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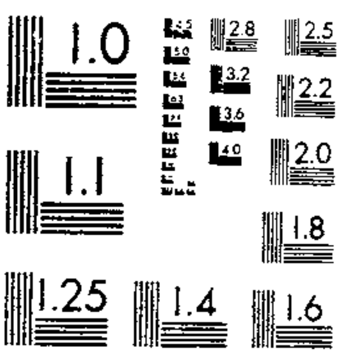

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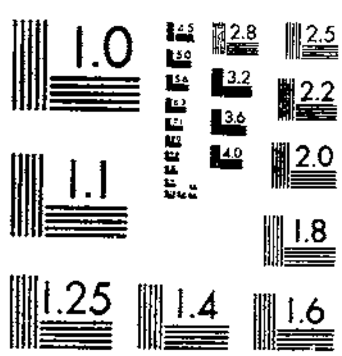

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Repellents to Protect Trees and Shrubs from Damage by RABBITS

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CONTENTS

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Repellents to Protect Trees and Shrubs From Damage by RABBITS[1]

INTRODUCTION

A major hazard in growing trees and shrubs is damage by rabbits.[2] Their depredations are most prevalent in cold or dry regions where, at certain seasons, green herbage is scarce. Perhaps no other part of the United States has suffered greater loss from rabbit damage to woody plants than the western half of the Great Plains. In this region of cold winters and frequent droughts, succulent forage may be deficient at any time of the year. Under such conditions it usually is impossible to operate nurseries or to establish orchards or plantings of trees and shrubs for windbreaks, erosion control, game cover, or rural landscaping without some kind of protection from these animals.

During the last 22 years the Cheyenne Horticultural Field Station has conducted extensive experiments on means of preventing injury to trees and shrubs by rabbits. Most of these studies were carried on at the station, near Cheyenne, Wyo., but tests were conducted also in other areas of the Great Plains through the cooperation of State and Federal agencies and private farmers. Results of this work are reported in this publication. These findings doubtless will have greatest application in the western part of the Great Plains where the tests were made and where rabbits are plentiful. The protective methods developed, however, should be useful wherever woody plants are attacked by jackrabbits or cottontails.

OCCURRENCE AND NATURE OF DAMAGE

On the western Great Plains rabbits attack trees and shrubs most frequently during the winter when typical plains vegetation is dry or covered with snow. Sometimes the injury occurs early in the fall before frost and sometimes late in the winter after the coldest weather of the season is past. New plantings may be destroyed in the spring just after the nursery stock has been set out. During severe drought, plantations may be damaged in midsummer. The time of attack seems to be determined by the availability of other palatable feed. Vigilance throughout the year is necessary if trees and shrubs are to be protected.

The commonest type of damage by rabbits results from their cropping dormant shoot growth. In another common type they nip off dormant buds. Under severe drought conditions small woody plants

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[1] Submitted for publication May 16, 1955.

[2] As used in this publication, the word "rabbit" refers collectively to the various species and subspecies of *Lepus* and *Sylvilagus*. Members of these genera found on the western Great Plains are commonly called, respectively, jackrabbits and cottontails.

may have their leaves and succulent tips eaten off repeatedly during the growing season. Native stands of seedlings, stock in nurseries, young plantations, and old trees and shrubs having small branches within reach of the rabbits are all subject to such browsing injury.

Serious damage is caused also by rabbits gnawing the bark, and sometimes the soft sapwood, from trunks and limbs. Young plantations up to 3 years of age are most liable to this type of injury; however, trees of any age may be injured. Benito Martínez (*10*)[3] mentions such injury on 100-year-old beech trees. On large trees bark gnawing generally is confined to species that retain fairly smooth bark on their trunks at maturity. The extent of bark injury may vary from a few nibbles to complete girdling of a trunk or limb. Damage is usually near the ground within easy reach of the pests. However, when snowfall is deep or when snowdrifts form around trees, rabbits working on top of the snow may break branches several feet above ground level.

