Truths are divine principles which regulate all things, or in other words, we do not control truth but truth controls us. Rules on the other hand set perimeters to what can happen to us. Three rules that I think necessary for excellence in range management are:

1. Severely graze the pasture.
2. Let it recover.
3. Keep pastures small enough that the animals cannot sustain themselves on regrowth.

In summary, Dr. Box made some good points on why we should adopt a new model and Dr. Laycock's model of different steady states connected by thresholds is a good starting point. But don't throw the baby out with the bath water! Plant progression and regression and increasers and decreasers reflect the boom and bustiness of nature. One can however throw out the "good" and "bad" labels and the concept of climax (plant Utopia).

Also since the range ecosystem is nonlinear, one should model using the principles of the science of choas to demonstrate: beginnings and ends; truths and the benefits of simple rules; the complexity of the thousands of variables in range science and the simplicity of range management (given the right conditions a pea-brained buffalo makes a good range manager. When you run out of food, move on.)

Tall Larkspur Poisoning in Cattle: Current Research and Recommendations

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Tall larkspurs (*Delphinium barbeyi, D. occidentale,* and *D. glaucesens*) are the most serious cause of cattle deaths on mountain rangelands in the western U.S. (Ralphs et al. 1988). We have documented annual death losses from 4 to 15% per year on Forest Service allotments in Utah, Colorado, and Montana. The presence of tall larkspur on mountain rangelands also contributes to enormous forage losses, as cattle grazing is deferred or curtailed to avoid death losses on these highly productive ranges.

Tall larkspur research has been a priority at the USDA Poisonous Plant Research Laboratory since 1985. The larkspur research team is composed of range scientists, veterinarians, chemists, toxicologists, and neurophysiologists. Research objectives are to: (a) identify and isolate toxic alkaloids, and determine structure:activity relationships; (b) determine the toxicity and mechanism of action of toxic alkaloids; (c) identify environmental factors that influence toxic alkaloid levels in plants; (d) understand cattle consumption patterns in pen and field grazing trials; and (e) evaluate management alternatives to prevent or reduce larkspur poisoning in grazing cattle.

Toxic Alkaloids and Mechanism of Action

The toxins in tall larkspur are diterpenoid alkaloids. Tall larkspurs contain 18–20 different individual alkaloids which vary greatly in toxicity (Manners et al. 1992, 1993). The most toxic major alkaloid is methyllycaconitine (MLA), to which we have assigned the relative toxicity of 100. Deltaline, the most abundant alkaloid, often makes up over 50% of the total alkaloid concentration. Deltaline is relatively nontoxic, with a relative toxicity of 5. At least 1 minor alkaloid is as toxic as MLA, and several other alkaloids are of intermediate and low toxicity compared to MLA.

Levels of total alkaloids and MLA vary greatly from site to site and year to year. The MLA concentration in *D. barbeyi* is shown in Figure 1; these samples were collected from an area where 30 of 180 cows were poisoned near Steamboat Springs, Colo., in late August, 1991. In mid-June, 1991, Colorado MLA levels were highest as concentrations were about 1.4% in leaves of vegetative and newly budded larkspur. Cattle began eating larkspur in early August during the pod stage. Levels of MLA in leaves and pods declined in mid-summer, then increased as larkspur matured. Cattle increased consumption during the late season when there was an increase in toxicity, with disastrous results. Interestingly, tall larkspur from Oakley, Ida., during 1988 contained no or low MLA (range 0 to 0.01%) during the entire summer. We don't understand why such large location or year differences exist, but these differences probably explain much of the variation in cattle losses.

How much larkspur does it take to kill an average cow?

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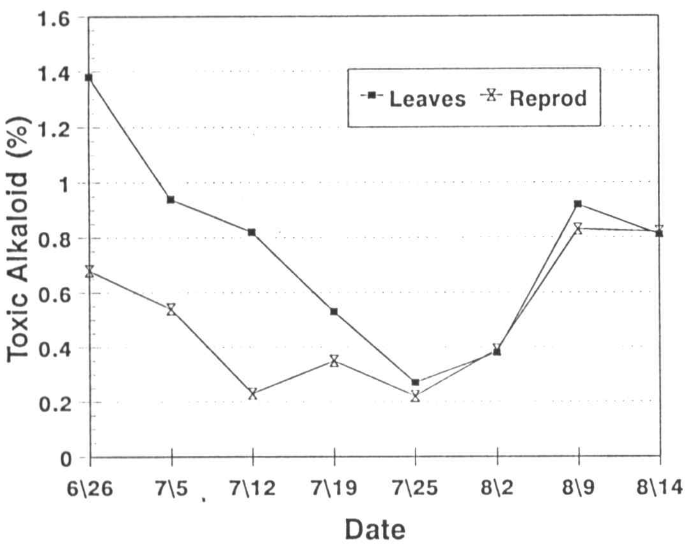

Fig. 1. *Level (% of dry weight) of the toxic alkaloid, MLA, in tall larkspur near Yampa, Colorado, during summer, 1991. Larkspur was in the bud stage until mid-July, in the flower stage from mid-July to late July, and in the pod stage after August 2.*

A 1,000-lb. cow consumes about 26 lb. of forage (dry weight) per day. If larkspur contained about 1% MLA (dry weight), a cow could consume a toxic dose of MLA by eating about 3.5 lbs. of larkspur (dry weight) (Pfister et al. 1993a).

