, sulfur fertilization will improve the growth of N-fixing microbes and the legume crop production will sometimes increase 2 to 3 times. However, greater forage production may dilute Se concentration in forage and Se deficiencies may be observed in cattle eating forage that received S fertilization. Another situation occurs where hay had been produced under rainfed systems and then upon irrigation the yield increased, but Se is diluted and some cattle eating this hay do not ingest sufficient Se for their needs.

Copper, Molybdenum, Sulfur, and Iron

Copper deficiencies may occur in grazing animals. Reduced bioavailability of Cu occurs in the presence of increased intake and bioavailability of Mo, S, and Fe. The formation of thiomolybdates in the gut may reduce absorption of Cu by animals. Copper requirements for cattle are about twice those for sheep. Sheep are very sensitive to moderately high Cu levels in the diet. Several incidences of Cu toxicity in grazing sheep have been reported on recently manured pastures. Research indicates these are associated with swine or poultry manures from operations where Cu-anthelmintics are used for control of intestinal parasites. Copper bioavailability differs among some grasses as scientists showed for cattle grazing tall fescue or quackgrass (Agropyron repens). Dietary Cu intake should be decreased in areas where herbage Mo levels are extremely low. When Mo levels are high, as they are in some meadow soils, then Cu supplementation should be increased. Nutritionists should be alert to signs of Cu deficiency or toxicity in animals, because of the many opportunities for interaction that affect Cu bioavailability. Blood plasma Cu should be monitored if dietary deficiency is suspected.

Silicon

Plants take up Si and deposit it in the cell walls of leaves, and especially on the leaf perimeter. These Si deposits provide physical support to plants, and reduce their susceptibility to insects and fungi. However, Si deposits may reduce livestock preference or palatability for certain plants. Silicon may also reduce digestibility of forage by: 1) acting as a varnish on the plant cell wall and reducing access to rumen microflora; 2) forming insoluble compounds with trace elements, like Zn, reducing their availability to rumen microflora; or, 3) forming compounds with enzymes involved in rumen metabolism. Other reports indicate that a water-soluble form of Si inhibits activity of some digestive enzymes, but the insoluble form is chemically inert. Therefore, Si ingested with soil or dust probably has little effect on digestibility.

Silicon, in addition to affecting forage quality, can cause animal health problems. In some early research, the incidence of stones in the urinary tracts of steers was related to Si concentrations in Montana forage grasses. Providing adequate and quality drinking water will reduce the incidence of urinary stones caused by Si. Ingestion of certain Si minerals may increase the rate of tooth wear, and reduce the effective lifetime of grazing animals.

Fluorine

Fluorine in concentrations of 1 to 2 mg F/kg, while not required by animals, is beneficial for high tooth and bone density. Concentrations of 4 to 8 mg F/kg will cause brown staining of tooth enamel and concentrations greater than 8 mg F/kg will reduce tooth and bone density and increase tendency for breakage. Drinking water is the primary source of F. Researchers believe sprinkler irrigation of forages, using high F water, is another way in which animals may ingest excess F. High F is often associated with thermal water from natural springs and with rock phosphates used for supplemental P in rations. Fluorine intake is seldom a problem for adult animals. However, intake of excess F will weaken tooth and bone formation for young growing stock and producers should consider growing these animals in other areas where F intake is not excessive.

Iodine

Research has shown animal performance can be good on pastures containing 0.3 mg I/kg DM, however, the northern half of the U.S. and Canada is generally I-deficient. Salt (NaCl) is a common carrier of supplemental I for humans and domestic livestock and will be identified as iodized salt. Dietary intakes of 1 to 2 mg I/kg DM should be considered when animals are eating goitrogenic (causing thyroid growth) plants like turnips and other mustard species.