Sometimes rabbits cause damage that appears to be pure mischief. The authors have seen young tree trunks from which dangled narrow strips of bark attached only at one end. Occasionally the strips were peeled completely from the tree and left lying on the ground. Such injury results from a rabbit catching hold of a piece of bark and pulling until a strip is loosened, often more than a foot above or below the point of gnawing. Whole rows of young trees have been found bitten off, with no part having been eaten. Shrubs and small trees have been observed with their branches nipped off smoothly without a bite having been taken out of them. Moore (*56*) reported that in Oregon tops of newly planted Sitka spruce seedlings were cut off by the redwood brush rabbit and left where they had fallen. Day (*26*) noted that in Michigan buds and shoots of conifers often were bitten off by rabbits and left uneaten.

KINDS OF TREES AND SHRUBS ATTACKED

Starving rabbits probably will eat any kind of tree or shrub. However, when the stress for food is not great, they show definite preference for certain species. This selectivity is more evident in the bark-gnawing type of injury than in the browsing type. Practically all species may at times suffer injury from having their shoots, buds, or foliage nipped off by rabbits. Although such cropping is usually for food, sometimes it seems to be sampling to test palatability and sometimes, a mischievous pastime. Significant bark damage, however, appears to result more definitely from eating to satisfy hunger and, therefore, it is on this type of injury that palatability of a species generally exerts its greatest influence.

Of broad-leaved trees commonly grown in the western part of the Great Plains, Siberian (Chinese) elm (*Ulmus pumila*)[4] seems to be preferred by rabbits, although American elm (*U. americana*), hackberry (*Celtis* spp.), and honey-locust (*Gleditsia* spp.) are only slightly less so. Green ash (*Fraxinus pennsylvanica lanceolata*), cottonwood

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[3] Italic numbers in parentheses refer to Literature Cited, p. 21.

[4] *Ulmus pumila* is called Siberian elm by some botanists. The species has commonly been known as Chinese elm in the Plains area since its introduction.

(*Populus* spp.), willow (*Salix* spp.), osage-orange (*Maclura pomifera*), locust (*Robinia* spp.), Russian-olive (*Elaeagnus angustifolia*), and mulberry (*Morus* spp.) are somewhat less favored, while boxelder (*Acer negundo*) and walnut (*Juglans* spp.) are less attractive to these pests. Of coniferous trees, ponderosa pine (*Pinus ponderosa*), eastern redcedar (*Juniperus virginiana*), and Rocky Mountain juniper (*J. scopulorum*) seem to be preferred to Colorado spruce (*Picea pungens*), Black Hills spruce (*P. glauca*), and arborvitae (*Thuja* spp.).

Among shrubs, the Manchu (Nanking) cherry (*Prunus tomentosa*) is a favorite rabbit food, but sandcherry (*Prunus* sp.), American plum (*P. americana*) and common chokecherry (*P. virginiana* and *P. melanocarpa*) are relished almost as much. Less attractive are Tatarian honeysuckle (*Lonicera tatarica*), lilac (*Syringa* spp.), golden currant (*Ribes aureum*), elder (*Sambucus* spp.), buffaloberry (*Shepherdia* sp.), skunkbush (*Rhus trilobata*), and various species of *Caragana* and buckthorn (*Rhamnus* spp.). Walker and Kerr (*84*) stated that on the Canadian prairies "Caranga, boxelder and spruce are less susceptible to attack than most other species." In England flowering currant (*Ribes* sp.), dogwood (*Cornus* spp.), syringa (*Syringa* spp.), snowberry (*Symphoricarpos albus*), and elder were reported (*13*) to be immune from rabbit injury, particularly the elder, which was said never to be touched by them.

Sweetman (*70, 71, 72*) studied 107 native and introduced woody plants in New England for susceptibility to injury by cottontails during severe winters. Of these trees and shrubs 64 species were extensively damaged, 30 were only moderately injured, and 13 were not appreciably damaged.

Nearly all kinds of fruit trees that can be grown on the Great Plains are liable to attack by rabbits, apricot (*Prunus armeniaca*), apple (*Malus* spp.), and pear (*Pyrus* spp.) being particularly so. On the other hand, jujube (*Zizyphus jujuba*) and persimmon (*Diospyros* spp.) on the southern Great Plains are particularly immune. Maney (*53*) found that a caged rabbit ate the bark of apple, pear, native plum (*Prunus* spp.), and sour cherry (*P. cerasus*), while peach (*P. persica*) was untouched. Neilson (*68*) reported that apple, pear, and peach were especially liable to rabbit injury, while cherry and plum were generally less subject to attack.

