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To capitalize on mammal-resistant plants, several approaches may be taken. The most common is to select crops not highly prone to mammal damage (i.e., resistant crops). If a generally susceptible crop is to be grown, the more resistant varieties or cultivars of that crop can be selected, if known. An approach that has not received the attention it warrants is the selection of parent stock with resistant characteristics and the selective breeding of useful species to develop strains, hybrids, or cultivars with improved mammal resistance. For several reasons, this latter approach shows the most promise for forest tree species.

It has long been known that most mammal pest species, herbivorous or omnivorous, have a preference for feeding on some plants or crops and not others. Food preferences consist of gradient values and relate to a variety of factors, some innate and others learned. It has also been observed that certain varieties or cultivars of normally susceptible crops are fed upon to different degrees. For example, 2 or 3 cultivars of the same crop grown in the same field may differ dramatically in severity of damage by deer *(Odocoileus* spp.) or rabbits *(Lepus* spp. and *Sylvilagus* spp.). All other factors being equal, a grower would select those cultivars least likely to sustain losses.

A few examples are offered to illustrate the practical value of careful and deliberate variety or cultivar selection. Where deer are a serious problem, standard size apple trees suffer less damage than dwarf or semidwarf apple trees because a greater proportion of the flowering buds are above the deer's reach (Moen 1983). The same, of course, is true of other kinds of dwarf fruit trees. Clements (1980) pointed out that with sugar-cane cultivars the persistence of the leaves including sheaths influences the amount of rat *{Rattus* spp.) damage suffered. The "self-stripping" type canes, such as "H37-1933," are much more susceptible to rat damage than the so-called "trashy" canes. Russian comfrey *(Symphytwn* sp.) has been used in England and elsewhere in Europe for stock feed and as compost for small farms and gardens. Unlike alfalfa, comfrey is not damaged by rabbits and some bird species because of the bristles on the plant (Hills 1954).

While many farmers know from experience that pest mammals cause damage to specific crops, unfortunately very little has been published on which varieties, strains or cultivars should be selected to avoid the more serious mammal damage problems.

Those researching bird depredation problems on agricultural crops have made significant strides in selecting or developing bird-resistant hybrids and cultivars of sorghum, sunflower, and corn (Parfitt and Fox 1986, Dolbeer and Woronecki 1988). Much is known of the plant chemistry and the morphological characteristics of those crop cultivars that are most or least susceptible to bird damage (Weatherhead and Tinker 1983, Bullard et al. 1989). Research on the selection and development of plants more resistant to mammal damage significantly lags behind that directed toward resolving bird problems. However, there is some renewed interest in mammal-resistant tree species for forest regeneration. With the emphasis on reforestation, Hansson (1988) presented a review of some of the research in the natural resistance of plants to pest rodents and an insight into some of the mechanisms by which they work.

## SELECTING CROPS, CULTIVARS, AND ORNAMENTAL PLANTS LESS DAMAGE PRONE

### *Deer*

Through trial and error, and accompanied by some research, it has been possible to rank ornamental plants for landscape purposes that are relatively resistant to specific mammal damage in a particular area. Several such lists have been developed and contain some useful selections. The most notable is the list of mule deer *(Odocoileus hemionus)* resistant plants, primarily ornamentals, principally used in California (Cummings et al. 1980). Several other lists of deer-resistant ornamental plants in the West have also been published (Cummings et al. 1963, Anon. 1966, Hogan 1988). In a Connecticut study, Conover and Kania (1988) identified and ranked a wide range of ornamental plant species as to their susceptibility to white-tailed deer *(O. virginianus)* browsing. Those species with little or no deer damage are provided in Table 1.

Where deer are a problem, and no deer-proof fence exists, artichokes, tomatoes, squash, rhubarb, or chives may be planted to help buffer the rest of a backyard garden. English and black walnuts, figs, pomegranates, persimmons, olives, date palms, and prickly pears are also relatively unpalatable to deer. Some of the most common deer-susceptible fruit and nut trees are apples, apricots, plums, prunes, cherries, peaches, oranges, almonds, and grapes. Beans, peas, carrots, and strawberries rank especially high in deer preferences. A deer-proof fence may be needed to profitably grow these in some areas of high deer populations.

### *Pocket Gophers*

Gardeners have identified a few ornamentals, such as marigolds, narcissus, and daffodils, that are not fed upon by pocket gophers.

