This paper deals with poisonous plants in relation to livestock, and emphasizes the present status of our knowledge concerning situations as they occur in veterinary practice in the United States. There are many poisonous principles found in or on plants which are potentially disastrous to livestock, but which have not yet been troublesome because of certain deep-seated protective feeding habits. With few exceptions, animals will not become poisoned by plants unless forced to do so by some unusual or artificial condition of husbandry. The important corollary of this statement, which can not be adequately developed in this paper, is that control of plant poisonings of stock is to be sought not in removal of the plant—an often costly and always temporary expedient—but by change in management.

Minimum standards for the successful elucidation of a problem involving one or more poisonous plants include: Description of management conditions which have led to poisonings, the kind and age of livestock affected, a competent veterinary description of symptoms and lesions, a competent botanical determination of the plant, proof that the plant identified is the etiological factor, both by demonstration that it has been eaten in sufficient quantity and by experimental creation of the symptoms, an experimental determination of the lethal dose in terms of percentage of the animal's weight or other basis, extraction and identification of the poisonous principle to kind at least (i.e., alkaloid, glycoside, etc.) and, finally, a preliminary investigation to determine if there is variation in toxicity of the plant with geographic location or with stage of growth. These requirements are rarely met, because it is uncommon to have the necessary botanical, chemical, and veterinary skills available in a given situation.

Muenscher (158) in his text treats 440 species of domestic poisonous plants. Some of these are excluded from the present discussion because they are solely dermatitis-producing in human beings. On the other hand, a number of new species which have been shown to be toxic to stock since 1951 must be added. Far less than half of the total number of these species conform to the standards listed above. Of those plants reported, categorization can most easily be accomplished on the chemical nature of the toxic principles. These principles include alkaloids, glycosides (glucosides), including cyanogenetic and saponic, irritant oils, organic acids, minerals including nitrates, selenium and molybdenum, resins or resinoids, phytotoxins, and toxic principles causing primary and hepatogenic photosensitivity. To these must be added a miscellaneous group of plants whose action is mechanical or whose toxic principle is unique or as yet partially uncharacterized. A few plants contain two or more toxic principles which are not in the same chemical group. In many cases, the chemical definitions of these groups are not on parallel grounds, and characteristics which identify a given moiety as a member of one may not exclude its concurrent
membership in another. Couch (54) has treated a number of these groups. Here it is intended briefly to characterize each toxic chemical moiety with emphasis on characteristics important in considerations of poisonous plants. A number of plants are listed for each category of toxic principle. The intention has been to include in these lists plants which reliably have been shown to have caused stock loss or sickness in the United States. It is difficult to draw a line between reliable and doubtful circumstantial reports.

Plants additional to those in this paper may be found listed as toxic in various compilations of poisonous plants. Sources of information for these additional reports are various; two predominate. Plants not domestically reported as poisonous may have been determined toxic to stock in other countries. Because of differences in management practices and growing conditions, it is unwise to use such information for other than casting suspicion on a given plant. For various reasons, it is similarly unwise to apply to livestock information gained solely from studies in human toxicology.

References in this paper were chosen on the basis of value, timeliness, and, to a degree, general availability.

In some instances, plants have been placed in a category on the basis of information developed from foreign studies which is not apparent in the domestic reference listed. On the other hand, mere chemical extraction of an alkaloid, glycoside, or other such compound from a toxic plant does not serve conclusively to incriminate that substance as the actual source of toxicity.

Alkaloids. Historically, alkaloids (lit. "alkali-like") are those products of chemical plant analysis which are not true bases (alkalis) but share certain chemical similarities with them. They are basic in reaction and form salts with acids. Generally insoluble in water but extractable in organic solvents, they occur as crystals (a few as liquids) in pure form, and in plants they are most often found as a soluble organic acid-alkaloid salt. They are almost universally bitter in taste. Alkaloids are found in less than 10% of all plant species, yet are common in certain families of plants. Further, alkaloids of similar structure are found in closely related plants, but on occasion identical alkaloids have been found in plants of no immediate relationship.

Most alkaloids exert a strong to very strong physiological reaction when introduced into an animal; a few produce no reaction. Activity is effected primarily via the nervous system by a mechanism at best poorly understood. The reaction may be quite specific for a given alkaloid in a given organism, yet may vary considerably both with different alkaloids in the same animal or with the same alkaloid in different animals. The major research interest in alkaloids is engendered by their importance in medicine and in human toxicology. Hundreds have been extracted and the molecular structure of many has been elucidated. Some have been synthesized. They are seen to be a heterogeneous assemblage of complex basic compounds containing nitrogen in heterocyclic and/or aromatic ring structure. A few similar substances of animal origin are often excluded by definition. Compounds answering the above description which may be found as normal intermediaries in metabolic pathways of plants and animals must be excluded.
The alkaloid content of a plant varies little, if at all, with factors such as nature of the growing season, climate, and availability of water. When present in a plant, alkaloids are frequently distributed throughout its structures. Any part may be dangerous to stock. Alkaloids may vary considerably with variety in cultivated plants. Their role in the plant has been variously ascribed. A view commonly held (118) is that they represent not particularly selective evolutionary “eddies” in plant nitrogen metabolism.

Some plant amines have physiologically toxic activity in animals. In this country, *Phoradendron* sp. (probably *Phoradendron villosum*) has been reported (224) toxic to cattle. The related *Phoradendron flavescens* contains phenylethylamine, which is credited (42) with a toxic action.

The genus *Astragalus* is large and complex. Some members are selenium accumulators (q.v.). Others, together with species of the genus *Oxytropus*, are responsible for the nervous disease of horses, sheep, and cattle called “loco” (128, 137). This syndrome has long been known in the West, where it has caused serious stock loss, and has been vigorously investigated; yet, it is still enigmatic in many ways. The syndrome itself is partially dependent in expression on the particular species of loco ingested. The poisonous principle has been stated (81) to be of alkaloidal nature. Recent work (71, 82) leaves the exact identity of the toxic compounds in doubt.

### Table 1

<table>
<thead>
<tr>
<th>Plants containing alkaloids toxic to stock*</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aconitum</em> sp.</td>
<td>Aconite, monkshood</td>
</tr>
<tr>
<td><em>Allium cepa</em></td>
<td>Cultivated onion</td>
</tr>
<tr>
<td><em>Amianthus muscalocenicum</em></td>
<td>Stagger grass</td>
</tr>
<tr>
<td><em>Amanita muscaria</em></td>
<td>Fly agaric</td>
</tr>
<tr>
<td><em>Arumone mexicana</em></td>
<td>Prickly poppy</td>
</tr>
<tr>
<td><em>Buxus</em> sp.</td>
<td>Box</td>
</tr>
<tr>
<td><em>Claviceps</em> sp.</td>
<td>Ergot</td>
</tr>
<tr>
<td><em>Conium maculatum</em></td>
<td>Poison hemlock</td>
</tr>
<tr>
<td><em>Corydalis</em> sp.</td>
<td>Pinweed</td>
</tr>
<tr>
<td><em>Crotalaria</em> sp.</td>
<td>Crotalaria</td>
</tr>
<tr>
<td><em>Delfinium</em> sp.</td>
<td>Larkspur</td>
</tr>
<tr>
<td><em>Dicentra</em> sp.</td>
<td>Bleeding heart, etc.</td>
</tr>
<tr>
<td><em>Festuca elatior</em></td>
<td>Fescue</td>
</tr>
<tr>
<td><em>Gelsemium sempervirens</em></td>
<td>Jessamine</td>
</tr>
<tr>
<td><em>Lupinus</em> sp.</td>
<td>Lupine</td>
</tr>
<tr>
<td><em>Peganum harmala</em></td>
<td>African rue</td>
</tr>
<tr>
<td><em>Senecio</em> sp.</td>
<td>Ragwort, groundsels</td>
</tr>
<tr>
<td><em>Sophora</em> sp.</td>
<td>Meskal bean, sophora</td>
</tr>
<tr>
<td><em>Taxus</em> sp.</td>
<td>Yew, ground hemlock</td>
</tr>
<tr>
<td><em>Veratrum</em> sp.</td>
<td>False hellebore</td>
</tr>
<tr>
<td><em>Zygadenus</em> sp.</td>
<td>Death camas</td>
</tr>
</tbody>
</table>

*For plants of the Solanaceae containing alkaloids toxic to stock, see text.