Mineral Summary

Most livestock managers are familiar with the basic dietary mineral needs of their animals. However, it is difficult to keep track of the many interactions between minerals and their implications to animal health. One of the best ways to ensure that animals are getting adequate amounts of minerals is to provide either a mineral mix in the feed ration, or a salt and mineral block that is formulated for the needs of a specific area. With the possible exception of phosphorous, there is no evidence that animals deficient in one or more minerals, are able to identify from a cafeteria offering, that element(s) that is deficient in their diet. Once the proper amounts of minerals are available, then potential mineral imbalances should be considered and mineral ratios adjusted. Use care when applying fertilizer to pastures, and learn the general mineral contents of various feedstuffs. If a dietary mineral imbalance is suspected, examine the feed and water sources and test them for mineral content. Then treat accordingly, or consult a veterinarian or nutritionist for advice. Solving the mineral puzzle may be difficult, but will yield benefits in animal health and production.

References for More Information

Ammerman, C.B., D.H. Baker, and A.J. Lewis. 1995. Bioavailability of Nutrients for Animals. Academic Press., N.Y.

Mayland, H.F. and P.R. Cheeke. 1995. Forage-induced animal disorders. In: R.F Barnes, D.A. Miller, and C.J. Nelson (ed.) Forages. The Science of GrasslandAgriculture. 5th ed. Iowa State University Press, Ames, Iowa.

McDowell, L.R. 1992. Minerals in Animal and Human Nutrition. Academic Press, Inc., N.Y.

National Research Council (NRC). 1980. Mineral Tolerance of Domestic Animals. National Academy Press. Washington, D.C.

Reid, R.L. and D.J. Horvath. 1980. Soil chemistry and mineral problems in farm livestock. A review. Animal Feed Science Technology. 5:95-167.

Spears, J.W. 1994. Minerals in forages. 281-317. In: G.C. Fahey (ed.). Forage Quality Evaluation, and Utilization. ASA, CSSA, SSSA. Madison, WI.

A Closer Look at Insects that Affect Forage Quality and Quantity[1]

John B. Campbell[2] and Daniel Patten[3]

Introduction

Over 1,500 species of insects occur on North American rangelands. Insects play important roles in rangeland ecosystem functions such as energy flow, nutrient cycling, water utilization, and vegetative changes. Fortunately, the vast majority of rangeland insects do not cause detrimental effects that reach economic significance. However, there are a few insect species that cause consistent or occasional losses in forage resulting in economic losses to livestock producers. The best known damaging species are grasshoppers, crickets, ants, caterpillars, beetles, and weevils. Many other insect species may sporadically cause severe damage to rangeland in limited areas. Termites, armyworms, army cutworms, leafhoppers, plant hoppers, spittle bugs, wireworms, billbugs and numerous others feed on range plants, but generally are not populous enough to warrant expensive control measures. A few species of insects, such as blister beetels, cause problems to livestock producers not by reducing forage quantity but by causing health problems to foraging animals. In this review, we will discuss the major groups of insects that affect rangeland and pastureland forages. We will also clarify the extent of damage by insects and potential cures for these pests.

Grasshoppers and Crickets

Grasshoppers are the most serious of the insect groups that contribute to forage losses in pasture and rangeland plants. While there may be 50 or more grasshopper species on a specific area, typically only 8 or 9 species cause significant economic losses. Some species are considered beneficial because they feed only on plants that are of low forage value for livestock. For example, Dodge grasshoppers feed primarily on Western ragweed (*Ambrosia psilostachya*) and the genus *Hesperottix* feeds mainly on Western ragweed and Missouri goldenrod (*Solidago missouriensis*).

Most grasshopper species do not hatch and begin active feeding until late spring. Therefore, plants that initiate growth in the early spring, such as

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[1]*Based on Campbell, J.B. 2001. Anti-quality effects of insects feeding on rangeland plants: A review. Journal of Range Management. 54:462-465.*

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needlegrasses (*Stipa* spp.) wheatgrasses (*Agropyron* spp.), and bluegrasses (*Poa* spp.), experience little grasshopper damage. By the time grasshoppers begin to defoliate these cool-season grasses they have completed growth and are becoming dormant. However, warm-season grasses such as the bluestems (*Andropogon* and *Schizachyrium* spp.), grama grasses (*Bouteloua* spp.), and buffalograss (*Buchloe dactyloides*) do not begin growth until May and grow most rapidly when temperatures reach 85-95° F, which coincides with the greatest grasshopper feeding activity.