Many instances have been recorded in which rabbits showed selectivity in feeding on woody species under forest conditions. Corson and Cheyney (*23*) found that at Cloquet, Minn., young conifers were eaten by rabbits in the following order, beginning with the most severely damaged: Tamarack, Scotch pine, white spruce, jack pine, Norway pine, white pine, black spruce, and balsam. Hendrickson (*43*) found *Rhus glabra* heavily barked, while dogwood, elderberry, prickly ash, basswood, willow, elm, and red oak showed less bark injury. Moore (*56*) reported that in Oregon and Washington, Port Orford cedar, "aside from light sampling, is not attacked by rabbits" (redwood brush and snowshoe rabbits), although Douglas-fir and most other trees and shrubs common to the region were cropped.

Kendall (*46*) reported observations of K. W. Woodward, indicating that cottontails in New Hampshire attacked blue beech, hazelnut, and staghorn sumac approximately 100 percent and badly damaged red maple and red oak; white pine, hemlock, and gray birch were not harmed. Benito Martínez (*10*) mentioned oak, hornbeam, beech, filbert, ash, maple, birch, and elm as trees preferred by European rabbits, while willow, mountain ash, linden and conifers in general were less acceptable. He indicated *Pinus sylvestris* as the conifer most subject to attack in central Europe. Hough (*45*) reported rabbits in the Allegheny National Forest in Pennsylvania as being very discriminative, feeding on red maple more than any other species; beech and sugar maple also were staple foods, and black cherry was fourth in preference; hemlock was only slightly browsed.

Kittredge (*48*) observed that in young forest plantations in northern Minnesota, snowshoe rabbits damaged 100 percent of the white pine, 78 percent of the white spruce, and 55 percent of the Norway pine. In Michigan and Wisconsin he noted damage to 53 percent of the plantations of Norway spruce, 38 percent of white pine, 8 percent of Norway pine, and 7 percent of jack pine. Both Day (*26*) and Dice (*27*) found that rabbits in Michigan prefer pine to spruce. Aldous and Aldous (*6*) reported that in the Northern Lake States snowshoe rabbits preferred species in forest plantations in the following order: Jack pine, red pine, white pine, and white spruce, but mentioned that under certain conditions the order of red and white pine might be reversed. Sweetman's records (*71*) indicated that preference for species may differ from year to year. Apparently the preference for woody species varies with localities and conditions and also among the different kinds of rabbits. Cardinell and Hayne (*16*) found evidence of differences in food preferences among individual cottontails.

Woody species that are closely related botanically may show marked differences in palatability to rabbits. Preference for Siberian elm over American elm is evident in plantings where the two species occur together. Austrian pine (*Pinus nigra*) has been badly damaged, while adjacent plantings of Ponderosa pine were untouched. Tatarian maple (*Acer tataricum*) was reported by Mathews and Clark (*55*) as being killed nearly to the ground by rabbits, although damage was not reported to boxelder (*A. negundo*) in the same planting. Maney (*52*) found that a caged rabbit ate bark of sour cherry and native plum (*Prunus americana*) but not of peach. Todd (*78*) observed that in New York cottontails ate the bark of *Acer saccharum* extensively, that of *A. rubrum* and *A. pennsylvanicum* only moderately, while *A. spicatum* had only shoots and small branches sparingly eaten. Sweetman's (*71*) data show that cottontails caused differential injury to related species of woody plants as follows: *Aronia arbutifolia* severely injured, *A. melanocarpa* slightly injured; *Cornus florida* severely injured, *C. alnifolia* slightly injured; *Juniperus virginiana* severely injured, *J. communis* var. *depressa* uninjured; *Lonicera morrowi* severely injured, *L. dioica* uninjured; *Prunus serotina* severely injured, *P. virginiana* slightly injured; *Rhus typhina* severely injured, *R. glabra* slightly injured.

Not only do rabbits show preference for certain species of trees and shrubs but also for individuals of a species. Sweetman (*71*) reported preference of rabbits for certain individual trees of white pine (*Pinus strobus*) and eastern redcedar when many other trees of these species were available.