Glycosides. Glycosides are compounds which yield one or more sugars and one or more other compounds (aglycones) when hydrolyzed either by dilute mineral acids or by enzymes. The term glucoside has often been used synonymously with glycoside, and this practice continues (154). Critical usage reserves the term glucoside for that particular kind of glycoside in which the sugar
component is glucose. Purified glycosides are usually bitter, colorless, crystalline solids. Glycosides are much more widely distributed in the plant kingdom than are alkaloids. Many are nontoxic (e.g., several of the common nonphotosynthetic plant pigments). Both the sugar and aglycone components of a glycoside may be of a wide variety of compounds. Thus, the glycosides, too, constitute a grouping of heterogeneity.

Two subgroupings of glycosides, cyanogenetic and saponic, deserve particular attention.

**Cyanogenetic glycosides.** Glycosides which yield hydrocyanic acid (HCN) upon hydrolysis are termed cyanogenetic or cyanophoric (cyanogenic, the word sometimes used, is etymologically incorrect). A representation of the glycoside amygdalin, probably the most common cyanogenetic glycoside, is given here (114).

\[
\text{H} \quad \text{C} \quad \text{CN} \\
\text{O} \quad \text{C}_{12} \text{H}_{21} \text{O}_{10}
\]

It is found in many Rosaceae. The intact glycoside is not toxic (33). The violent toxicity of the compound is caused solely by its HCN component, acting as a free molecule after hydrolysis. Little free HCN is found in healthy, actively growing plants. In natural circumstances hydrolysis is brought about by enzymatic action in the plant (53) or animal (154). The frequently observed higher content of free HCN in wilted, frosted, or stunted plants may be caused by the joining of plant enzyme and cyanogenetic glycoside under these conditions, with resulting release of free HCN. Ruminant animals are held more susceptible to HCN poisoning from plants for the reason that the microflora of the rumen provokes greater enzymatic breakdown than that accomplished in nonruminants.

HCN is a small molecule readily taken into the blood stream and readily excreted by several routes. Chronic HCN poisoning as it is known in human beings is rare in animals. Not only are total cyanogenetic glycoside and free HCN fraction in the plant important in determining poisonings, but rate of ingestion and size and kind of animal also are important. There is little difference between toxic and lethal blood HCN levels. Two milligrams HCN per pound of animal per hour is close to the minimum lethal dose, and as a rule of thumb, plants which contain more than 20 mg. of HCN per 100 g. can be considered dangerous (154). The well-known picrotest for cyanide has recently been adapted for easy field use on plant or stomach-content samples by Burns (29). Cases of poisoning are frequent under circumstances which allow animals unaccustomed access to dangerous pasture (such as immature sorghum) or browse (such as wilted wild cherry trimmings).

In the animal, HCN acts by inhibiting the action of the porphyrin enzyme cytochrome oxidase. This enzyme’s function is to pass oxygen into the metabolic respiratory pathway. Thus, HCN poisoning constitutes asphyxiation at the cellular level. The ability of the blood to carry oxygen is unimpaired (of diag-
nestic importance). Death usually follows ingestion of a lethal dose within
15 min. to a few hours. Experimentally, it has been possible (26) to protect
an animal from up to three times the minimum lethal dose by prompt injection
of sodium thiosulfate and sodium nitrite, but the veterinarian usually can not
arrive in time. This treatment (sodium thiosulfate) is designed to cause for-
motion of the relatively harmless sulphocyanides and (sodium nitrite) to convert
some of the blood hemoglobin to methemoglobin. Cyanide in the blood combines
preferentially with methemoglobin to form the nontoxic cyanmethemoglobin
(84). The amount of nitrite injected is critical since sufficient unaltered hemo-
globin must remain to carry a necessary minimum amount of oxygen to the
tissue; otherwise nitrite poisoning will result (see later). Recent experiments
with mice (159) have shown hydroxo-cobalamin (B_{12a}) efficacious in cyanide
poisonings. Large amounts of this molecule, which combines preferentially with
the cyanide radicle, safely may be used.

The content of cyanogenic glycoside in a given wild plant or crop may
vary widely with a number of external conditions. This variation has been
explored most thoroughly in the case of sorghum (80). It has been shown that
factors such as climate, season, amount of rainfall, fertilization, and stage of
growth are influencing. Heritable strain differences are important in sorghum.
Hay made from some plants may be dangerous when cut but may become safe
in time, possibly through volatilization of its HCN content.

TABLE 2

Plants containing cyanogenic glycosides toxic to stock

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Family</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia sp.</td>
<td>Leguminosae</td>
<td>1</td>
</tr>
<tr>
<td>Bahia oppositifolia</td>
<td>Compositae</td>
<td>57</td>
</tr>
<tr>
<td>Cercocarpus sp.</td>
<td>Rosaceae</td>
<td>1</td>
</tr>
<tr>
<td>Hydrangea sp.</td>
<td>Saxifragaceae</td>
<td>217</td>
</tr>
<tr>
<td>Linum usitatissimum</td>
<td>Linaceae</td>
<td>104</td>
</tr>
<tr>
<td>Phaseolus lunatus</td>
<td>Leguminosae</td>
<td>175</td>
</tr>
<tr>
<td>Prunus sp.</td>
<td>Rosaceae</td>
<td>75, 99, 172</td>
</tr>
<tr>
<td>Sorghum halepense</td>
<td>Gramineae</td>
<td>136, 211, 225</td>
</tr>
<tr>
<td>Sorghum vulgare</td>
<td>Gramineae</td>
<td>22, 80, 211</td>
</tr>
<tr>
<td>Suckleya suckleyana</td>
<td>Chenopodiaceae</td>
<td>205</td>
</tr>
<tr>
<td>Triglochin sp.</td>
<td>Juncaginaceae</td>
<td>48</td>
</tr>
</tbody>
</table>

* See also Table 4.
* See also Table 7.
* See also Table 11.

Saponic glycosides. Saponins are large molecules which form a colloidal solu-
tion in water and produce a soapy froth or foam when agitated. They occur as
amorphous glycosides (in which the aglycone is sometimes termed a sapogenin)
and are of wide distribution in the plant kingdom. Many are nontoxic; those
few of considerable toxicity have been termed (5) sapotoxins. In these the
sapogenin is chemically related to the sterol hormones. The primary action of
a saponin is to bring about a lysis of erythrocytes. It has been suggested (5)
that this hemolytic action is due to combination of saponin with cholesterol in
the membrane of the erythrocyte. Apparently, saponins are not readily absorbed
into the blood stream through the uninjured gut. Therefore, potentially hemolytic saponins are not toxic unless they also possess an irritant action sufficient to allow them to be absorbed into the blood stream through an injured gut wall. The major symptoms observed in cases of saponin poisoning are those of gastric irritation.

### TABLE 3

<table>
<thead>
<tr>
<th>Plants containing saponic poisonous principles</th>
<th>(References)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agrostemma githago</td>
<td>Caryophyllaceae 97</td>
</tr>
<tr>
<td>Ageratum sp.</td>
<td>Euphorbiaceae 67, 178</td>
</tr>
<tr>
<td>Daubentonia drummondii*</td>
<td>Leguminosae 121</td>
</tr>
<tr>
<td>Daubentonia punicea*</td>
<td>Leguminosae 217</td>
</tr>
<tr>
<td>Glottidium vesicarium*</td>
<td>Leguminosae 17, 72, 186</td>
</tr>
</tbody>
</table>

* These plants are variously called coffeeweed, coffeebean, bagpod, rattlebrush, sesbania, and poison bean. Their Latin binomials are also confused, with Sesbania sometimes used as a collective generic name. There appear to be three entities that have been demonstrated poisonous. The binomials used here follow the treatment of Small (191).

**Other glycosides.** Several plants have toxic principles which have been identified only as glycosides or as particular glycosides which are neither cyanogenetic nor saponic. Coumarin is a lactone, but probably occurs in plants in glycosidic combination (153). Plants containing it which have proven toxic to animals under natural circumstances are the sweet clovers *Melilotus alba* and *Melilotus officinalis*. Coumarin is released from its glycosidic linkage and is changed to dicoumarin (*C_{19}H_{12}O_{6}*, a hemorrhagic agent, upon spoilage of sweet clover hay. Both natural and synthetic dicoumarin reduce blood prothrombin level in a similar fashion and cause the blood to be incapable of clotting (200). Poisoned animals (usually cattle) will produce large subdermal weals in areas that become bruised, particularly about the neck and shoulders in stanchioned cattle.

The common foxglove (*Digitalis purpurea*) contains a number of so-called cardiac glycosides. Although this plant is available to animals in many parts of this country, cases of poisoning are absent or infrequent. Oleander (*Nerium oleander*), which has been responsible for cases of poisoning in the southern United States (227), contains a glycoside of similar action.