According to some authorities, alfalfa cultivars with creeping or several large roots are less easily damaged by pocket gophers *(Thomomys* spp. and *Geomys* spp.) than alfalfa plants with single taproots (Melton et al. 1988). Less susceptible alfalfa varieties such as Rambler, Teton, and Travois were specifically mentioned with reference to Nebraska (Case and Stubbendieck 1976). More recent studies in Nebraska indicate that Spredor 2 may be more resistant to gophers than the Wrangler (Jasch, pers. commun.).

### *Rats*

To avoid roof rats *(Rattus rattus)* in landscaped areas, lists of plants that are not good harborage for roof rats in California have been developed (Santa Clara County Health Department, n.d.; Anonymous 1978) along with a list of plants highly favored by rats and which often harbors them (Table 2).

Table 1. Ornamentals found to be browsed little or not at all by white-tailed deer *(Odocoileus virginianus)* in a landscape nursery study conducted in Connecticut. This list is after Conover and Kania (1988).

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| American dogwood | *Cornus sericea* |
| American holly | *Ilex opaca* |
| Bridal-wreath | *Spiraea spp.* |
| Chinese holly | *Ilex cornuta* |
| Colorado blue spruce | *Picea pungens* |
| Common boxwood | *Buxus sempervirens* |
| Common lilac | *Syringa vulgaris* |
| Doghobble | *Leucothoe fontanesiana* |
| Douglas fir | *Pseudotsuga menziesii* |
| Evergreen hybrid rhododendron | *Rhododendron* spp. |
| Flowering dogwood | *Cornus florida* |
| Fraser fir | *Abies fraseri* |
| Golden-bells | *Forsythia* spp. |
| Japanese cedar | *Cryptomeria japonica* |
| Kousa dogwood | *Cornus kousa* |
| Lily-of-the-valley bush | *Pieris japonica* |
| Magnolia | *Magnolia* spp. |
| Mountain laurel | *Kalmia latifolia* |
| Mountain pine | *Pinus mugo* |
| Norway spruce | *Picea abies* |
| Pear | *Pyrus communis* |
| Rose-of-Sharon | *Hibiscus syriacus* |
| Scotch pine | *Pinus sylvestris* |
| Shadbush | *Amelanchier* spp. |
| Snowball viburnum | *Viburnum tomentosum* |
| Weeping birch | *Betula pendula* |
| White pine | *Pinus strobus* |
| White spruce | *Picea glauca* |

Table 2. Ornamentals found to harbor roof rats *(Rattus rattus)*. This list was developed by the Santa Clara County Health Department, California. These should be avoided where roof rats are a potential problem.

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| Algerian ivy | *Hedera canariensis* |
| Arborvitae | *Platycladus orientalis* spp. |
| Bamboo | *Bambusa* spp. |
| Date palm | *Phoenix dactylifera* |
| Hall's honeysuckle | *Lonicera japonica halliana* |
| Himalayan blackberry | *Rubus procerus* |
| Italian cypress | *Cupressus sempervirens* |
| Lombardy poplar | *Populus nigra italica* |
| Pampas grass | *Cortaderia selloana* |
| Star jasmine | *Trachelospermum jasminoides* |
| Tamarix juniper | *Juniperus sabina tamariscifolia* |
| Variegated Algerian ivy | *Hedera canariensis variegata* |

As mentioned earlier, certain varieties of sugarcane are more susceptible to rat damage. Varietal characteristics of rat-resistant sugarcane are thick-barreled, moderate-to-hard-rinded, grow erect, and are not prone to lodging (Barnes 1974, King et al. 1965). In Taiwan the variety POJ2725, which is soft-rinded with inclined stems, suffers greater rat damage than POJ2878, which is hard-rinded with more upright growth (Blackburn 1984).

### *Rabbits and Hares*

Sheail (1971), a British author, provided a relatively short list of ornamentals resistant to feeding by the European rabbit *(Oryctolagus cuniculus).* How pertinent that list would be for our rabbit species is unknown. Unfortunately, these lists are not as comprehensive as landscape designers would like, but nevertheless they are highly valuable and provide a basis for further work and list expansion.

The browse preferences of white-tailed jackrabbits *(Lepus townsendii)* and eastern cottontails *(Sylvilagus floridanus)* for some species commonly used in shelterbelt plantings in Minnesota and elsewhere in the midwest were studied by Swihart and Yahner (1983). The genera which include black locust *(Robinia),* Russian-olive *(Elaeagnus),* spruce *(Picea)* and northern white-cedar *(Thuja)* were among the least preferred by eastern cottontails. White-tailed jackrabbits had a low preference for Austrian, Scotch, and pitch pines *(Pinus* spp.). Pear, cotoneaster, and buffaloberry were much preferred by both jackrabbits and cottontails, but pine and honeysuckle *(Lonicera)* were resistant to both (Swihart and Yahner 1983). Some 30 shelterbelt species in all were ranked for cottontails and 13 genera for white-tailed jackrabbits as to their preferred and least-preferred species. These provide a basis for avoiding serious rabbit problems in shelterbelts by planting the least-susceptible species.