Grasshoppers cause damage by defoliating plants which can reduce plant vigor and slow root growth. Grasshoppers also cut stems and blades while eating only part of them. They eat closer to the ground than livestock and may kill growing tips of grasses. They cut off seed stocks, reducing seed production, and increasing susceptibility to soil erosion by leaving the soil unprotected.

Personnel from the Bureau of Entomology and Plant Quarantine kept seasonal grasshopper density records for western ranges from 1932 to 1952. They estimated that the average number of 2 grasshoppers per square yard would eat or destroy 14.65 million tons of forage on 262 million acres of western rangeland. This would have provided feed for about 4.9 million animal units.

Morman and coulee crickets are a kind of grasshopper that can have sporadic outbreaks. In outbreak years, they increase in number and form great migratory bands that denude the rangeland of practically all plants in places. They seem to prefer flower and seed parts, reducing the reseeding potential of the plants. If denuding occurs later in the year, the plant may not be able recover and store nutrients in the roots for overwintering.

Western Harvester Ants

The genus *Pogonomyrinex*, consisting of 22 species, is the primary group of harvester ants in North America. This group ranks next to grasshoppers in rangeland damage. The ants create mounds that may be a foot high and 30 feet in diameter. The area around the mound is devoid of all vegetation. Not only is the vegetation destroyed, but wind erosion increases in the denuded areas. The ants also collect seeds that may affect plant production, particularly with annual plants.

Colonies survive for 15 to 20 years, and one mound may consist of as many as 60 chambers. New colonies are formed, usually in later summer, by mated winged reproductive ants. After mating, the queen sheds her wings and digs a burrow several inches deep in the soil. The first brood is composed mostly of female workers. This brood forages, enlarges the colony, cares for the young and protects the mound. The workers move the eggs of the second brood to newly-constructed chambers which have been stocked with seeds and insect parts as a food source. Most of the mound expansion is in the spring, but regrowth in the area around the mound is removed throughout the season. A single acre of rangeland can support as many as 15 colonies and worker ants from these colonies can strip vegetation from as much as one-seventh of the acre. Grazing management to maintain adequate biomass and limit disturbance will serve to slow the increase of new mounds. Insecticides can be used to treat the mounds, but this is labor intensive and should be approached from an integrated, area-wide control effort to be successful.

Rangeland Caterpillars

The range caterpillar has three discontinuous populations, one in Mexico, one in southcentral New Mexico and the third in northeastern New Mexico, Colorado, Oklahoma, and Texas. Some scientists believe these were once a continuous population. The caterpillar distribution is generally in blue grama (*Bouteloua gracilis*) - dominated rangeland at elevations between 4500 and 7900 feet. The northern distribution into Colorado is probably limited by decreasing late summer precipitation.

As the populations become larger, food consumption is heavy. Caterpillars consume grass, often down to the crown, wasting unconsumed portions of leaves. If drought conditions exist, there is little regrowth, and the roots are unable to store nutrients for the winter, and there is no reseeding of annual plants. In addition, caterpillars discourage subsequent livestock grazing because of spines from the larvae and their shed skins. These spines cause irritation around the mouth and nose of livestock. The larvae may tie several grass stems together with the cast skin. Livestock tend to avoid areas heavily used by caterpillars because of the spines.

As they search for food, caterpillars gather in bands 3 to 4 feet wide and several miles long. Ranchers refer to the feeding of these bands as “windrowing”. The range caterpillar feeds on 40 or more species of grass. The economic threshold may be as low as 2 larvae per square yard.