How does larkspur kill livestock? Evidence to date indicates that MLA blocks acetylcholine receptors in both the central nervous system and in muscles. With receptor blockage, muscles become progressively fatigued beginning with the fine motor controlled muscles of the mouth, ears, and limbs, progressing to the diaphragm, and leading to respiratory paralysis. An inability to eructate also may result in death from bloat or aspiration of rumen contents into the lungs (Olsen 1978). Rats given a lethal dose of MLA can be kept alive indefinitely when respiration is maintained mechanically. Because exercise can heighten larkspur toxicity due to muscular fatigue, it is important that poisoned cows not be driven or excited.

Cattle Grazing Tall Larkspur

We have conducted grazing studies examining when and how much larkspur is eaten by range cattle for the past 7 years: 3 years in central Utah (Manti), 3 years in Colorado (Yampa), 2 years in southwestern Montana (Sheridan), and 1 year in southern Idaho (Oakley). Several significant findings have emerged from these studies. First, cattle generally eat little or no larkspur during years of severe drought. Although this may lower death losses to larkspur, some losses may still occur if cattle consume larkspur during storms. Conversely, cattle consume more larkspur at the same location during years of normal or above normal precipitation.

Second, weather patterns and larkspur maturity are very important in determining consumption of larkspur. During years when larkspur is generally acceptable to cattle, cattle usually begin consuming leaves and flowers after larkspur elongates flowering racemes (Pfister et al. 1988b). We have seen virtually no consumption during the bud stage in any of our studies. Consumption usually peaks during the pod stage later in the summer, when cattle may eat 25–30% of their diets as larkspur in any given day. This consumption pattern is often not fatal, but we have noted that rain or snow showers may greatly influence consumption and increase death losses. During or just after storms, cattle may consume large amounts of larkspur in short periods of time (i.e., 30 min). We feel that these weather-related episodes are responsible for most cattle deaths.

Because larkspur toxicity generally declines throughout the growing season and cattle tend to eat more larkspur after flowering and in the pod stage, we have termed the period of greatest danger a 'toxic window' (Fig. 2)

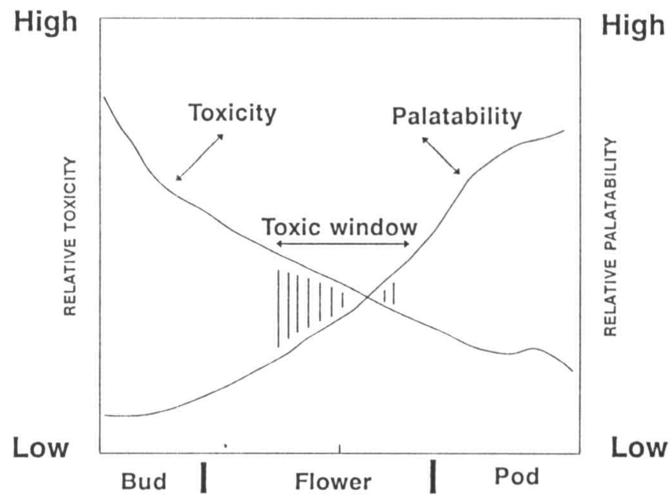

Fig. 2. *Relative toxicity and palatability (no units) of tall larkspur to cattle during years of normal precipitation on high mountain rangeland. The time of greatest danger is losing cattle is termed a toxic window because of increasing palatability combined with relatively high toxicity in plants. This representation was developed primarily from grazing studies near Manti, Utah.*

(Pfister et al. 1988a). Larkspur consumption is at or near zero when the plant is most toxic in the vegetative and bud stages. When larkspur elongates flowering racemes, cattle begin eating the leaves and/or flowers as toxicity is declining. Cattle may eat a great deal of larkspur in the pod stage, but depending on the weather and the location, at these stages larkspur is generally much less toxic. The late season increase in leaf MLA levels shown in Figure 1 may not be typical of other areas, although an increase in pod MLA concentrations is usually noted later in the summer.

Can tall larkspur ranges be safely grazed? Deferment of larkspur ranges has been a sound practice for many years; however, much forage goes unused and cattle graze on ranges with declining nutritional quality in late summer and early fall. In the course of 3 grazing studies (Pfister et al. 1988a, Pfister and Manners 1991, Pfister unpublished data), cattle grazed larkspur ranges while larkspur was vegetative or in the bud stage. In none of these years or locations (Manti, Oakley, Yampa) did cattle consume more than a few bites of larkspur before the plants flowered. Thus, we speculate that ranchers can safely graze larkspur ranges early in the summer, remove cattle after larkspur begins flowering, and then return for late summer grazing. This grazing pattern may minimize, but not eliminate the risks from grazing larkspur ranges, while providing greater use of available forage than simple deferment.