**Irritant oils.** Some plants contain fixed or essential (volatile-in-steam) oils which produce irritant properties of themselves or perhaps in some cases by

### TABLE 4

<table>
<thead>
<tr>
<th>Plants containing other glycosidic poisonous principles</th>
<th>(References)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesculus sp.</td>
<td>Liliaceae 32, 172</td>
</tr>
<tr>
<td>Convallaria majalis</td>
<td>Liliaceae 88</td>
</tr>
<tr>
<td>Helianthus sp.</td>
<td>Compositae 126</td>
</tr>
<tr>
<td>Ligustrum vulgare</td>
<td>Oleaceae 172</td>
</tr>
<tr>
<td>Linum neomexicanum*</td>
<td>Linaceae 65</td>
</tr>
<tr>
<td>Melilotus sp.</td>
<td>Leguminosae 200</td>
</tr>
<tr>
<td>Nerium oleander</td>
<td>Apocynaceae 227</td>
</tr>
<tr>
<td>Robinia pseudo-acacia*</td>
<td>Leguminosae 91</td>
</tr>
</tbody>
</table>

* See also Table 2.

b Also stated to contain a phytotoxin (84).
TABLE 5
Plants containing irritant oils

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Common Name</th>
<th>Family</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anagalis arvensis</td>
<td>Scarlet pimpernel</td>
<td>Primulaceae</td>
<td>172</td>
</tr>
<tr>
<td>Brassica sp. * b</td>
<td>Mustards</td>
<td>Cruciferae</td>
<td>90, 204</td>
</tr>
<tr>
<td>Ranunculus sp.</td>
<td>Buttercups</td>
<td>Ranunculaceae</td>
<td>155</td>
</tr>
<tr>
<td>Thlaspi arvense</td>
<td>Fan weed</td>
<td>Cruciferae</td>
<td>93</td>
</tr>
</tbody>
</table>

* And other Cruciferae.

b See also Table 11.

reason of substances dissolved in them. In some, at least, they occur in glycosidic combination (218). In general, in this country they are produced by a variety of plants that may cause low-grade poisonings if ingested in sufficient amounts. The irritant effect is produced in the gut and various degrees of gastroenteritis up to death will be produced, depending upon toxicity and dosage.

Solanaceous alkaloids. Special attention to this group of complex alkaloids, several of which are helpful in medicine, can evoke a number of useful conclusions. Solanaceous alkaloids may be divided into three major groups on the basis of chemical structure and physiologic activity. At least one plant known to have caused stock loss in this country occurs in each group.

The major alkaloid in the atropine group is hyoscyamine (isomeric with atropine) (153).

\[
\text{H}_2\text{C} \quad \text{H} \quad \text{CH}_2
\]

Plants containing this alkaloid, which have been poisonous to stock, include belladonna (Atropa belladonna) (195) and Jimson weed (Datura stramonium) (37).

The major alkaloid in the nicotine group is nicotine (118). Both wild (134) and cultivated (172) tobaccos (Nicotiana sp.) have caused stock loss.

\[
\text{H}_2\text{C} \quad \text{N} \quad \text{CH}_3
\]

Species of nightshade (Solanum sp.) and some others contain solanine as their major alkaloid (119).
Plants whose toxic principle falls in this group include potato (115), tomato (37), and several wild species of the genus Solanum (34, 172, 217).

These formulas are figured so that several conclusions may be drawn: (a) Alkaloids within a group of closely related plants (such as Solanaceae) may chemically be very dissimilar. (b) On the other hand, a given alkaloid may be found in a wide variety of plants. For instance, nicotine is found not only in various tobaccos but also in a wide variety of plants including two unrelated genera (Lycopodium and Equisetum) of the spore-bearing division of the plant kingdom (118). (c) On the other hand, an alkaloid characteristic of a given plant species may be found in a number of other species closely related to it. For example, well over a dozen species of Solanum contain solanine or a molecule closely similar to it. (d) A toxic principle may fall into more than one category on the basis of its structure and physical properties. For example, solanine is an alkaloid by reason of its nitrogenous nature and basic reactions. It is also a glycoside, since chemically it consists of a sugar (solanose) linked to a nonsugar or aglycone moiety (solanidine). Since it is a molecule which forms a stable foam when shaken with water, additionally it answers the definition of a saponin. Nicotine is one of the very few alkaloids which also has the physical characteristics of a volatile oil.

The Solanaceae can be used to demonstrate the relative uselessness of common names (192) and the necessity of a botanical determination of the plant in question. To choose two solanaceous plants as illustrative, we find the following confusing items in the literature: Atropa belladonna, whose active principle is of the atropine group, is commonly called belladonna (158), but also deadly nightshade (41, 195). Solanum nigrum, whose active principle is of the solanine group, is commonly called black nightshade (158), but also deadly nightshade (37, 101). This confusion in common names leads to confusion in plants and poisonings. Again from the literature, deadly nightshade is equated with belladonna without botanical identification of the plant in question (12). Deadly nightshade, identified as Solanum nigrum, causes belladonna poisoning (101), with symptoms including widely dilated pupils (characteristic of the atropine group, but either unexpressed, or expressed very mildly, in poisonings by plants whose major poisoning principle is of the solanine group). Deadly nightshade is identified as Solanum nigrum, but black nightshade is botanically unidentified and gives
PLANTS POISONOUS TO LIVESTOCK

a strong cat's-eye test for atropine (37). All poisonous Solanaceae produce bella
donna poisoning (101). Members of the Solanaceae are collectively termed
nightshades. Many, perhaps the majority, are potentially lethal. These examples
show that the term deadly nightshade is a poor identification for a solanaceous
plant.

Organic acids. Oxalic acid is toxic not because of its acidity but because of
the specific action of the oxalate ion. It is the only organic acid in plants that
is toxic to stock under natural conditions. It occurs in plants in the form of
soluble (sodium and potassium) and insoluble (calcium) oxalates. Insoluble
oxalates pass through the animal gut without being absorbed into the blood
stream and are, therefore, nontoxic. Many plants contain small amounts of
soluble oxalates; only a few contain enough to be toxic. A maximum is found
in Halogeton (a recent Russian immigrant) which may contain as much as
28% soluble oxalates. The content of soluble oxalates in plants varies widely
with season, reaching a maximum in late summer and fall. The Utah Experi-
ment Station has recently investigated Halogeton (49) and oxalic acid poisoning.
Soluble oxalates are readily eliminated from the blood by the kidneys. Both
the amount of oxalate consumed and the time required for its consumption are
important factors in determining when the toxic level of blood oxalate will be
reached. Roughly one ounce of soluble oxalate is lethal to a sheep. Presence
of food in the stomach reduces the rate of absorption. About half again as much
is required for symptoms to be developed under these circumstances. A total of
several times these amounts may be ingested without untoward effect if taken in
small amounts over the period of a day.

Ingestion of a toxic dose of soluble oxalates is followed in a few hours by
death after general symptoms of dullness, depression, and a final comatose state.
Incoordination and stiffness, especially of extremities, are commonly observed.
The uptake of soluble oxalates into the blood stream from the gut results in the
precipitation of calcium oxalate from the blood serum. Calcium ion content
of the blood will be lowered, yet total calcium may change but little, especially
at first. The immediate cause of death is difficult of determination, but appears to
be the result of asphyxiation or heart failure brought on by acute hypocalcemia.
In addition, crystals of calcium oxalate will be formed in the kidney tubules,
especially of the cortex, sometimes in such great quantity that practically every
tubule is filled. Rupture of the tubules and other degenerative changes in the
kidney follow.

Experiments at Utah have shown that injections of calcium gluconate help
little if at all in cases of poisoning, but feeding of calcium-rich feed along with

<table>
<thead>
<tr>
<th>Plants that may contain toxic concentrations of oxalic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Halogeton glomeratus</strong></td>
</tr>
<tr>
<td><strong>Oxalis sp.</strong></td>
</tr>
<tr>
<td><strong>Rheum rhaponticum</strong></td>
</tr>
<tr>
<td><strong>Sarcobatus vermiculatus</strong></td>
</tr>
</tbody>
</table>

(References)
the dangerous plants may be beneficial. The greater the amount of soluble oxalate precipitated in the gut, the less will be available to produce a toxic reaction.

Mineral poisonings. Plants may be made toxic secondarily through deposition on their surfaces of certain minerals such as arsenic or fluorine (98) in the vicinity of particular industrial installations. Such situations are usually obvious and are not detailed here.

