

# Behavioral toxicology of livestock ingesting plant toxins

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## Abstract

Traditionally, effects of plant toxins on livestock have been measured using tissue or biochemical changes to determine the extent of intoxication. In addition to traditional approaches, toxic effects can be measured using behavioral principles; this discipline is called behavioral toxicology. Behavioral toxicology is a combination of toxicology, pharmacology, and the experimental analysis of behavior. Behavioral toxicology offers a sensitive means to determine toxic impacts by evaluating behavior, since behavior is a functional integration of all body systems. Concurrent use of behavior and traditional pathological measures will enhance our understanding of plant-caused intoxications. Operant analysis of animal behavior is a powerful technique used often in behavioral toxicology for establishing normal behavior, and detecting toxicity-induced deviations from normal behavior. Behavioral toxicology can provide an understanding of ingestive and reproductive (sexual and maternal) responses of livestock after exposure to a variety of plant toxins. Such information, together with knowledge about plant/animal interactions, will provide range and animal managers with tools to use in preventing or reducing livestock losses to poisonous plants.

**Key Words:** animal behavior, poisonous plants, neurobehavioral toxicology, cattle, sheep, operant analysis

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Poisonous plant ingestion results in various well-documented symptoms in herbivores (Keeler et al. 1978), yet little research exists to document the impacts of plant toxins on animal behavior. Poisonous plants can impair ingestive and reproductive (sexual and maternal) behavior, thus reducing animal productivity. For example, sheep consuming locoweed (*Astragalus* or *Oxytropis* spp.) may have difficulty prehending forage (M. Ralphs, pers. comm.). Understanding behavioral effects is crucial to determine why animals ingest poisonous plants (Provenza et al. 1991), and implementing preventative measures.

Behavioral toxicology is founded in pharmacology, toxicology, and the experimental analysis of behavior (Wiess and Laties 1975, Annau 1986, Hopper 1987). Behavioral toxicologists use concepts and methods from these fields to examine how toxins impact behavior (Thompson and Schuster 1968). The combined study of behavior and toxicology has gained legitimacy as a scientific discipline for 2 reasons (Weiss 1986): (1) toxins can profoundly and recognizably alter behavior; and (2) methods in experimental analysis of behavior can be rigorously applied to problems in toxicology and pharmacology.

Our objective in this review is to show how emerging principles from behavioral toxicology can be applied to an analysis of livestock ingesting toxic plants by: (1) providing a rationale for studying behavior as altered by poisonous plants; (2) defining behavior and contrasting behavioral and morphological tests of toxicity; and (3) reviewing methods used in behavioral toxicology.

## Why Study the Impacts of Plant Toxins on Behavior

Ingestive behavior can be severely modified by plant toxins. Toxins can cause adverse post-ingestive consequences resulting in food aversions; food aversion learning is an important mechanism allowing herbivores to cope with poisonous plants (see Provenza et al. 1991). In the apparent absence of food aversion learning, cellular damage caused by a toxin may alter subsequent food ingestion. For example, liver damage (cholestasis) alters food preferences in rats (Deems and Friedman 1988); this type of toxicity is commonly found in livestock consuming hepato-toxic plants. Some pharmacological agents like amphetamine and nicotine selectively decrease or increase intake of specific nutrients in rats (Jias and Ellison 1990); a number of plants contain nicotine or related alkaloids and amphetamine-like compounds. Plant-induced neuromuscular deficits also impact food ingestion as animals experience tremors or reduced motor activity; such deficits probably reduce efficiency in searching for and prehending forage. For example, cattle intoxicated from larkspur have periodic muscular seizures for 24 hours after ingestion of a sublethal dose, and food intake is reduced for up to 3 days post-dosing (Pfister et al. 1991).

If a plant toxin causes cognitive (learning and memory) disabilities, then ingestive behavior may suffer, because animals require such abilities to: (1) discriminate pasture locations to graze based on previous grazing experience (Bailey and Rittenhouse 1988, Bailey et al. 1990); (2) relocate patches of food that have been previously sampled (Bailey et al. 1987, 1989); and (3) learn by imitation about what and where to forage (Thorhallsdottir et al. 1990). We understand little about how cognitive impairments impact behavior, whether initiated in utero, early in life, or in adulthood.