### *Seed-eating Rodents*

In reforestation efforts in the west, it has been found that white fir seed was less preferred by seed-eating rodents, such as deer mice *(Peromyscus maniculatus)* than that of Douglas-fir (Krauch 1945). Seeds of Port-Orford-cedar, the true firs, and red alder were found less acceptable to rodents than those of western hemlock and Douglas-fir (Moore 1940). For some regions such information is useful where natural or artificial seeding is relied upon as a reforestation strategy.

### *Tree Squirrels*

A study of bark-stripping damage conducted in England showed that the introduced gray squirrel *(Sciurus Carolinensis)* had a definite preference for beech, oak, and western hemlock of the major species, and sycamore and sweet chestnut of the minor species (Rowe and Gill 1985). The conifers were generally avoided. Such information is of value in establishing new woodlots and in reforestation practices. A study by Williams and Van Sambeek (1984) demonstrated that both gray and fox squirrels *(S. niger)* had a preference for black walnuts *(Juglans nigra)* from certain trees or families of trees. They concluded that the possibility exists for breeding walnuts from squirrel-resistant seed sources for direct seeding.

## RESISTANCE AND MECHANISMS OF RESISTANCE

Certain plants may be rejected because of their spines, thorns, or prickly leaf structure. Plant-produced secondary chemical compounds may be taste repellents, toxic to various degrees, cause postingestinal stress, or interfere with the digestive process. Considerable information has been published on secondary compounds and their effects on mammals and for the sake of brevity will not be reviewed here. Secondary compounds are thought to provide much greater protection to the plants than would simple food preferences (based on subtle taste differences), low palatability or digestibility, or low nutrient values. Mammals that are stressed for food due to shortages often feed on plants not normally highly preferred or that are low in needed nutrients. Mammal resistance, like insect resistance in plants, may be based on 1 or a combination of several factors or mechanisms.

Resistance is frequently not an all-or-none rating. Hence, the term "resistant" must be interpreted relatively loosely because, as stated previously, a pest species severely pressed for food may feed upon plants which it normally would not touch and which may be detrimental to its health, especially if consumed over a long period. Resistance per se is often dependent on whether or not other more preferred alternate foods are available. For example, certain varieties of strawberries are preferred by deer over others when planted in the same field. However, if the preferred cultivars are eliminated and only the least preferred planted, severe damage may still occur if all strawberry cultivars are more preferred than any other plants (natural or cultivated) in the immediate area. A farmer who selects a more damage-resistant cultivar of a crop may benefit; however, if all the farmers in the area do the same, it is very possible that no one will gain, and the economic losses overall will remain about the same. Alternative food availability, in amount and variety, as well as preferences, play interrelated roles in animal damage problems and represent a basic principle that must be considered with the use of more resistant crops or plants. Alternative food availability and associated preferences of plants vary with season, growth phase, and climate and generally do not remain static. For example, young succulent new growth of conifers or other trees may be browsed by deer, but when that growth hardens, damage ceases. Likewise, the nutritional needs of the pest species may change over the year with the sex, age, reproductive status, and other factors influencing diets, causing them to feed on different plants or parts of plants at different times.

Certain learned behavioral traits of the mammal species may make it more difficult to resolve some pest problems. A case in point are deer that for years have been coming from their natural habitat to feed on a particular irrigated alfalfa field. They may continue that feeding pattern if the alfalfa is removed and planted with another crop not usually damaged by deer. In this instance, the deer have habituated to the feeding site and it may take some time to abandon the area and find a new feeding ground. Unlike pest birds, which may immediately move substantial distances for more preferred foods, troublesome mammals are relatively sedentary once their home ranges have been established.

Introduced (non-native) plants, which include a good many of our ornamentals and most of the crops we grow, are often subject to greater mammal damage than native species, presumably because they did not evolve together. Many crops could not be profitably grown if surrounded by expansive areas of natural habitat that supported moderate-to-large populations of native mammals. Most of our crops lack defensive chemicals (i.e., secondary compounds), which is why they are palatable and highly preferred by humans and domestic animals. Because crops are selected for their edible value, and since crop-breeding efforts are generally directed towards improving these qualities, it is unlikely that much selective crop breeding can be conducted to make crops less palatable to pest mammals without affecting their value as crops. Possible exceptions are those crops from which we eat or utilize only the fruit or seed and the pest mammals cause their damage by eating only the vegetative parts of the plants.