Nitrate. Poisoning by nitrate or compounds elaborated from it has been known in this country since the late 19th Century but has recently assumed new dimensions. Many crop plants (especially, oat hay, corn, and sorghum), vegetables and weeds (especially of the amaranth, goosefoot, mustard, composite, and nightshade families) have been found on analysis to contain nitrate (usually as the potassium salt) at a level potentially toxic to animals. Several have been definitely incriminated in cases of poisoning. Plants are considered potentially dangerous when they contain more than 1.5% nitrate (as KN0₃, dry weight) (18). Recently (40), subclinical nitrate poisoning has been attributed to a feed intake nitrate level of 0.5%.
Nitrate poisoning has recently been reviewed by Whitehead and Moxon (221). It can be produced by ingestion of nitrate fertilizers, machine oil, natural well and pond water of high nitrate or nitrite content, pickling brine and the like, as well as by plants and hay or silage made from them. Nitrite formed from nitrate in the animal gut is about ten times as toxic. Reduction appears to be effected more quickly and easily in the ruminant digestive process when compared with the nonruminant. Nitrite impairs the blood's ability to transport oxygen. Ferrous hemoglobin picks up oxygen in a chemically loose combination, releasing it easily to the tissues on demand. Nitrite causes oxidation of ferrous hemoglobin to ferric hemoglobin, termed methemoglobin, which can not transport oxygen. This compound causes the blood to become dark chocolate-brown in color (diagnostic in nitrite poisoning). Death through asphyxiation (anoxia) occurs when about three-fourths of the blood hemoglobin is converted to methemoglobin and usually eventuates within a few hours to a day after ingestion of a lethal dose. Effective treatments may be attained by injection of methylene blue (19). This reducing agent causes ferric methemoglobin to change to ferrous hemoglobin, which again can carry oxygen. In pregnant animals the fetus is particularly sensitive to a reduction in oxygen in the parent's circulation. In mild cases of nitrate poisoning, abortion may result (38).

Additional kinds of poisonings by various combinations of nitrogen have recently come to light. Nitrite (NO₂) can be reduced still further to a nitroso (NO) radical. Nitrosohemoglobin exhibits many of the color and toxicity characteristics of carbon monoxide hemoglobin. Poisoning via the formation of nitrosohemoglobin in the blood may occur under natural conditions (40) and is distinguishable from carbon monoxide poisoning by obvious differences in the source of the poisonous principle or by a simple test as detailed by Case (40). Abnormally high concentrations of nitrate in forage being ensilated lead to dangerous and even explosive fermentations in the silo. Decomposition of nitrate in an acid medium results in the production of nitrogen dioxide, a toxic, yellow-brown gas. This has been responsible for toxicity in human beings (silo-filler's disease) (58) and recently has been shown to be toxic to cattle (182). In the latter situation, nitrogen dioxide may have been generated directly in the bovine rumen. Treatment with intramuscular injection of adrenocortical steroids has been suggested in animal practice (3). Although silage fermentation results in a decreased nitrate content, the silage may retain enough nitrate to be toxic for a considerable time.

A number of factors may influence the amount of nitrate contained in plants. Soil nitrogen content, both original and after fertilization, amount and kind of other elements in the soil, amount of light, and availability of water during the growing period, the kind of plant, and the stage of its growth are all important. Treatment with the herbicide, 2,4-D, has been shown to produce two unexpected results (199): First, a number of normally unpalatable weeds, such as pigweeds (Amaranthus sp.), ragweeds (Ambrosia sp.), and Jimson weed (Datura stramonium) are made palatable. Second, the resulting upset in nitrogen metabolism may cause the treated plant to accumulate nitrate to a toxic level. A convenient field test for nitrate and nitrite is given by Case (40).
TABLE 7

Some plants that may contain toxic concentrations of nitrate

<table>
<thead>
<tr>
<th>Weeds:</th>
<th>Amaranthus sp.</th>
<th>Pigweeds</th>
<th>Amaranthaceae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardueae sp.</td>
<td>Bull thistle</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>Chenopodium sp.</td>
<td>Pigweed, lamb’s quarters</td>
<td>Chenopodiaceae</td>
<td></td>
</tr>
<tr>
<td>Cirsium arvense</td>
<td>Canada thistle</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>Convolvulus sp.</td>
<td>Bindweeds</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>Eranthera discolor</td>
<td>White ragweed</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>Helianthus annuus</td>
<td>Wild sunflower</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>Kochia scoparia</td>
<td>Fireball</td>
<td>Chenopodiaceae</td>
<td></td>
</tr>
<tr>
<td>Lycopersicum juncea</td>
<td>Skeleton weed</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>Panicum capillare</td>
<td>Witchgrass</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td>Rumex sp.</td>
<td>Dock</td>
<td>Polygonaceae</td>
<td></td>
</tr>
<tr>
<td>Salsola pestifer (= S. kali)</td>
<td>Russian thistle</td>
<td>Chenopodiaceae</td>
<td></td>
</tr>
<tr>
<td>Solanum sp.*</td>
<td>Nightshades</td>
<td>Solanaceae</td>
<td></td>
</tr>
<tr>
<td>Sonchus asper</td>
<td>Sow thistle</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>Crop plants:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avena sativa*</td>
<td>Oat hay</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td>Hordeum vulgare*</td>
<td>Barley</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td>Sorghum vulgare*</td>
<td>Sudan grass</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td>Triticum aestivum*</td>
<td>Wheat</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td>Weeds:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amsinckia sp.*</td>
<td>Tarweeds</td>
<td>Boraginaceae</td>
<td></td>
</tr>
<tr>
<td>Datura sp.*</td>
<td>Bluegreen algeae*</td>
<td>(Cyanophyta)</td>
<td></td>
</tr>
<tr>
<td>(Echinocloa crusgalli)</td>
<td>Barnyard grass</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td>Euphorbia maculata*</td>
<td>Milk purslane</td>
<td>Euphorbiaceae</td>
<td></td>
</tr>
<tr>
<td>(Polygonum)</td>
<td>Smartweeds</td>
<td>Polygonaceae</td>
<td></td>
</tr>
<tr>
<td>Silybum marianum</td>
<td>Variegated thistle</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>(Sorghum halepense)*</td>
<td>Johnsongrass</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td>(Stellaria media)</td>
<td>Chickweed</td>
<td>Caryophyllaceae</td>
<td></td>
</tr>
<tr>
<td>Thelypodium lasiophyllum</td>
<td>Mustard</td>
<td>Cruciferae</td>
<td></td>
</tr>
<tr>
<td>Crop plants:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta vulgaris</td>
<td>Beet and mangold</td>
<td>Chenopodiaceae</td>
<td></td>
</tr>
<tr>
<td>(Ipomoea batatas)</td>
<td>Sweet potato vines</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td>(Medicago sativa)*</td>
<td>Alfalfa</td>
<td>Leguminosae</td>
<td></td>
</tr>
<tr>
<td>Zea mays*</td>
<td>Corn</td>
<td>Gramineae</td>
<td></td>
</tr>
</tbody>
</table>

( ) Indicates reference cited did not give scientific name identification.
* See also Solanaceous Alkaloids, in text.
+ See also Table 11.
+ See also Table 13.
+ See also Table 2.
+ And other Cruciferae.

Selenium. Of plants which vary in toxicity with geological formation, those which take up selenium are by far the most important. Stock loss, now known to have been caused by ingestion of selenium, has been reported from as early as 1857, but sustained work to elucidate the causes dates only to 1932. Diseases locally called with various degrees of inappropriateness blind staggers and alkali disease as well as an acute poisoning syndrome, have since been shown to be caused by selenium ingestion. Major contributions to the study of the geology, geography, and biological implications of naturally occurring selenium deposits have come from the South Dakota and Wyoming Experiment Stations and from the late S. F. Trelease at Columbia University. Much has been learned, yet certain observations remain obscure and several gaps in information exist. The massive accumulation of data has been reviewed by Moxon and Rhian (157) of
the South Dakota group, and in a relatively nontechnical presentation by Trelease and Beath (207) (the latter of the Wyoming group).

The nonmetallic element selenium is found in various forms in soils and rocks of geological formations from Pennsylvanian to Recent, particularly the Cretaceous, in 15 western states. Because of the small amounts of total selenium which rarely exceed 100 p.p.m., determination of the form of selenium in the soil and rocks has been difficult. It appears that some amounts of elemental selenium, and certain selenides, selenites, and selenates are present in varying ratio. Elemental selenium and the selenides are relatively insoluble. Some selenites and selenates are insoluble, others are soluble. These forms are originally of geologic origin, but physical, chemical, and perhaps biological forces cause a degree of interconversion. Organic selenium compounds are also found in the soil but are strictly of biological origin. Some are soluble; some are not. Soil selenium concentration will vary from a trace to not more than 150 p.p.m., with the majority of soils containing less than 5 p.p.m. The fraction of total selenium that is soluble and, therefore, available for plant uptake, is usually less than 50%. Amount and kind of other soil constituents, especially sulfur, also influence the availability of soil selenium to plants. These factors are more operative in the root-bearing soil horizon than at the soil surface.