Plant toxins can also adversely impact reproductive behavior, including reductions in estrous behavior (Kaldas and Hughes 1989), and male libido (Panter et al. 1989). Locoweed disrupts milk production, suckling behavior, and maternal-infant bonding in sheep following in utero exposure (Pfister, unpubl. data).

### Respondent and Operant Behavior

To determine how normal behavior is modified by plant toxins requires an understanding of learning mechanisms used by different animal species in various environments. Two major types of learning behavior are characterized in the experimental analysis of behavior: respondent and operant conditioning (Mazur 1986). The first, called respondent, is usually a smooth muscle- or gland-mediated activity elicited by a specific antecedent event. For example, gut contractions and enzyme release are reflexively induced by food entering the stomach. If a signal, say a dinner bell, is consistently sounded just before food delivery, the sound alone will eventually come to elicit digestive activity. This pairing of food with an arbitrary stimulus, in this case the bell, was first systematically investigated by Pavlov (1927) using dogs. Pavlovian, also called classical, conditioning is the procedure wherein a previously neutral stimulus (e.g., bell) becomes effective in eliciting a response (e.g., salivary secretion) as a result of being paired with an already effective stimulus (e.g., food presentation). Thus respondent conditioning is akin to an animal learning when or under what circumstances some event will occur (Cabe and Eckerman 1982). Strength of conditioning is measured by amount of glandular output (e.g., saliva production) or latency (e.g., time from bell to peak activity).

Respondent behavior can be contrasted with operant behavior, so-called because organisms operate on the environment and behavioral actions produce consequences. While respondent behavior deals with innate or reflexive responses, operant behavior involves voluntary actions. Strength of operant conditioning is measured in terms of rate of the response, and the number of

responses per unit of time can be manipulated by altering consequences. For example, if rate increases when followed by stimulus R, that stimulus is a reinforcer. If the rate decreases as a function of stimulus P, then we call that stimulus a punisher. If poking our finger in a light socket results in a severe shock, our rate of light socket poking may suddenly and permanently drop to zero. On the other hand if placing coins in a machine is followed on occasion by the delivery of many coins, the rate of coin insertion may increase and persist at that level for a long time.

Toxins can affect both respondent and operant behaviors; and behavioral toxicologists establish normal behavior in the absence of a toxin and evaluate how respondent or operant behavior changes once a toxin is introduced to the animal. Can behavioral measures alone be used to evaluate how toxins affect animals, or should other measures be used in conjunction with behavioral measures?

### Behavior and Morphology

Ingestion of toxic substances generally results in changes at the molecular, cellular, tissue, or organismal level. Traditionally, these changes have been measured using pathological evaluation of tissues, cells, and biochemical reactions. Pathological evaluations are often termed morphological tests because pathologists rely heavily on light or electron microscopy to detect and define animal responses to toxins. We include biochemical evaluations of toxicity with morphological tests for convenience in discussion. Conversely, behavioral tests measure changes at the organismal level. Analyzing behavior is a means of evaluating an animal's functional integrity, encompassing the sensory, motor, and cognitive (learning and memory) abilities of the animal (Mello 1975, Tilson and Harry 1982, Cory-Slechta 1989).

Do behavioral analyses have any advantages over morphological tests? Behavioral analysis of toxicosis can track the toxic process over time, while morphological measures generally observe toxicity at a single point in time (Weiss 1986). For example, in immature animals behavior is a more sensitive index of developmental injury than measures such as birth defects (Vorhees 1986). Examination of behavior may help identify cellular and molecular mechanisms (Koob and Bloom 1988). For example, larkspur (*Delphinium* spp.) poisoning has been thought to primarily affect the peripheral nervous system. However, recent work indicates that the plant has stimulant properties at low doses, implicating central nervous system (CNS) effects (Pfister et al. 1991).