### *Crop Abandonment*

When vertebrate pest problems are exceptionally severe with no practical or economical solution, the crop may have to be abandoned in favor of another which does not suffer to the same extent. As an example, in some South Pacific islands sweet potatoes cannot be grown because the damage by rats *(Rattus* spp.) is so severe and extensive that few potatoes are left to be harvested (Howard, pers. commun.). Pocket gophers *(Thomomys* spp.) or jackrabbits *(Lepus* spp.) in some local areas of the western United States are so numerous that alfalfa cannot be profitably grown in spite of control efforts.

The abandonment of certain or all crops does not occur often in countries with highly developed agriculture except possibly for land being cultivated and cropped for the first time. For most agricultural regions, this has been sorted out long ago, and only crops that can be grown economically have evolved as mainstay agriculture. In developing countries where agriculture is on the increase and new land is constantly coming under cultivation, the problem of mammal damage influencing the crops that can be grown is most significant (e.g., elephants in Africa). It is not unlike the experience of our early forefathers in this country. Giving up certain crops prone to extensive mammal damage was very prevalent during the time of the early pioneers because there were few methods available for animal damage control.

Referring to growing pest bird problems in North America and Africa, Dyer and Ward (1977) stated: "... damage avoidance by crop substitution or changes in crop phenology ought to be contemplated." The same statement applies to pest mammal problems. At least in North America, significant changes in major crops grown in an area would probably have significant economic ramifications and bring about severe regional economic hardship. Yet in the long run changing crop phenology is a sound ecological approach to avoiding agricultural problems with mammal and avian pests. Planting less-susceptible crops in a major way, however, is not apt to come about voluntarily or without strong economic incentives.

## RESEARCH PROGRESS IN SELECTIVE PROPAGATION AND BREEDING

Research progress to date on the selection and development of mammal-resistant plants has been focused for the most part on forest trees. Though not extensive, it is important because it provides optimism to stimulate continued efforts. Research has resulted in several significant advances that are important to vertebrate pest management, and they illustrate potentially useful principles and concepts which have long been used in pest insect and plant disease management.

Foresters have long noted that individual tree seedlings within the same species may be fed upon or rejected by deer, hares, voles, tree squirrels, or pocket gophers, which suggests that genetic make-up and variability undoubtedly contribute to these differences. In this country, research along these lines has periodically received some significant attention, but progress on the development of resistant strains of trees for solving mammal damage problems in reforestation remains limited for a multitude of reasons (Dimock 1974). In agriculture, a vole-resistant apple variety, "Novole," has resulted from relatively recent research, and this represents a significant step.

While genetic manipulation is a potentially effective way of increasing mammal resistance in certain forest tree species and possibly in some ornamental plants, this approach has less merit for many agricultural crops. Making certain crops unpalatable to mammals would run the risk of reducing their value as food items for humans or domestic animals.

Foresters and forestry researchers have spent and continue to spend more time and effort researching the development of mammal-resistant trees than has the agricultural industry in developing cultivars less prone to mammal damage. Presently because of the seriousness of some of their problems, the Scandinavian countries seem to be doing the most in this area (Hansson 1988, Rousi 1988, Rousi 1990), but others are also active.

### *Voles*

Various species of voles *(Microtus* spp.) cause extensive and serious damage by girdling the roots or crown bark of deciduous orchard trees, particularly apple orchards that are maintained with permanent vegetative ground cover. The discovery of apple rootstocks apparently resistant to pine vole damage has led apple tree breeders in the east to add this line of resistance to their list of disease and production characteristic objectives. For the last 10 years or so, considerable efforts in New York and Virginia have been directed towards determining which apple varieties were most susceptible or resistant to vole damage. Byers and Cummins (1977) published their research findings on variation in susceptibility of apple stems to attack by pine voles, and the influence of texture and taste on gnawing by the same species was studied by Geyer and Cummins (1980). In other studies, series of apple clones were also evaluated for susceptibility to *Microtus* (Pearson et al. 1980, Wysolmerski et al. 1980). As a direct result of this and other research, the "Novole" crab apple emerged, which is highly resistant to the gnawing of the pine vole (M. *pinetorum)* and meadow vole (M. *pennsylvanicus)* (Cummins et al. 1983, Cummins and Byers 1984).

The Novole has also been used as rootstock for Mclntosh and Northern Spy varieties. The Cornell Research Foundation holds the patent and has licensing agreements with nurseries for its propagation and distribution.