Plants show a remarkable and unexpected relationship to selenium in the soil. They accumulate it or they do not. The strength of selenium accumulation exhibited by some plants is considerable. The accumulators may be further divided into obligate and facultative selenium species.

Obligate selenium species seem to require selenium for proper growth and will be found only where there is selenium in the soil. For this reason they are termed indicator plants (8) throughout the selenium literature and have been useful in pointing to selenium-bearing geologic formations of potential toxicity. These plants invariably contain selenium during the greater part of their life cycle and maximum tissue concentrations have been reported (207) approaching 15,000 p.p.m. Their selenium content, determined by chemical analysis, can be used as an index of toxicity for the soil bearing them. Twenty-four species and varieties of Astragalus, all species so far examined of Xylorrhiza (woody aster), all species examined of Oonopsis (goldenweed), and all species examined of Stanleya (prince’s plume) have been found to be reliable selenium indicator plants. All of these are conspicuous elements in the areas where they occur. There are some 300 American species in the genus Astragalus. Those accumulating selenium fall into genetically related groups which can be recognized as such by criteria other than selenium accumulation. Four species, A. racemosus, A. bisulcatus, A. pectinatus, and A. pattersoni, are most useful as indicators by reason that they enjoy a wide geographic distribution. One or more is found in Montana, North and South Dakota, Nebraska, Kansas, Oklahoma, Texas, Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, and Nevada. With the exception of California, these are all the states in which selenium is found. Astragalus preussii is an indicator species which is found in California.

The facultative selenium species or, as commonly called, the secondary
selenium absorbers, are not limited to soils containing selenium. They will accumulate selenium when growing in seleniferous soils but, other conditions being equal, will grow just as well on soils containing no selenium. They are commonly the cause of stock poisoning; for among them are a number of genera (for example, Aster, Atriplex, Sideranthus, and Machaeranthera) that are grazed, and on nonseleniferous soil may be palatable and valuable forage plants. Fortunately, increasing selenium content tends to make a given species increasingly unpalatable.

Most plants are nonaccumulators. However, any plant may passively take up selenium dissolved in the soil. The amount taken up will be small and will be determined by the amount available in the soil. Moderate amounts of selenium exert a markedly toxic effect in many plants, which become stunted or are otherwise harmed. Within the genus Astragalus, some species (indicators) require, are stimulated by, and vigorously accumulate quantities of selenium. Others are inhibited in growth or killed by selenium and take it up only passively. Growing on the same seleniferous soil, the former species may contain several thousand parts per million, and the latter only a trace. The basis of the accumulatory power of obligate and facultative species is unknown. Some experimental results indicate that the accumulatory power is not to be correlated with any particular form of selenium in the soil; all kinds of available selenium are taken up in greater amount by an accumulator plant than by a nonaccumulator.

In summary, the amount of selenium in a given plant will be determined by its selenium-accumulating power and the soil’s selenium-supplying power. The former is determined, in turn, by the species of plant, its stage of growth, and its general vigor. The latter is determined by the form of selenium, its concentration in the root zone, and the amount and kind of other elements present. As a rough approximation, if the amount of selenium in an indicator species on a given soil is 100 ×, then the amount in a facultative species will be of the order of magnitude of 10 ×, and in a nonaccumulating species, of ×. Five p.p.m. selenium renders a plant potentially toxic. The higher amounts of selenium in plants can be detected by the characteristic garlicky odor which they impart.

Of the nonaccumulators, both native range plants and crop plants may occasionally build up toxic levels of selenium. There are few natural soils containing a high enough level of soluble selenium to cause nonaccumulators growing on them to be potentially toxic. Such soils are found in limited areas of western South Dakota, northern Nebraska, northeast Wyoming, and in a few other places. More important is the toxicity conferred upon nonaccumulators, especially cereal plants, through the action of converter plants. As has been seen, obligate and facultative selenium plants can accumulate high concentrations of selenium. Selenium, concentrated thus, is returned to the soil upon leaf drop, by death of the accumulating plant, or through its being plowed under. The local concentration of soluble selenium compounds thus may be increased to a point at which toxicity may be imparted to those nonaccumulating plants subsequently growing there. Native grasses and other plants growing within a few feet of a perennial converter plant thus may be made toxic. Entire fields of grain or
crop plants may be made toxic if grown where a stand of converter plants was plowed under.

Animal disorders caused by ingestion of selenium are determined by the amount and form of the selenium ingested. Three basic syndromes are presented. Cattle, sheep, swine, and horses may be poisoned; the form, severity, and frequency are in part determined by the different habits of the animals.

When plants containing more than about 250 p.p.m. selenium are ingested, acute selenium poisoning is produced. Obligate selenium species, particularly of the genus *Astragalus*, are usually responsible. Poisoning has occasionally been severe under range conditions where these plants grow. Death in a few hours to days follows ingestion of a massive lethal dose. The pathology of this and the two following forms of selenium poisoning have been detailed by Rosenfeld *et al.* (174). In acute poisoning much of the pathologic picture of necrosis and hemorrhage can be attributed to direct injury of capillaries by selenium.

A chronic selenium poisoning, rather inappropriately termed blind staggers, results from the continued ingestion of native-range plants containing small to moderate amounts of selenium (usually less than 200 p.p.m.). Whereas some time is required for the development of this disease, the onset of symptoms often is abrupt. Severe nutritional disturbances result in wasting. Variable impairment of vision to complete blindness in cattle correlates with decrease of vitamins A and C. A depraved appetite and terminal paralytic stage are typical. Death is the immediate result of respiratory failure. Injection of strychnine sulfate and drenching with warm water is an effective treatment if undertaken before the final paralytic stage.¹

A chronic selenium poisoning, equally inappropriately termed “alkali disease”, results from the continued ingestion of crop plants such as corn, wheat, barley, oats, grass, and hay containing 5 to 40 p.p.m. selenium. Emaciation, lameness, and loss of long hair are typical. The most characteristic feature is hoof deformity, which may become severe enough to result in sloughing of all four hooves. Death, which may occur after two months on seleniferous feed, is often the result of the refusal of the animal to move and is via starvation or thirst.

The difference in clinical syndrome between blind staggers and alkali disease may be correlated with the form of selenium in cereal crops (entirely organic, roughly half-soluble), as compared with that in range plants. Selenium content of hair may be used as a diagnostic aid in borderline cases of alkali disease (163). In areas where grain crops regularly contain small amounts of selenium, addition of very small amounts of inorganic arsenic to the seleniferous ration has greatly lessened its toxic effect. However, there has been a tendency for arsenic to accumulate in animal tissues to an extent that might make meat dangerous for consumption. Recently, it has been shown (213) that various

¹ Recent investigations in Colorado (107) report a condition, locally called “forage poisoning,” of identical clinical syndrome with “blind staggers.” “Forage poisoning” occurs in feed lots and in pastured cattle and sheep. Neuropathologic changes are reported. Doubt is cast on selenium as the etiological agent.
Plants which may accumulate selenium

<table>
<thead>
<tr>
<th>Obligate or indicator:</th>
<th>Facultative or secondary selenium absorbers:</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Astragalus</em>, certain species*</td>
<td><em>Aster</em> sp.*</td>
</tr>
<tr>
<td><em>Stanleya</em>, all species</td>
<td>Saltbushes</td>
</tr>
<tr>
<td><em>Oenopsis</em>, all species*</td>
<td>Paint brushes</td>
</tr>
<tr>
<td><em>Xylorrhiza</em>, all species</td>
<td><em>Bastard toadflax</em></td>
</tr>
</tbody>
</table>

**Obligate or indicator:**
- Poisonevetches
- Prince's plume
- Goldenweeds
- Woody asters

**Facultative or secondary selenium absorbers:**
- *Aster* sp.*
- *Atriplex* sp.
- *Castilleja* sp.
- *Commandra pallida*
- *Grayia* sp.
- *Grindelia* sp.
- *Gutierrezia* sp.
- *Machaeranthera* sp.*
- *Penstemon* sp.
- *Sideranthus* sp.

* References

Crops which have taken up toxic levels of selenium include corn, wheat, oats, barley, grass, and hay.