TREATMENT AND PREVENTION OF INJURY

Means of coping with the problem of rabbit damage fall into two general categories: (1) Treatment of injured trees and shrubs and (2) prevention of the damage.

For the type of injury resulting from rabbits browsing off shoots, branches, buds, and foliage, no remedial measure is possible. Bark-gnawing damage, however, often can be repaired. If the wound does not girdle the trunk or limb but leaves a substantial strip of bark intact, immediate coating with a tree-wound dressing is advisable. If girdling is complete, drastic measures are necessary. Broad-leaved shrubs and young seedlings of broad-leaved trees so injured may be cut back to sound bark below the wound, in the hope that new sprouts will be sent out from which new tops can be developed. Of course, topworked trees or those propagated by budding should not be cut back below the point of insertion of the bud or scion, as the new sprouts will not be the same variety as the former top. Large broad-leaved trees that have been girdled can be saved by bridge grafting.

Most coniferous species do not send up shoots from the base and do not bridge graft readily. Girdled coniferous trees and shrubs generally must be replaced.

Means of preventing damage to woody plants by these pests include: (1) Destruction of the rabbits; (2) enclosing the planting with a rabbit-tight fence; (3) wrapping trunks with various materials; (4) enclosing the trunks with guards or cylinders of various kinds; (5) planting species of trees and shrubs that are unpalatable to rabbits; and (6) coating the woody plants with rabbit-repellent materials. Perhaps the most satisfactory protection would be provided by applying to the trees and shrubs some preparation that would repel the rabbits and be noninjurious to the plants.

RECORDS OF THE SEARCH FOR A SATISFACTORY REPELLENT

Repellents Applied to Areas

Recently, much consideration has been given to repelling rabbits, but the idea is not new. Some early attempts at tree protection employed the principle of area repellents, not involving applications to the trees themselves. A German writer in 1823 (*1*) described such a method in which cord, coated with asafetida, fox grease, lard, and gunpowder, was stretched through a garden and nursery. Cameron (*14*) reported that train oil on stakes protected nearby trees for about 6 weeks. Rope-yarn coated with tar, which was renewed occasionally, was recommended (*66*). The Dillistones (*28*) used rags or wads of tow fastened on sticks and dipped in melted sulfur. These sticks set at intervals throughout a tree planting were said to give complete protection. Cord, coated with night soil and tar, suspended on four stakes set in a square around each tree was advocated (*87*).

Zürn (*91*) mentioned boards coated with gas tar and set among trees, but he doubted the value of the method. He considered fish oil and *Oleum animale foetidum* as area repellents generally effective over a long period, the oil being applied to about every fourth tree in the border of an orchard or nursery. Fernandez Salcedo (*32*) protected areas by enclosing them with cord treated with fish oil or empyreumatical oil and supported 15 to 20 cm. above the ground. Some of these European methods were recommended also by American authors of the 19th century. However, in this country area repellents are not now regarded as effective means of preventing rabbit damage to plants.

Repellents Applied to Trees and Shrubs

Most attention has been given to protecting trees and shrubs by coating them with repellent materials. In 1831 Lindley (*51*) recommended a compound of quicklime, fresh cow dung, lamp black and sulfur, mixed with boiling urine and soap suds. Lime has since been much used in repellent formulas, apparently both as a repellent and as an adhesive. Preparations tried included lime, urine or drainings of a dung hill, cow dung, sand, and both wood and coal ashes (*2*); lime, tar, cow dung, and stale urine (*33*); lime and soot (*80*); lime, cow manure, and gas tar (*58*); quicklime, sulfur, soft soap, and soot (*76*); lime, bitter aloes, black sulfur, soft soap, and soot (*90*); lime, cow manure, and water (*67*); freshly slaked lime and copper sulfate (*34*); whitewash and copperas (*12*); lime, copperas, and glue (*83*); lime, soap suds, gas tar, sulfur, and crude carbolic acid (*8*).