The range caterpillar has been considered cyclic which is probably true in the sense of large populations in extensive areas. In recent years, however, some extensive damage has occurred in localized areas virtually every year. Control has changed from massive aerial spray programs over large areas to smaller mist applications of pyrethroids to localized areas. If insecticide applications are effective and occur early in the year, grassy vegetation may recover if soil moisture is sufficient.

White Grubs

Beetles from the family *Scarabaeidae* are among the most numerous on rangelands. The immature growth stage, when beetles appear as grubs, is the most damaging stage. In most species, plant damage occurs from the grubs feeding on roots which can kill the grass, however adults of a few species also cause plant damage. The *Phyllophaga* spp. complex is the best-known plant damaging group.

The white grubs (May-June beetles) are creamy white with shiny brown heads, have 6 prominent legs and are generally shaped like a “C” in cross-section. Much of the damage on rangeland probably goes unnoticed if it is of moderate intensity. It is generally diagnosed as plant stress as a result of drought. Heavy damage may occur only in spots ranging from 10 to 100 yards in diameter. In some areas such as the Nebraska Sandhills, damage may occur only in wet meadows that are valuable for hay and grazing.

White grubs can destroy grasses and leave communities susceptible to weed invasion. Feeding by white grubs can also create a mode of entry for bacterial and fungal diseases that kill the weakened plant. Skunks and rodents can cause further damage to plants by digging up grubs as a food source. This occurs in Nebraska in wet meadow areas. Although there are certain cultural or chemical control measures that reduce grub numbers, they would generally not be feasible for pasture or rangeland.

"Plant Bugs" of the *Miridae* Family

Many species of the *Miridae* family are associated with range plants. They have piercing mouth parts with which they suck juices from plants. The adults of this group are about ¼ inch long and are blackish grey, with buff margins around the edges of the wing. The black grass bugs are the best known of this group of insects. They are also called big-eye bugs because their eyes appear to be bulging from the side of their heads. There are 34 species of concern from the *Labops* and *Irbisia* genera. These insects feed by sucking fluids from the cell which can considerably reduce forage plant quality, quantity, and plant survival.

The black grass bugs were first noted as pests around 1950 when range improvement programs were replacing native grasses with introduced grasses, especially wheatgrasses (*Agropyron* spp.). The large areas of a single species of grass provided an excellent niche for the black grass bugs. In one study, a density of 15 bugs/foot^2 reduced seed head production in intermediate wheatgrass (*Agropyron intermedium*) by 56%. Black grass bug feeding can reduce leaf length, seedhead height, and carbohydrate reserves in root crowns of crested wheatgrass.

Control strategies include application of insecticides, or heavy grazing in the spring. Insect resistant plant varieties have also been evaluated. Tall (*Agropyron elongatum*), slender (*Agropyron trachycaulum*), and intermediate wheatgrasses are somewhat tolerant to feeding by the black grass bugs.

Blister Beetles

Blister beetles are generally considered beneficial because the larvae of several species are predacious on grasshopper eggs. Others are predators of ground-dwelling bees. Adult blister beetles tend to be gregarious, and several may be noted feeding on the same flowering alfalfa plant. They also feed on soybeans, blooming goldenrod, and other range plants. Adult blister beetles vary in size and color, but are easily recognized by their elongated, narrow, cylindrical and soft bodies. When viewed from above, they have a constriction at the back of the head where it attaches to the body or thorax.

The interest in the blister beetles is not from the standpoint of damage to range plants, but because they can injure horses or other livestock. Livestock can ingest blister beetles while foraging. The bodies of blister beetles contain a substance called cantharadin that causes blisters on skin tissue upon contact. It is usually ingested with the consumption of alfalfa hay. Horses are very susceptible to blister beetle poisoning. The digestive tract of horses can be severely irritated bringing about secondary infections and bleeding. Cantharadin is absorbed and excreted through the kidneys, thus irritation of the kidney and urinary tract potentially causing infections and bleeding. The substance also lowers calcium levels and causes damage to heart muscle tissue.