Although behavioral tests are often sensitive indicators of toxicity, morphological tests are also necessary (Norton 1978, 1982). Norton (1982) emphasized several principles when toxicity is evaluated: (1) chemical and physical changes in cells govern all functional (i.e., behavioral) changes; (2) damage to an organ can result in functional damage; and (3) homeostatic mechanisms can obscure functional change, because of structural redundancy and tolerance. Tolerance, the compensation by body systems for a toxic insult, may obliterate behavioral changes in certain instances. Thus we emphasize that investigations of behavioral toxicology should concurrently examine behavioral and morphological indicators when possible. Table 1 indicates how animal responses to toxins in larkspur and locoweed might vary depending on the type of evaluation.

Behavioral toxicology encompasses diverse ways of examining toxicity, and each level of explanation can shed light on the toxic process. At the organismal level, the site of action of ingested toxins is the behavioral function(s) that are altered; at tissue and cellular levels, the physiological process is the mechanism of action underlying the toxin's effect on behavior (Thompson 1984). The focus in many behavioral toxicology studies is on the mechanism of action, with the behavioral analysis providing clues to the physi-

**Table 1. Predicted livestock responses to ingestion of larkspur and locoweed.**

	Toxin <sup>a</sup>				
	Effect	Type	Reversibility	Morphological	Changes Functional
Larkspur	Pharmacological	Acute	Rapid (hours/days)	None <sup>b</sup>	Reversible <sup>c</sup>
Locoweed	Toxicological	Neuromuscular Chronic	Possibly not or very slow (weeks/months)	Permanent <sup>d</sup>	Permanent <sup>e</sup> /reversible

<sup>a</sup>The toxins in larkspur are diterpenoid alkaloids; the alkaloid methyllycaconitine likely accounts for most of the toxic response (Manners et al. 1991); the toxin in locoweed is the indolizidine alkaloid swainsonine.

<sup>b</sup>Larkspur intoxication produces no observable biochemical or morphological lesions in cattle or rats (D. Baker, Diplomate, American College of Veterinary Pathologists, pers. comm.).

<sup>c</sup>Behavioral observations indicate that cattle intoxicated from larkspur recover within 36–72 hours (Pfister, unpublished data).

<sup>d</sup>When locoweed comprises 25% of the diet of sheep, kidney and CNS lesions are evident in less than 2 weeks (Van Kampen and James 1970).

<sup>e</sup>Permanency or reversibility of behavioral changes is speculative, and probably depends on the severity of lesions and the circumstances under which behavior is examined. Apparently recovered animals may display aberrant behaviors under stress (L.F. James, pers. comm.).

ological processes that have been disrupted. In other studies, the behavioral analysis provides an index of toxicity. For example, diterpenoid alkaloids from larkspur leave no detectable biochemical or tissue lesions in intoxicated animals, thus behavioral measures may be the only means of accessing toxicity. Some plant toxins (e.g., locoweed) produce reversible lesions, and behavioral analysis can provide an assessment of toxicity as it occurs and disappears over time.

The primary emphasis in behavioral toxicology studies is on how the toxin affects behavior, not on the behavioral response *per se* (Glick and Goldfarb 1976). For example, the locoweed toxin, swainsonine, typically causes a reduction in feed intake (anorexia) when locoweed is eaten for days or weeks, but why this occurs is unclear. Although we typically don't consider loss of appetite as beneficial, in sick animals anorexia can be an adaptive response to slow cell growth and differentiation (Hart 1988). Swainsonine's anorectic effect may be mediated by changes in brain neurotransmitter levels, alterations in brain structure, changed taste perceptions, reduced ability toprehend and masticate food, or through decreases in eating time, or some combination of the above. Concurrent behavioral and morphological tests can be employed to determine interactions of dose and duration, and determine the cause of adverse effects.

How can behavioral tests evaluate toxic plant impacts on animals? Detecting adverse behavioral effects depends largely on the sensitivity and reliability of the chosen methods. In the following section, we examine research methods in common use.