Zürn (*91*) mentioned smears composed of lime, cow dung, and putrescent oxblood; or slaked lime, sewage, and clay, to each of which could be added oxgall, herring brine, or old cheese; but he considered their repellency of only short duration. He reported also the use of oxblood and dog dung mixed with warm water and mentioned greasing trunks with bacon rind or mutton tallow. Green (*36*) suggested a spray of lime or cement with carbolic acid and paris green added. In Australia, smearing trees with lime and night soil was advocated (*5*). Ballou (*9*) advised lime, soap suds, carbolic acid, sulfur, and soft soap. Talbert (*73*) listed whitewash among repellents noninjurious to trees. Whitewash protected trees from chinchilla rabbits (*38*) and hydrated lime with linseed oil repelled cottontails (*53*). The Dillistones (*28*) found such substances as lime, soot, tar, and both tarred and oiled string of no value in repelling rabbits. Smith (*69*) reported whitewash with soap and "like ingredients" ineffective and Cardinell and Hayne (*16*) found whitewash of little or no repellent value.

Animal fat, flesh, and blood have been used extensively to repel rabbits. Rivers (*68*) in 1845 employed a mixture of lard and train oil. Also advocated were bullock's blood, soot, and brimstone (*77*); blood (*3*); fresh liver rubbed on the bark every few weeks (*74*); strong-smelling grease (*67*); and bloody meat rubbed on trees (*15*). An Australian fruit grower protected trees by rubbing the trunks with a rabbit carcass (*5*). Mooring (*57*) recommended rubbing trees with hog intestines or cheap meat products. Cunningham (*24*) proposed a mixture of tallow and tobacco. Wickson (*89*) stated that rancid grease, putrescent flesh and blood soon lose their effectiveness. Blood and liver were reported ineffective (*5*). Maney (*52*) found that starved rabbits attacked trees painted with rabbit blood and in his later experiments (*53*) both blood and raw liver failed to give protection. In Harvey's experiments (*38*) starved cottontails ate trees coated with blood, although in his earlier test blood had repelled chinchilla rabbits. Cardinell and Hayne (*16*) found blood ineffective.

Other materials in great variety have been used or proposed for protecting trees from rabbits. Among them are night soil, soot, and water (*14*); coal tar (*59*); tar and milk (*29*); soot and milk (*88*); such substances as tobacco, asafetida, hen or pigeon manure mixed with mud or clay (*21*); cow dung and soot (*85*); wood tar and oil (*25*); buttermilk and soot (*67*); liquid manure (*89*); soft soap, ashes, and flour (*4*); axle grease (*7*); potash and clay (*63*); aloes or quassia (*89*). Lantz (*49*), however, stated that bitter substances such as aloes and quassia were useless in repelling rabbits.

Walker (*83*) reported that W. B. Alwood, of the Virginia Agricultural Experiment Station, advised applications of pure white lead and pure linseed oil to treat trunks. Walker found this treatment effective. A wash of soap and water with carbolic acid added (*61*) and rubbing the trunks with a cake of cheap soap (*37*) were recommended. Lantz (*49*) earlier had reported volatile substances such as carbolic acid as giving only temporary protection. Cory (*23*) observed that rabbits gnawed through white lead and linseed oil paint in most instances and that various washes such as fish-oil soap, glue, lime, and blood had been used with little success. Maney (*53*) found that a rabbit ate trees painted with white lead and raw linseed oil. Coe (*19*) recommended a mixture of resin, beeswax, yellow ocher, asafetida, and strychnine melted and applied with a brush.

Several insecticides and fungicides have been tried as rabbit repellents, often with considerable success. Sulfur had a long history of use in repellent preparations before its insecticidal and fungicidal properties were known. In 1907 Lantz (*49*) recommended lime-sulfur wash, developed to control San José scale, as a rabbit repellent and indicated that its adhesiveness could be improved by adding salt. Later he (*50*) suggested also soap and cheap glue as adhesives. Cory (*23*) reported dilute commercial lime-sulfur thickened with stone lime as a satisfactory repellent. Ellenwood (*31*) suggested full-strength liquid lime-sulfur; dry lime-sulfur dissolved in water to a painting consistency; or a mixture of dry lime-sulfur, flour, yellow ocher, linseed oil, asafetida, and sour milk. Maney (*52*, *53*) found lime-sulfur ineffective, but Harvey (*38*) using similar test conditions found that it had considerable repellency. Talbert (*73*) listed lime-sulfur among the safe repellents for use on trees. At the Oklahoma Agricultural Experiment Station (*62*) undiluted commercial lime-sulfur was rated the best of 25 formulas tested for protection against cottontails. Cardinell and Hayne (*16*) found lime-sulfur ineffective.