There are differences in amounts of cantharadin found between species and sexes. Males apparently produce cantharadin and pass it to females at mating. The lethal dose of cantharadin is quite low (i.e., about 1 mg/Kg). Thus, a few beetles with a high cantharadin level could kill a small horse. Extension entomologists field quite a few questions yearly from either horse owners or alfalfa producers on how to avoid buying or selling alfalfa hay that contains blister beetles. Generally, blister beetles are present at the second and third cuttings, but seldom in the first or fourth cuttings. Random inspection of bales is not practical because the gregarious behavior of the beetles might cause one bale to have a large number of beetles, and the next bale might not have any. For the same reason, chemical control is probably not practical unless hay for horses was bringing a premium price. Killing the beetles does not reduce their toxicity; dead beetles still contain cantharadin.

References for More Information

Many entomology textbooks refer briefly to range insects, but the two major publications that deal specifically and exclusively with the subject are Haws et al. (1982) "An Introduction to Rangeland Insects of the Western United States" and Watts et al. (1989) "Rangeland Entomology." This latter publication has been noted as the world's most authoritative treatment on the important role of insects in rangeland ecosystems. Another publication of note is Pfadt (1994) "Field Guide to Common Western Grasshoppers." This publication contains colored plates of adult and nymphs of the major rangeland grasshoppers, and the text details the biology habitat and feeding choices for each species. "Grasshoppers Integrated Pest Management User Handbook" is a Wyoming Experiment Station Bulletin, but it is included in the USDA – APHIS Technical Bulletin 1809. This publication contains material by several authors on range management considerations to reduce damage from grasshoppers and/or to reduce grasshopper numbers based on range management techniques.

Haws, B.A., J.F. Werner, D.B. Thomas, J.L. Capinera, R.W. Lauderdale, J.B. Knight, E.W. Huddleston, W. Smith, W.C. Campbell, J.D. Evans, A.F. Glover, B.E. Norton, and E.A. Richardson. 1982. Rangeland Insects of the Western United States. Utah Agric. Exp. Sta. Special Rept. No. 23. Logan, UT.

Pfadt, R.E. 1994. Field Guide to Common Western Grasshoppers. Wyoming Agric. Exp. Sta. Bull. No. 912. Laramie, WY.

USDA-Animal Plant Health Inspection Service. 1996. Grasshopper IPM User Handbook. Tech. Bull. No. 1809. Washington, DC.

Watts, J.G., E.W. Huddleston, and J.C. Owens. 1982. Rangeland entomology. Annual Review of Entomology. 27:283-311.

The Grazing Lands Technology Institute

Rangelands, grazed forestlands, pasturelands, haylands, as well as forage croplands constitute almost half of the private land in the United States. These are in every state plus the Caribbean and Pacific Basin areas. Although these lands have many economic and conservation uses and benefits, the term 'grazing lands' is used to refer to these lands collectively.

The Grazing Lands Technology Institute (GLTI) develops, coordinates, and provides state-of-the-art science and technology for the Natural Resources Conservation Service (NRCS) on national and regional grazing land issues. The GLTI coordinates the technical requirements for regional and state grazing land conservation delivery and serves as a leader on grazing land technology issues within NRCS and with other Federal agencies, universities, and conservation groups and producer organizations.

New technology applicable to the use and management of these lands is developing at a rapid rate. The NRCS must have the capability of packaging and conveying new science to regional, state, and field offices in an effective manner. The GLTI provides the link between universities, research agencies, and NRCS policy development to ensure appropriate new science is incorporated into NRCS policy and technical guidance documents in a timely manner for use by field office staffs.

The GLTI works with the NRCS field staff who provide technical assistance to owners and managers of grazing lands. Ecologically and economically sound alternatives can only be provided in a timely manner when the advancing technological knowledge base is kept current and made available to field personnel.

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