Preventative Measures

Grazing Sheep Ahead of Cattle

Although larkspur is toxic to sheep, sheep are 4–6 times more resistant to larkspur alkaloids than are cattle (Olsen 1978). The reason(s) for this difference in susceptibility is not clear. Sheep may graze ahead of cattle, eating or trampling larkspur, reducing subsequent availability (or acceptability) to cattle. Sheep readily graze larkspur late in the growing season, but for sheep grazing to be effective, they must graze larkspur early before cattle enter the pasture. During some years sheep grazed 40–90% of the larkspur plants while in other years sheep refused to eat larkspur (Ralphs et al. 1991a, Ralphs and Olsen 1992). When sheep did consume larkspur, they removed the leaves and inflorescence, or a combination of eating and trampling reduced the acceptability to cattle grazing later. We have also noted that concentrating sheep bands on patches of larkspur may reduce larkspur acceptability to cattle.

Mineral Supplementation

Many ranchers feel that providing mineral supplements will reduce cattle consumption of tall larkspur, or decrease its toxicity if they consume larkspur. We found that no level of mineral supplement altered the amount of larkspur consumed by cattle (Pfister and Manners 1991, Pfister unpublished data). We noted some effects of mineral supplements on water consumption, with higher levels of mineral resulting in increased water intake. However, mineral supplementation did not greatly affect ruminal liquid passage rate, suggesting no beneficial effect such as rapid dilution of larkspur alkaloids in the rumen. We have concluded that, if mineral supplements alter animal susceptibility to larkspur, then other, unknown mechanisms are operating.

Aversive Conditioning

Cattle can be trained to avoid eating larkspur through food aversion learning. We have successfully created aversions by feeding larkspur to an animal, then giving the animal a gastrointestinal emetic (lithium chloride LiCl) to induce nonlethal sickness (Ralphs 1992). The animal then associates larkspur with the illness and will not graze the plant.

We have formed aversions to larkspur in pen-feeding trials, and then allowed these animals to graze larkspur-infested pastures to test the aversion (Lane et al. 1990). When grazing with other averted animals, heifers have refused to eat larkspur while control animals in other pastures have readily eaten larkspur. Animals tested a year later still avoided larkspur. However, when averted animals grazed with nonaverted animals that were eating larkspur, the aversion soon extinguished. The influence of other animals consuming larkspur apparently overrides the aversive conditioning, and once averted animals graze larkspur with no negative consequences (i.e., LiCl dose), then the aversion rapidly disappears (Ralphs 1992). It may be possible to permanently avert new or replacement cattle grazing a tall larkspur-infested pasture, but these averted animals would need to be kept separate from other animals for an unknown number of years.

Drug Intervention

Because larkspur kills animals by blocking acetylcholine receptors, drugs that increase acetylcholine concentrations at the receptor sites have great potential for reversing larkspur toxicity. We have tested one such drug, physostigmine, in cattle in pen and field situations (Pfister et al. 1993b). Physostigmine given intravenously (i.v.) or intraperitoneally (i.p.) will rapidly reverse tall larkspur poisoning. We have injected physostigmine into cattle intoxicated by larkspur in the field, as well as in pen tests and found the drug simple and easy to use. Physostigmine is not commercially available, nor is it licensed by the FDA for use in cattle. Related drugs that are more available may also reverse the poisoning.

Herbicidal Control

Cattle losses to larkspur can be reduced substantially by controlling larkspur with herbicides. The best control opportunity occurs when larkspur grows in large, discreet patches where cattle losses occur frequently. Although eradication is not feasible, reducing larkspur density may sufficiently reduce cattle ingestion rate to reduce animal losses.

Tall larkspur is difficult to kill with herbicides. One must kill the entire tap root and the underground buds, or the top-killed plant will regrow the next year. Since the EPA withdrew registration for 2,4,5-T in 1983, we initiated research on alternative herbicides (Mickelsen et al. 1990; Ralphs et al. 1991b; Ralphs et al. 1992).

Picloram (1 to 2 lb/ac) was effective throughout the growing season, and may be used later in the summer when access is improved to high mountain areas. Metsulfuron (0.5 to 2 oz/ac) was effective only in the early vegetative stage, and efficacy declined as larkspur matured. However, metsulfuron had no adverse effect on grasses, and low application rates and a short half-life make it environmentally acceptable. Efficacy of glyphosate also declined as larkspur matured; this nonselective herbicide must be spot-sprayed (2% solution) to individual plants. Herbicidal control can be economical under some circumstances, and picloram, metsulfuron or glyphosate may be used effectively to kill larkspur.

Conclusions

In the past few years, we have seen a tremendous increase in our knowledge about tall larkspur, from alkaloid chemistry and toxicity testing to knowledge about plant/animal interactions. Several promising management alternatives such as sheep grazing or grazing larkspur ranges early in the grazing season are being evaluated. Studies to examine how alkaloids change in tall larkspur due to environmental conditions and range site are underway, and may someday provide a model that will allow predication of relative toxicity before cattle are moved into pastures. Some form of drug therapy to alter animal susceptibility is a real possibility for future use. We are confident that as research on tall larkspur continues, a variety of possible solutions will be available to the livestock industry to reduce or prevent livestock losses.

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