Copper compounds, extensively used as fungicides, have also been employed as rabbit repellents. A mixture of slaked lime and copper sulfate used to repel rabbits in 1887 (*34*) was essentially the fungicide bordeaux mixture. Copper sulfate was reported to protect grapevines from rabbits (*18*); a repellent developed by Maney (*53*) consisted of the fungicide copper carbonate mixed with linseed oil to a painting consistency. Copper soap, long used as a fungicide, was added by Harvey (*38*) to a rabbit repellent to increase its fungicidal action when applied as a tree-wound dressing. Copper compounds have been used or recommended by other authors (*16, 35, 41, 60, 86*) for repelling rabbits.

Hicks (*44*) mentioned that tobacco water or cresylic soap was effective; also petroleum with paris green or strychnine. Smith (*69*) found tobacco ineffective. Cardinell and Hayne (*16*) found that a mixture of 1 part of nicotine sulfate and 15 parts of asphalt emulsion gave little or no protection to trees. Hayne (*41*) reported both tobacco dust and nicotine preparations among the most effective materials tested for preventing rabbit damage to vegetable crops. In 1917 an Arizona farmer was reported by Paschall (*64*) as employing nicotine oil to protect trees from rabbits. Paschall recommended whitewash mixed with a commercial preparation of nicotine sulfate. The U. S. Fish and Wildlife Service (*79*) reported nicotine sprays applied to garden plants at intervals of a few days as having a deterrent effect on rabbits.

The introduction by Maney (*53*) of the use of penned rabbits in testing repellents on trees gave experimenters a better method of comparing materials than was previously available and ushered in a period of precise research on repellents. As a result of carefully designed experiments, numerical data were suitable for statistical analysis. In recent years, most experimenters have confined rabbits in enclosures for at least part of their studies on repellents. Objections have been raised against this method on the basis that such unnatural conditions might influence the rabbits' food preferences. Nevertheless, investigators have found the penning of rabbits in enclosures practical for screening large numbers of materials for repellency. It has generally been recognized, however, that the selected materials should be tested further in open field trials.

Harvey (*38*) found sulfonated or sulfurized linseed oil the most repellent of several materials tested. The addition of an extract of cayenne pepper in turpentine was suggested to increase the repellency. For application as a spray he advocated emulsifying the sulfonated oil with water or thinning with high test gasoline (*40*). Sulfonated linseed oil was widely used as a rabbit repellent with varying results. In some areas it was satisfactory but in others it was ineffective.

Neilson (*60*) conducted extensive trials with repellent preparations in various parts of Michigan. Only four of them were considered effective—a resin-linseed oil mixture; a resin-fish oil-copper soap mixture; and two commercial preparations, Hood River Tree Paint and Tree Saver.

Cardinell, Toenjes, and Hayne (*17*) tested over 200 materials and mixtures applied to fruit trees. The only repellent they found effective against cottontails and noninjurious to trees was a resin-ethyl alcohol mixture. Eadie and Hamilton (*30*) reported this preparation ineffective against jackrabbits.

Garlough, Welch, and Spencer (*35*) recommended three mixtures for repelling rabbits: (1) Heavy alkyos-type resin, ethylene dichloride, asphalt emulsion, copper carbonate, and lime-sulfur; (2) asphalt emulsion, water, wood alcohol, and copper carbonate; and (3) asphalt emulsion, water, diatomaceous earth and lime-sulfur. Welch (*86*) reported that repellent 96a of the U. S. Fish and Wildlife Service was successful in preventing damage to trees by rabbits. "The active ingredients of this preparation are copper carbonate, powdered copper sulphate, and dry lime sulfur. Asphalt emulsion and a synthetic resin serve as adhesives and ethylene dichloride as the thinner."