* Of the species groups *bisulcatus*, *diholcos*, *pectinatus*, and *grayi*, especially.
  * Sometimes lumped with the genus *Aplopappus*. (See also Table 13, and footnote.)
  * May be grazed.
  * See also Table 13.
  * Sometimes lumped with the genus *Aster.*

Organic arsenicals are effective in counteracting the baleful influences of selenium in pigs; yet, they are lost from the tissues within five to ten days after cessation of treatment.

**Molybdenum.** Molybdenum is another mineral element occasionally found in soils in sufficient quantity to cause the vegetation growing on them to be toxic to stock. Molybdenum poisoning was first recognized in England (where it is called teartness), and has since been reported in this country (23, 223), principally from the San Joaquin Valley in California. Soils containing more than 7 p.p.m. molybdenum are considered potentially dangerous. The element is accumulated in the animal body and symptoms will appear from one to seven months after dangerous forage is continuously grazed. Well-cured hay is less dangerous. Nonruminants are relatively resistant.

Prominent symptoms include emaciation, scours, and change in coat color. There is usually a severe anemia. It is possible that the action of molybdenum is effected by causing an imbalance in minerals, particularly copper, in the animal’s nutrition. Treatment with soluble copper compounds is useful (102).

**Resins or resinoids.** Active principles of considerable virulence found in some plants are classified chemically as resins or resinoids. These terms denote a grouping for convenience of a heterogeneous assemblage of complex compounds, differing widely in chemistry but united on the basis of certain shared physical characteristics. Upon extraction, they are solid or semisolid substances at room temperature, are brittle and easily melted or burned. They are soluble in a number of organic solvents but insoluble in water and do not contain nitrogen.

Physiologic activity is effected by direct irritation of nervous or muscle tissue and is sometimes quite specific. Plants of widely differing relationships...
may contain resins, but a few plant families are noted for their content of the same or similar resins among their several species. Certain resin-bearing plants are among the most dramatic poisoners of human beings as well as animals. One such is Cicuta maculata, water hemlock, which produces major symptoms of violent convulsion. This plant, widely distributed in the United States, is responsible for a human mortality probably second only to that caused by ingestion of poisonous mushrooms. It should not be confused with the closely related poison hemlock (Conium maculatum), whose toxic action is alkaloidal. Both may cause stock losses. Neither should be confused with true hemlock (Tsuga), an evergreen needle-bearing tree not known to be toxic to stock, or ground hemlock (Taxus), whose toxic principle is an alkaloid.

### TABLE 9
Plants containing resinoid poisonous principles

<table>
<thead>
<tr>
<th>Plant</th>
<th>Family</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asclepias sp. a</td>
<td>Asclepiadaceae</td>
<td>54, 196, 208</td>
</tr>
<tr>
<td>Cicuta sp.</td>
<td>Umbelliferae</td>
<td>79, 105</td>
</tr>
<tr>
<td>Iris sp. b</td>
<td>Iridaceae</td>
<td>25</td>
</tr>
<tr>
<td>Kalmia sp. b</td>
<td>Ericaceae</td>
<td>46, 170</td>
</tr>
<tr>
<td>Leucothoe sp. b</td>
<td>Ericaceae</td>
<td>63</td>
</tr>
</tbody>
</table>

a Species of Asclepias vary greatly in toxicity. Some are nontoxic. There has been botanical confusion among the toxic ones (196).
b Several other members of the Ericaceae (Rhododendron, Pieris, Lyonia, Azalea, and others) contain the same or similar resinoid (54).

### TABLE 10
Plants containing phytotoxin poisonous principles

<table>
<thead>
<tr>
<th>Plant</th>
<th>Family</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrus precatorius</td>
<td>Leguminosae</td>
<td>216</td>
</tr>
<tr>
<td>Ricinus communis</td>
<td>Euphorbiaceae</td>
<td>226</td>
</tr>
</tbody>
</table>

a See also Robinia pseudo-acacia (Table 4).

**Phytotoxins.** Phytotoxins (also called toxalbumins) are protein molecules of high toxicity produced in a small number of plants. Few native plants produce them and those that do are rarely the cause of livestock loss. Phytotoxins are large, complex molecules similar to bacterial toxins in structure and causing similar reactions in animals. Like bacterial toxins they act as antigens, eliciting an antibody response in the reacting animal. Toxicity is conferred by an ability to cause agglutination of erythrocytes. True immunity can be produced through administration of immunizing doses of increasing strength. Passive immunity can be conferred by injection of antisera. Antisera are commercially unavailable because of the rarity of cases. Phytotoxins are nondialyzable, heat-labile, and can be positively identified by precipitin reactions with sera containing known antibodies. Toxic castor-bean press cake can be made nontoxic simply by heating.

**Photosensitization.** Under certain circumstances animals become hypersensi-

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2 An intensely graphic, though unscientific, description of a poisoning by Cicuta, is that by J. Wepfer (1679), which is found translated from the original Latin as "Case VI" in Nevada Tech. Bull. 81 (105).
tive to light. Compounds in certain plants may bring about hypersensitivity in a direct or indirect fashion. Certain compounds of various nonplant origins, both within and without the animal, may also effect hypersensitivity; these are not discussed in the following. Clare (44) has thoroughly reviewed the extensive literature on photosensitization. His terminology is used in the following summary, which intends to relate the kinds of photosensitization with the plants shown responsible for producing cases of photosensitization in this country.

The exact mechanism by which photosensitization is produced is not understood, but from other biological situations in which light effects changes in living systems, it appears that the basic reaction is an oxidation enhanced by energy from incident light. Light is trapped and made chemically available by a light-receiving substance. Although such substances usually absorb specific wave lengths of light in the visible region of the spectrum and, therefore, are pigments, a substance may absorb light in the ultraviolet region of the spectrum and be photodynamic even though colorless. The wave length(s) of absorption, and particularly the wave length(s) at which the engendered reaction is greatest, can be used to characterize the light-absorbing substance. Plant-caused photosensitivity thus can be distinguished from true sunburn by differences in activating wave lengths. In photosensitization, light-catalyzed reactions—the details of which are not clear—effect a greatly increased permeability of the capillary wall in the surface beds where reaction takes place. The presence of both a reactant substance in the peripheral circulation and of light are required. Therefore, the reaction will occur only in areas of unpigmented or lightly pigmented skin which are not covered by a dense light-screening coat of hair. In classical photosensitization, white sheep are affected about the head, and cattle on white or unpigmented areas of the skin, but particularly about the udder. Black sheep are resistant. However, Case (36, 39) presents conflicting evidence in which animals show photosensitizations in pigmented parts of the body. Pathology is remarkably similar no matter what the source or chemical identity of the reactant substance. In animals, restlessness is followed by a reddening of the skin (erythema), which in turn is superseded by an edematous infusion under the skin of affected parts, caused by leakage of serum from the capillary beds. In severe cases there will be a serous seepage through the skin. Necrosis follows and in time varying amounts of skin will slough off, depending upon the severity of the photosensitization. In seriously affected sheep the lips may be lost and ears may be seriously deformed. Secondary invasion of necrotic areas by bacterial infection is common. The photodynamic action, by itself, is not usually lethal, but death is common by reason of starvation, liver damage (see below), or other secondary effects. In sheep that recover, areas of affected skin will not grow further wool.

Photosensitivities may be divided into types on the basis of the nature of the photodynamic substance, and particularly its source. In photosensitizations caused by plants, the photodynamic substance may come directly and unchanged from the plant (Type I of Clare), or it may be a normal breakdown product in digestion usually eliminated by the liver (Type III of Clare). The former may
be called primary photosensitivity, and the latter may be termed hepatogenic photosensitivity. Sometimes the latter is termed ictrogenic photosensitivity, from the fact that a pronounced icterus throughout the animal is a common symptom.

Two plants occurring in the United States have been shown to produce primary photosensitivity. Both were known as photosensitizers in Europe and had been early investigated before cases were reported in this country. *Hypericum perforatum* (St.-John's-wort, or Klamath Weed) is widely distributed as a common weed, particularly in the Northeast and the Northwest. *Fagopyrum sagittatum* (buckwheat) is a crop grown for its grain. The vegetation from either plant contains a pigment (probably not the same) which passes the gut wall, enters the circulation, is not eliminated by liver or kidney and, therefore, reaches the peripheral circulation. All symptoms produced by either of these plants are solely those of photosensitization. In neither case has the pigment been conclusively identified, although attempts at its elucidation have been made. In the case of *Hypericum*, it has been incompletely identified (165) as a partly reduced polyhydroxy derivative of helianthrone. Three substances, experimentally shown photodynamic, have been isolated (215) from buckwheat, but have not been chemically identified. Cases produced by ingestion of *Hypericum* are not common, and those produced by ingestion of buckwheat vegetation are rare in this country. It is interesting to note that elimination of *Hypericum* has been the objective in one of the more publicized attempts at biological control (through use of insects of the genus *Chrysolina*).