### Methodology in Behavioral Toxicology

Methods in behavioral toxicology can be characterized as examining either learned or unlearned respondent or operant behaviors. Screening tests are simple evaluations of toxicity and generally rely on unconditioned (unlearned) behaviors. Walking in an open field or a maze is an example of unlearned operant behavior (Mitchell 1982), while smooth muscle activity in the presence of a stimulus is an example of unlearned respondent behavior. Taste aversion learning is an example of learned respondent behavior, since the animal learns that a flavor is linked with nausea and then avoids the flavor in subsequent encounters. Pressing a button or breaking a beam of light to gain a feed reward is an example of learned operant behavior. Learned operant behavior is often used to evaluate complex behavior dealing with learning and memory (Cory-Slechta 1989).

### Screening Tests

Screening tests are observational or simple mechanical tests that can rapidly determine the presence or absence of behavioral effects. A battery of such tests (functional observational battery, FOB) is often used to screen for toxic effects (Moser et al. 1988).

Typically, the FOB contains numerous rodent tests which would be inappropriate for livestock. However, we suggest that screening tests with rodents are beneficial for evaluating unfamiliar plant substances in order to determine potential impacts on behavior. Such rodent tests can quickly and inexpensively provide an indication of possible toxicity to livestock (Nelson et al. 1980). We refer the interested reader to Tilson et al. (1979), Tilson and Mitchell (1984), and Mitchell et al. (1982) for comprehensive reviews of screening techniques.

Since gross motor activity is often of interest when livestock ingest plant toxins (Keeler et al. 1978), a maze may have particular utility. Simple mazes are useful in screening for presence or absence of toxic effects, while complex arrangements may be designed to examine learning and cognitive functions (Bailey et al. 1987, Cory-Slechta 1989). Pfister (unpublished data) used a detour maze to examine learning deficits in sheep consuming locoweed. A detour maze has movable barriers which can be rearranged to provide an assessment of correct path acquisition and memory. Sheep that ingest locoweed for 30 days have more difficulty mastering the maze when changes are made than do controls.

Besides using various screening tests, behavioral toxicologists also examine operant behavior, or how animals act when given rewards or punishment under different circumstances. Examination of learned operant behavior is termed operant analysis; operant analysis has proven to be one of the more powerful techniques for detecting and examining toxic effects on animals.

### Operant Analysis

Operant analysis examines acquisition of behavior, or animal learning (Reynolds 1975). Learning is examined as animals are tested under controlled circumstances. As animals learn, responses change depending on the consequences. Responses may be pushing buttons, or pressing a lever; a consequence may be delivery of a food pellet, or absence of food. Researchers can manipulate potential consequences to increase or decrease animal responses (e.g., how often a cow must press a lever to gain a grain reward). Manipulating behavior by altering consequences is termed schedule-controlled behavior, because the consequences control how often responses will be made.

Schedules of reinforcement are rules for determining which responses among many will be reinforced (Ferster and Skinner 1957). Since operant behavior is selected and maintained by consequences, altering the pattern of available consequences is a major independent variable for manipulating behavior (Laties 1982). Reinforcement procedures, by definition, strengthen or increase the rate of behavior (Reynolds 1975). Food, sexual activity, and water often serve as positive reinforcers; however, the evidence of such depends upon the increased or sustained rate of the behavior

(Hart 1985). Food offered to a satiated animal may not increase the rate of the response upon which the food is contingent.

There are numerous examples of operant behavior in all livestock. We present one simple example to illustrate operant behavior and schedule-controlled responses. Cattle are often watered individually using a water bowl, with water flow regulated by a metal panel; depressing the panel delivers a burst of water into the bowl. Naive but thirsty cattle quickly learn to press the panel with their nose if access to water follows. This operant behavior (panel pressing) is a function of its consequences (water delivery into a bowl). With no water delivery into the bowl, the animal would cease to press the panel. The pattern and rate of nose pressing depend on the degree of deprivation and the schedule of water delivery. The pattern and rate of presses that a cow will make will be altered if by chance the water-delivery system malfunctions, and water is available only after every third or fifth press. If the water bowl were only functional for 30 sec during every 5 min period, a different pattern of responding by a thirsty cow would eventually emerge. The point is that consequences control operant behavior, as water delivery (reinforcer) controls nose presses (responses). Operant responding gradually becomes very predictable and stable as animals learn a particular schedule (i.e., discover rules governing presentation of reinforcers).