There appears to be no published information of Novole being tested or planted in the west, either as a crab apple variety or rootstock for other varieties. However, there is preliminary evidence from the state of Washington which suggests that the rootstock may not solve its vole problem (Askham pers. commun.). No known comparable research is under way in the northwest apple-growing region.

Relevant to forestry, research being conducted in Finland appears promising for breeding birch *(Betula* spp.) for resistance against voles, mainly *Microtus agrestis* (Rousi 1988, 1990; Rousi et al. 1988). Other interesting results with regard to voles come from Canada, where it was determined that the phenol compounds of coniferous trees play a significant role in deterring meadow voles (M. *pennsylvanicus)* from debarking, which suggests that some selective breeding may be rewarding in preventing vole depredation (Roy and Bergeron 1990).

### *Pocket Gophers*

Foresters in Oregon observed the ponderosa pines appeared more heavily damaged by pocket gophers than Jeffrey or lodgepole pines. This led to a study by Crouch (1971) who found in his field experiment that all 3 species were severely and equally damaged. This points out that much is yet to be learned regarding the susceptibility of 1 species over another and the various contributing factors.

The feeding preferences of pocket gophers for ponderosa pine strains was the subject of a masters thesis (Cummins 1975). In another study of ponderosa pine, essential oils and their terpenoid components were evaluated to determine if these secondary plant chemicals were implicated in the susceptibility or rejection by pocket gophers of individual plants of this species (Radwan et al. 1982). In this study gophers discriminated among pine seedlings grown from seed collected from different sources (states) with damage rated from 0 to 31%. However, the authors reported no apparent morphological or measurable chemical differences among the sources to explain the feeding variability.

### *Tree Squirrels*

In Taiwan studies have determined that the higher resin content of the bark of the Chinese fir *(Cunninghamia lanceolata),* the greater the rejection by the red-bellied tree squirrel *(Calloscirus erythaeus)* (Hwang et al. 1985). They conclude from this that the breeding of squirrel-resistant strains of Chinese fir is possible.

### *Deer, Rabbits, and Hares*

Research on genetic resistance of Douglas-fir genotypes to snowshoe hare *(Lepus americanus)* and black-tailed deer has also received some attention (Radwan 1972, Dimock et al. 1976). In other studies it was shown that progeny seedlings of ponderosa pine from different geographic sources significantly influenced browsing by black-tailed jackrabbits (Read 1971). Dimock et al. (1976) concluded that genetic analysis in Douglas-fir suggests that resistance based on nonpreference is strongly inherited and chiefly additive. This was further supported by Silen et al. (1986) in their measurement of genetic parameters of Douglas-fir relative to deer damage.

Various chemical components (e.g., phenols, terpenes, resins, essential oils) of forest tree species have been studied to determine the relationship between secondary compounds and resistance to animal damage with both positive and negative results (Oh et al. 1967, Radwan and Ellis 1975, Tucker et al. 1976, Radwan 1978, Radwan and Crouch 1978, Connolly et al. 1980, Radwan et al. 1982, Welch et al. 1983, Rousi and Haggman 1984, Tahvanainen et al. 1985, Hansson et al. 1986, Roy and Bergeron 1990). Much has been learned from these studies although many questions remain.

It's worth mentioning that pine oil is now being seriously evaluated as a repellent for deer, voles, and hare. Its repellent action is thought to be based on interference in the food digestive process (Bell and Harestand 1987). This coincides and is consistent with the research previously cited by Oh et al. (1967), Radwan (1978), Connolly et al. (1980) and others.

## SUMMARY

The selection of crops and cultivars or plants less prone to mammal damage is a potentially effective management option. But in reality, with a few exceptions, its practice is currently limited because other factors are often much more compelling in making crop cultivar and ornamental plant selections. This appears to be changing with greater restrictions being placed on the population reduction of various pest species, especially more limited use of pesticides. Organic and sustainable agricultural objectives are also very instrumental in changing pest management practices.

The selection of more naturally resistant genotypes or selective breeding of forest tree species in a deliberate attempt to increase their resistance to mammal damage has received attention over the last two decades and continues to receive some serious attention by researchers, but the progress to date in this country provides very little that is useful at this time to foresters. Several of the Scandinavian countries are currently energetically researching this area relative to reforestation.

New and changing concepts relevant to natural plant defenses (i.e., secondary compounds), in-depth studies of the chemical components of plants, the effects of plant chemistry on animal feeding behavior, and the potential of genetic engineering on crop protection all contribute to a potentially brighter outlook for an increase in useful vertebrate-resistant plants for the future.

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