Hepatogenous photosensitivity has been investigated most thoroughly in Africa. In this and other work it has been determined that the photosensitizing plants contain a toxic compound (not completely elucidated for any given case) which produces injury of the liver and liver dysfunction. Normally, the liver eliminates (in the bile) a number of usual breakdown products of digestion. The injured liver in hepatogenous photosensitivity is unable to eliminate certain pigments found as normal breakdown products in digestion and which, therefore, may reach the peripheral circulation and cause photosensitization. It has been shown in more than one such plant that the porphyrin, phylloerythrin, a normal product of animal digestion of chlorophyll, is the photodynamic pigment and is caused to reach the peripheral circulation by dysfunction of the liver. It may which are absorbed through the gut and reach it through the portal circulation. prove to be the universal photodynamic pigment in this type of photosensitivity, or it may not. A method of testing for hematoporphyrin in the urine is given by Sippel and Burnside (188).

Much of the African work has been with *Tribulus terrestris*, which produces bighead (Geeldikkop) in sheep. This plant (commonly called caltrop, or puncture vine) is found in several of the western states, but cases of photosensitization by it in this country appear to be rare. The plant which produces the heaviest domestic loss by photosensitization is the horse brush, *Tetradymia*, a common brushy plant of several of the western states. Typical bighead in sheep is produced within 16 to 24 hr. after ingestion of a toxic dose. It is accompanied by liver damage, but neither the liver toxin nor the photodynamic pigment has
been identified. If sufficient of the normally distasteful plant is ingested, death will follow within one day directly as a result of liver injury and without the development of photosensitization symptoms.

Fig. 2. Sheep A. Typical photosensitization ("bighead") in sheep produced experimentally at Utah State Agricultural College by feeding *Tetradymia*.

Fig. 3. Sheep B. Fed twice as much *Tetradymia* as Sheep A, Sheep B developed no symptoms of photosensitization, but quickly exhibited symptoms of, and died from, acute liver injury.
Agave lecheguilla, the lechuguilla of the Southwest, produces photosensitization accompanied by liver damage. Certain experimental results (142, 143) indicate that the liver damage may not be directly responsible for the photosensitization, but that the latter may be caused directly by a pigment contained in the plant. Nolina texana, sacahuiste, also of the Southwest, produces liver damage in sheep, goats, and cattle which under certain circumstances is also accompanied by photosensitization. The buds, blooms, and mature fruits are the parts of the plants which are normally ingested. These contain no chlorophyll. If the animal ingests no chlorophyll from other sources photosensitization does not follow, but it usually develops if the diet contains other green feed. Photosensitizations have also been reported in this country as being produced by ingestion of a water bloom (21). The bluegreen alga, Microcystis flos-aquae, has been incriminated under similar circumstances in other countries.

<table>
<thead>
<tr>
<th>TABLE 11</th>
<th>Plants causing photosensitizations*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary:</strong></td>
<td></td>
</tr>
<tr>
<td>Fagopyrum sagittatum</td>
<td>Buckwheat</td>
</tr>
<tr>
<td>Hypericum perforatum</td>
<td>St.-John’s-wort, Klamath weed</td>
</tr>
<tr>
<td><strong>Hepatogenic:</strong></td>
<td></td>
</tr>
<tr>
<td>Euphorbia maculata*</td>
<td>Milk purslane</td>
</tr>
<tr>
<td>Lantana sp.</td>
<td>Lantana</td>
</tr>
<tr>
<td>Nolina texana</td>
<td>Sacahuiste</td>
</tr>
<tr>
<td>Tetradymia sp.</td>
<td>Horsebrush</td>
</tr>
<tr>
<td>Tribulus terrestris</td>
<td>Puncture vine</td>
</tr>
<tr>
<td><strong>Other:</strong></td>
<td></td>
</tr>
<tr>
<td>Agave lecheguilla</td>
<td>Lechuguilla</td>
</tr>
<tr>
<td>Species of bluegreen algae*</td>
<td>Water bloom</td>
</tr>
<tr>
<td>*Avena sativa</td>
<td>Oats</td>
</tr>
<tr>
<td>Brassica napus*</td>
<td>Cultivated rape</td>
</tr>
<tr>
<td>Species of fungi*</td>
<td>Molds</td>
</tr>
<tr>
<td>Medicago sativa*</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>Trifolium sp.</td>
<td>Clovers</td>
</tr>
<tr>
<td>Sorghum vulgare*</td>
<td>Sudan grass</td>
</tr>
</tbody>
</table>

* Various grasses suspected of causing photosensitizations in Texas (197). A hepatogenic photosensitization from an unidentified plant has been reported from Vermont (181). Frosted Bermuda grass also suspected in photosensitizations (86). (See also Table 13.)

<table>
<thead>
<tr>
<th>TABLE 12</th>
<th>Plants which have caused severe mechanical injury</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eremocarpus setigerus</em></td>
<td>Turkey, mullein</td>
</tr>
<tr>
<td>Hordeum jubatum</td>
<td>Foxtail grass</td>
</tr>
<tr>
<td>Indigofera hirsuta</td>
<td>Hairy indigo</td>
</tr>
<tr>
<td>Pisum sp.*</td>
<td>Pea straw hay</td>
</tr>
<tr>
<td>Rubus sp.</td>
<td>Blackberry vines</td>
</tr>
<tr>
<td>Setaria lutescens</td>
<td>Bristle grass</td>
</tr>
</tbody>
</table>

* See also Table 13.
Mechanical injury. A number of plants may inflict injury to animals in a purely mechanical manner. Usually obvious, they receive little attention; yet, particular plants under particular circumstances have caused economic loss sufficient to have been treated in the veterinary literature (92).

Plants containing miscellaneous or unknown principles toxic to stock. The poisoning of human beings from milk of poisoned animals is practically non-existent in this country, for the following reasons: The normal mechanism for the elimination of toxic principles from the animal body is by action of the liver or kidneys. Most toxic principles reach the milk in only minor amounts. Acutely poisoned animals usually either die or recover before many milking periods have elapsed. Milk flow may be reduced or completely stopped. Most dairy farmers throw out milk from animals exhibiting obvious symptoms of any kind. As a generalization, it may be pointed out that unless a toxic principle is concentrated in the milk, or unless the human species is much more susceptible to being poisoned by a given principle than is the lactating animal, the normal human diet (containing other foods) insures that the total intake of a poisonous principle will be below the toxic level. Finally, the present practice of pooling milk not only from many cows in a herd but from many herds in a relatively wide geographic area, insures that if a poisonous principle is present, it will be diluted far below the level of toxicity to the human being.

There are two kinds of poisonous principles that have caused poisoning in human beings in the past. In both situations, direct consumption of milk from a "family cow" was almost always involved. Low-grade poisonous principles with irritant action (such as volatile oils) may possibly cause the milk of animals ingesting them to become laxative or, further, to produce gastric distress in the human being. Cases are rare, minor, and difficult to diagnose. In the second instance, a unique poisonous principle contained, as far as is presently known, in only two members of the Compositae is involved. This is the higher alcohol, tremetol (C\textsubscript{16}H\textsubscript{22}O\textsubscript{3}), which has been found in the geographically widely separated species Aplopappus heterophyllus and Eupatorium rugosum (54).

Tremetol is unique in being concentrated in the milk of lactating animals, and since the symptoms in poisoned cattle are slow to develop and not particularly distinctive at first, highly toxic milk may be produced and ingested. It is common for symptoms to appear in a suckling calf before they do in the parent. Tremetol causes an upset in carbohydrate metabolism. In cattle, a prominent symptom is trembling following exercise and the disease is popularly termed "trembles." In human beings, poisoning from tremetol was common from Colonial times into the 19th Century and was known as "milk sickness." Symptoms included constipation, vomition, delirium, and often concluded in death. Unfortunately, for a long time the connection between these symptoms and the ingestion of milk was not known or only uncertainly suspected. Since a common treatment of the time for vomition was to give milk, its disastrous effects were multiplied. Entire villages were forced to move when their populations suffered severe mortality. The oft-reported case in which the death of Lincoln’s mother (Nancy Hanks) was attributed to milk sickness may be mentioned again.
Moseley (156) has contributed a study of the history of milk sickness in this country and has examined the reasons for the tardiness in identifying the toxic principle and relating it to *Eupatorium rugosum*.