Because schedule-controlled behavior is stable and consistent, deviations from stability can indicate the effects of toxins in plants. Examination of schedule performance in the presence and absence of a drug or toxin can provide indications of the toxic effect. Following the establishment of a stable behavioral baseline the animal can be exposed to the toxin and deviations in responding from baseline are then examined. Typically, subjects are used as their own controls in that the drug is given, then removed and baseline reestablished, then another dose of the drug administered, and baseline reestablished. This is called a reversal design within subjects.

There are several reasons why operant analyses are widely used in behavioral toxicology: (1) electronic technology allows for automated data collection and analysis under many different schedules with several subjects simultaneously, thus reducing bias and errors introduced by human observers; (2) animals can be trained to respond in virtually any manner within that species' capabilities and physical limitations (e.g., lever press rapidly or slowly; small or great amounts of force; pausing or not); (3) operant procedures provide sensitive baselines for ascertaining the effects of many types of toxins in short- or long-term studies (McMillan and Leander 1976, Laties 1982); (4) relatively few animals are needed as subjects, and their behavior can be studied intensively (Laties and Wood 1986); and (5) each animal can serve as its own control, which increases sensitivity.

### Operant Procedures

A continuous reinforcement schedule is one in which every response is followed by the reinforcer. Continuous reinforcement is generally used only during initial training when satiation is not critical. Intermittent schedules reinforce some responses according to the number of responses emitted or the time since last reinforcer. These are called ratio and interval schedules. Under fixed-interval (FI) schedules, only the first response after a specified interval of time is reinforced. FI schedules generally produce a curvilinear pattern of responding (Fig. 1), with low rates early in the interval and higher rates toward the end. Variable interval schedules make reinforcers available after unpredictable amounts of time. Fixed ratio (FR) schedules specify that reinforcement follow a fixed number of responses. Any fixed ratio payoff produces high and very stable rates of responding, sometimes punctuated with pauses after each reinforcement event. Variable ratio (VR) schedules are similar to the type used in slot machines and generate high rates of

responding which show great resistance to extinction. Numerous other schedules are possible, including combinations of schedules (Ferster and Skinner 1957).

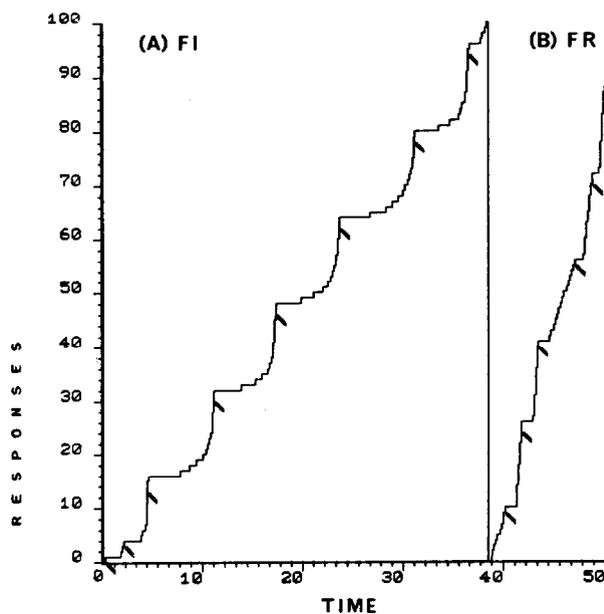


Fig. 1. Examples of 2 operant reinforcement schedules typically used in behavioral toxicology studies: (a) FI (fixed interval schedule): Y-axis indicates number of responses (breaking of a light beam with nose) by cattle; X-axis indicates time in 0.1 min increments. Every response after a time interval was reinforced. Reinforcements (e.g., 3-sec access to grain) are shown as a diagonal slash line. Fixed interval schedules typically produce a series of scalloped shaped lines, as animals respond slower early in the interval, and increase response rate as the interval nears completion. (b) FR (fixed ratio schedule): X- and Y-axes as above; every response after a fixed number is reinforced; the steeper the vertical slope of the response line, the faster the rate of responding; a horizontal response line indicates a pause by the animal. High rates of responding as shown here are typical of FR schedules.