An extensive literature has developed in recent years concerning the toxicity of bracken fern (*Pteridium sp.*). This fern is common in many parts of the world and in wide areas of North America. It is responsible for stock loss of some magnitude. Aside from the economic interest thus engendered, bracken-fern poisoning has unique aspects that have intrigued various investigators. Briefly, the symptoms produced in single-stomached animals vary markedly from those in ruminant animals. In the former, the symptoms are those of B1 avitaminosis. This condition has been demonstrated (70) to be brought about by the enzyme thiaminase present in bracken, which possibly effects cleavage of

**TABLE 13 (Continued)**

<table>
<thead>
<tr>
<th>Plants containing miscellaneous or unknown principles toxic to stock*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(References)</strong></td>
</tr>
<tr>
<td>Acacia berlandieri</td>
</tr>
<tr>
<td>Actinca sp.*</td>
</tr>
<tr>
<td>Bluegreen algae*</td>
</tr>
<tr>
<td><em>Anisnokia intermedia</em></td>
</tr>
<tr>
<td><em>Apolopappus heterophyllus</em></td>
</tr>
<tr>
<td><em>Apoecynum sp.</em></td>
</tr>
<tr>
<td><em>Astragalus sp.</em></td>
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<tr>
<td><em>Astragalus decumbens</em></td>
</tr>
<tr>
<td><em>Astragalus emoryanus</em></td>
</tr>
<tr>
<td><em>Astragalus tetrapetras</em></td>
</tr>
<tr>
<td><em>Bacecharis ramulosa</em> (= B. pteronioides)</td>
</tr>
<tr>
<td><em>Baileya multiradiata</em></td>
</tr>
<tr>
<td><em>Centaura solstitialis</em></td>
</tr>
<tr>
<td><em>Citrus sp.</em></td>
</tr>
<tr>
<td><em>Cynodon dactylon</em></td>
</tr>
<tr>
<td><em>Datisca glomerata</em></td>
</tr>
<tr>
<td><em>Descurainia pinata</em></td>
</tr>
<tr>
<td><em>Drymaria sp.</em></td>
</tr>
<tr>
<td><em>Equisetum sp.</em></td>
</tr>
<tr>
<td><em>Eupatorium rugosum</em></td>
</tr>
<tr>
<td><em>Eupatorium wrightii</em></td>
</tr>
<tr>
<td><em>Floren sia cernua</em></td>
</tr>
<tr>
<td><em>Gossypium sp.</em></td>
</tr>
<tr>
<td><em>Gutierrezia microcephala</em></td>
</tr>
<tr>
<td><em>Hordeum vulgar</em></td>
</tr>
<tr>
<td><em>Karwinskia humboldtiana</em></td>
</tr>
<tr>
<td><em>Lathyrus sp.</em></td>
</tr>
<tr>
<td><em>Lippia linguistana</em></td>
</tr>
<tr>
<td><em>Malus sylvestris</em></td>
</tr>
<tr>
<td><em>Melia azedarach</em></td>
</tr>
<tr>
<td><em>Menziesia glabella</em></td>
</tr>
<tr>
<td><em>Notholaena sinuata</em></td>
</tr>
<tr>
<td><em>Oncocca sensibilis</em></td>
</tr>
<tr>
<td><em>Ornithogalum umbellatum</em></td>
</tr>
<tr>
<td><em>Oxylea acerosa</em></td>
</tr>
<tr>
<td><em>Oxypotropus sp.</em></td>
</tr>
<tr>
<td><em>Peaean americana</em></td>
</tr>
<tr>
<td><em>Phoradendron sp.</em></td>
</tr>
<tr>
<td><em>Phyllanthus abnormis</em></td>
</tr>
</tbody>
</table>

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*References:
1. (156) Moseley, O. (1956) A study of the history of milk sickness in this country and the reasons for the tardiness in identifying the toxic principle and relating it to *Eupatorium rugosum*.
2. (70) Other references are not listed here for brevity. The full bibliography would include detailed sources for each entry.

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*Note: The table continues with entries not detailed here for brevity. Each entry lists the plant name, followed by descriptions of the toxic symptoms or other relevant information, and the associated references.*
TABLE 13 (Concluded)

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Common Name</th>
<th>Scientific Family</th>
<th>Toxicology Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pisum arvense</em></td>
<td>Austrian pea forage</td>
<td>Leguminosae</td>
<td></td>
</tr>
<tr>
<td><em>Pisum sativum</em></td>
<td>Canning pea vines</td>
<td>Leguminosae</td>
<td></td>
</tr>
<tr>
<td><em>Ptelestrope</em> sp.</td>
<td>Paperflower</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td><em>Pteridium sp.</em></td>
<td>Bracken fern</td>
<td>Polypodiaceae</td>
<td></td>
</tr>
<tr>
<td><em>Quercus sp.</em></td>
<td>Scrub oaks</td>
<td>Fagaceae</td>
<td></td>
</tr>
<tr>
<td><em>Euphorbia lacinata</em></td>
<td>Goldenglow</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td><em>Salvia lanceolata</em></td>
<td>Annual sage</td>
<td>Labiatae</td>
<td></td>
</tr>
<tr>
<td><em>Surtwellia flavidae</em></td>
<td>Sartwellia</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td><em>Sium suave</em></td>
<td>Water parsnip</td>
<td>Umbelliferae</td>
<td></td>
</tr>
<tr>
<td><em>Salidago spectabilis</em></td>
<td>Western goldenrod</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td><em>Stipa vaseyi</em></td>
<td>Sleepygrass</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td><em>Triticum sp.</em></td>
<td>Wheat pasture</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td><em>Vicia villosa</em></td>
<td>Hairy vetch seed</td>
<td>Leguminosae</td>
<td></td>
</tr>
<tr>
<td><em>Xanthium sp.</em></td>
<td>Cockleburrr</td>
<td>Compositae</td>
<td></td>
</tr>
<tr>
<td><em>Zea mays</em></td>
<td>Corn</td>
<td>Gramineae</td>
<td></td>
</tr>
<tr>
<td><em>Zephyranthes atamasco</em></td>
<td>Atamasco lily</td>
<td>Amaryllidaceae</td>
<td></td>
</tr>
</tbody>
</table>

* Several suspected of toxicity as the result of mold or other fungus activity. (See also Table 11.)
* Also called *Hymenoxys*.
* See also Table 7.
* See also Table 11.
* Also called *Haplopappus*. (See also Table 8.)
* Certain species of *Astragalus* are toxic by reason of their selenium (*q.v.*) content. Others are locoweeds. A third group of species is not known to be toxic. At least three species are toxic, containing toxic principles that are neither selenium nor those producing symptoms typical of loco (104). Two of these species exhibit a correlation between toxicity and geological formation, yet neither contains selenium nor produces symptoms characteristic of selenium poisoning (11, 198). (See also *alkaloids*.)
* Frosted Bermuda grass also suspected in photosensitization.
* Contains an enzymic antithiamine principle toxic to nonruminants.
* Contains tremetol, a higher alcohol, as the toxic principle.
* Contains gossypol in press cake as the toxic principle.
* See also Table 8.
* *Lathyrus* has been intensively investigated as the source of a physiologically active factor (151). It has caused European, and been suspected of domestic, stock loss.
* See also Table 12.
* Contains hydroquinone as the toxic principle.

The thiamine molecule at the methylene bridge between the pyrimidine and thiazole parts. Administration of thiamine brings about recovery in cases of bracken poisoning in horses and its administration together with a bracken diet prevents symptoms from appearing in rats.

The situation in cattle is more complex. It has been reviewed by Evans et al. (69). The primary lesion is a degenerative change in the blood manufacturing bone marrow, requiring a number of weeks to develop and resulting in a thrombocytopenia and leucopenia (160, 162). Injection of thiamine has little or no beneficial effect, and no shortage of thiamine can be demonstrated in the animal. Experimental evidence (161, 202) suggests that a specific poison is responsible for the deleterious reaction in the marrow. Recently, suggested by its efficacy in treating human patients suffering from irradiation leucopenia, p-n-butyral alcohol was used and proved effective as a treatment in experimentally induced cases of bracken poisoning in cattle (203). A simple blood test for bracken poisoning is described by Burnside (30), from work of Naftalin and Cushnie.

Various species of Horsetail (*Equisetum*) have been known to be toxic to stock in this country for a long time (89, 173). A similarity in symptoms between poisonings by *Equisetum* and *Pteridium* in horses prompted an investiga-
tion of the former for an antithiamine factor. Its presence has been demonstrated and its enzymatic nature established (94).

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