An initial examination of toxicity often involves either an FI or FR schedule, or both (Laties 1982, Laties and Wood 1986). Schedules of reinforcement are of paramount importance in evaluating toxic effects in animals because the schedule dictates the pattern of responding and therefore largely determines if a behavioral alteration can be detected (McMillan and Leander 1976, Sieden and Dykstra 1977). The base rate of responding is the pattern and rate established by the animal under no drug circumstances. As noted above, animals on FR schedules develop high rates of responding, while those on FI schedules typically show low rates of responding early in the interval and accelerating rates near the end. Because of these characteristic patterns of responding, FR and FI schedules show differential sensitivity to toxic compounds (Laties and Wood 1986). Several generalities have emerged from years of behavioral testing with drugs: (1) schedules with high baseline rates of responding generally show reduced rates after drug administration. This is true across a broad range of drug classes such as stimulants, narcotic agents, hallucinogens, cholinergic blockers, or agonists (Seiden and Dykstra 1977, Katz 1990), and even lead intoxication (Cory-Slechta 1984); and (2) schedules such as FI, with temporal patterns of responding, generally show an increased rate of responding early in the interval, and a decreased rate late in the interval after drug administration (McMillan and Leander 1976, Seiden and Dykstra 1977, Laties and Wood 1986, Katz 1990). Overall (i.e., average) response rate may not be altered when considered over an entire session but pattern and interresponse times may vary. Reliance on rate only during an experimental

session may obscure important serial patterns of responding (Weiss et al. 1989).

### Use of Operant Analysis with Livestock

Operant analysis has been successfully used with many livestock species, including cattle (Albright et al. 1966, Arave et al. 1983), horses (Myers and Mesker 1960), goats (Baldwin 1979a), sheep (Baldwin 1981), and pigs (Baldwin 1979b). Most livestock studies have not been concerned with toxicity, but with questions about discriminatory abilities, such as differentiating between the urine odor of cohorts (Baldwin 1977), or distinguishing among various visual shapes or colors (Baldwin 1979a). In a toxicological analysis, Van Gelder and colleagues (Sandler et al. 1969, Sandler et al. 1971, Van Gelder 1973a,b; Van Gelder 1975) used operant conditioning to examine sheep behavior after exposure to lead or insecticides. They found that sheep exposed to insecticides showed reduced ability to detect an auditory signal.

We are currently using operant procedures to examine larkspur intoxication. The toxins in tall larkspur are diterpenoid alkaloids that probably block acetylcholine (ACh) receptor sites at the neuromuscular junction (Benn and Jacyno 1983). Our primary objectives are to determine doses of larkspur that cause behavioral alterations but not overt clinical signs of toxicosis, and to examine potential antidotes. For example, we plan to examine the drug neostigmine, an anticholinesterase drug (ACh agonist in the peripheral nervous system), for its ability to reverse the effects of larkspur alkaloids (Nation et al. 1982). Cattle responses during baseline and intoxicated conditions are presently being monitored in operant chambers using both FR and FI schedules (Pfister et al. 1991).

We have also initiated a behavioral study of chronic locoweed intoxication. The toxin swainsonine in locoweed inhibits enzymes responsible for cellular glycoprotein processing resulting in cellular destruction in various tissues (James et al. 1989), including the cerebellum (Hartley et al. 1989). The cerebellum plays a crucial role in controlling movement, judging time, and learning (Leiner et al. 1989), and cerebellar lesions can disrupt simple learned motor actions (Kandel and Schwartz 1985). Behavioral analysis of locoweed-induced CNS intoxication can help answer questions about dose-response relationships and long-term persistence of intoxication. We are evaluating the effects of stress in intoxicated sheep which display no overt symptoms of loco poisoning, and examining the interaction between degree and reversibility of intoxication in sheep consuming locoweed in a cyclic pattern. Sheep are responding in operant chambers under FI and FR schedules (Pfister, unpublished data).

### Taste Aversion Learning as an Index of Toxicity

Conditioned taste aversions (CTAs) (Garcia et al. 1985, see also Provenza et al. 1991 and Ralphs 1991) have also been proposed as a sensitive means of testing compounds for toxicity (Riley and Tuck 1985, Miller and Eckerman 1986). In this paradigm, the degree of taste aversion is gauged by the reduction in intake of a food, when food flavor has been paired with adverse gastrointestinal consequences. Alternatively, CTAs can be used to determine if a particular toxic compound interferes with the acquisition of an aversion, a test of learning and memory (Miller and Eckerman 1986). For example, pyrrolizidine alkaloids found in *Senecio* spp. cause liver lesions, and hepatic damage can alter food preferences (Smith et al. 1976), and may affect acquisition of CTAs. We could expose cattle to *Senecio* spp., and after liver damage is confirmed by biopsy, the animals could be tested for ability to develop a CTA, then retested periodically to assess retention of the CTA.

Numerous toxic compounds are effective in inducing taste aversions, while other putative and known toxins do not produce aversions (Riley and Tuck 1985). A necessary element in establish-

ing CTA is stimulation of the emetic center in the brain stem. Such activity appears to reduce the hedonic value of the food (Garcia et al. 1985). Little work has been done to determine how effectively plant toxins establish CTAs. Larkspur alkaloid extracts cause muscular paralysis and death at high doses (Olsen 1978), and can cause CTAs at lower doses (Olsen and Ralphs 1986). Pfister and Cheney (unpublished) found that both low and high alkaloid doses were effective in creating both food aversions and place aversions in hamsters. Although the exact mechanism is unclear (Pfister et al. 1990), they speculated that larkspur-caused CTAs are partially conditioned by the cardiovascular system. Because taste aversions play a key role in herbivores learning to avoid toxic plants, elucidating how CTAs are formed is critical in understanding why animals eat poisonous plants. Thus, studies of taste aversion learning should be part of any test battery used to evaluate toxicity (Riley and Tuck 1985). However, it seems unlikely that the CTA paradigm will successfully detect toxicity of all compounds, simply because some toxins do not stimulate the emetic center (e.g., cyanide, strychnine).

### Summary

Behavioral toxicology is an important combination of toxicology, pharmacology, and behavioral analysis that shows great promise for elucidating the effects of plant toxins on livestock. A broad goal of behavioral toxicology is to develop principles that apply across a range of plant and animal species. Such principles would indicate the ingestive or reproductive response by animals after exposure to a particular class and dose of toxins. Knowledge about behavioral responses, coupled with other information on plant/animal interactions, will provide range and animal managers with predictive tools for use in preventing or reducing losses to toxic plants. What contributions can behavioral toxicology make to range and animal managers dealing with toxic plant problems?

The following examples illustrate how behavioral toxicology can answer questions important to livestock producers. Anecdotal evidence from ranchers with locoweed problems indicates that ewes consuming locoweed are poor mothers, and that lambs from these ewes may be "stupid", that is may not suckle normally at birth, and may be less productive than "normal" cohorts. We have found (Pfister and Astorga, unpubl. data) that locoweed consumption during gestation severely reduces maternal-infant bonding at parturition, and that lambs from ewes do not suckle normally at birth. We are presently evaluating the learning ability of lambs from intoxicated ewes. Many livestock producers believe that once cattle, horses, or sheep consume an intoxicating dose of locoweed, the animal will never fully recover. If true, this means that such animals should be culled, as they can never be brought back to a fully productive status. We are examining this question of residual toxicity using operant analysis, and hope to be able to provide recommendations about dose-duration interactions and normality of previously intoxicated animals. How do livestock perceive toxins in range plants? Can livestock learn to avoid plants based on smell from a toxic constituent? Again, operant analysis can be used to determine discriminatory abilities of animals in relation to toxic compounds. Can mineral supplements or feed additives be used to decrease the susceptibility of cattle to larkspur? One can determine how larkspur affects behavioral responses of individual animals, and then determine how responses change with the additional of mineral (or other substances in question) to the diet. We conclude that behavioral toxicology research can answer numerous important questions about livestock and poisonous plants.

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