Cardinell and Hayne (*16*) reported details of extensive tests of repellents on trees. Most effective of these materials were a rosin-ethyl alcohol mixture, a rosin-linseed oil mixture, a rosin-linseed oil-gasoline mixture, the Fish and Wildlife Service repellent 96a, Venice turpentine, and the commercial preparations Burt Gum, Tree Tanglefoot, Dow 3 (a phenolic tar), and Castle Chemical Company's Rodent Repellent.

Hayne (*41*, *42*) tested a large number of materials for protecting vegetable plants from cottontails. Tobacco dust, red pepper and flour, a nicotine sulfate preparation, a nicotine bentonite preparation, zinc dithiocarbamate-amine complex with polyethylene polysulfide (Z.I.P.) and G and C Rabbit Repellent were most effective of the materials tested.

Coker (*20*), in a replicated experiment, coated 1-year-old apple shoots with materials to be tested and exposed bundles of them in a rabbit-infested area. He found repellent 96a promising but zinc dithiocarbamate with polyethylene polysulfide and a proprietary deer repellent were ineffective.

Thompson and Armour (*77*) found that rosin-ethyl alcohol gave a high degree of protection from rabbits; bone oil was slightly less repellent; repellent 96a was still less effective; and Z.D.C., a commercial preparation which contains a zinc dimethyl dithiocarbamate-cyclohexylamine complex and polyethylene polysulfide suspension, gave no protection. Trees treated with Z.D.C. were generally eaten more than controls.

Welch (*87*) reported zinc dimethyl dithiocarbamate-cyclohexylamine complex, tetraethylthiuram monosulfide, tetramethylthiuram disulfide and trinitrobenzene-aniline complex of value in repelling rabbits. These materials were combined with adhesives polyethylene polysulfide, Hycar latex, or Aroclors for application to the trees.

Besser and Welch[5] demonstrated that trinitrobenzene-aniline formulations applied to trees in varying concentrations gave protection against rabbit damage. They noted a phytotoxic effect on some coniferous species.

Materials Injurious to Trees

It was early recognized that rabbit repellent materials might be injurious to trees and the literature records many instances in which damage resulted from their use. Cameron (*14*) considered train oil injurious to plants. Rivers (*68*) observed that oils and greases were to a certain degree injurious to trees. Quin (*67*) advised against applying gas tar to young trees. Palmer (*63*) cautioned against applying to woody plants preparations containing petroleum in any form. Zürn (*91*) reported that applications of gas tar or petroleum

[5] Besser, Jerome, and Welch, Jack F. THE RESULTS OF FIELD AND ENCLOSURE EXPERIMENTS WITH TRINITROBENZENE-ANILINE FORMULATIONS AS RABBIT REPELLENTS SPECIAL REPORT. U. S. Fish and Wildlife Serv., Wildlife Res. Lab., Denver. 16 pp 1954. [Processed.]

might cause more damage than would rabbits. Lantz (*49*) stated that coal tar, pine tar, tarred paper, and various oils were likely to kill trees. At the Oklahoma Agricultural Experiment Station (*61*) coal tar and axle grease were reported injurious to young trees but axle grease was considered safe for use on trees 5 or 6 years old. Talbert (*73*) cautioned that paint, coal tar, axle grease, and concentrated oils applied as rabbit repellents may cause serious injury or death to young trees. Sulfurized linseed oil applied to trees as a rabbit repellent caused severe injury in many instances, although Maney (*53*) in Iowa and Blair (*11*) in Canada found it noninjurious. Harvey (*40*) reported injury in some cases where the sulfurized oil had been thinned with gasoline for application as a spray. He attributed this injury to the presence of nonvolatile kerosene fractions in the low-test gasoline employed. He reported serious injury also to certain trees and shrubs when turpentine had been used to dilute the sulfurized oil. Kerr (*47*) reported tests showing injury from raw and boiled linseed oil, creosote, axle grease, crank case oil, and some paints.

Maney (*53*) found that a copper sulfate-raw linseed oil mixture killed trees; and that lime-raw linseed oil, white lead-raw linseed oil, and copper carbonate-raw linseed oil mixtures all caused bark injury. Schrader[6] reported that the copper carbonate-raw linseed oil preparation caused bark injury unless care was exercised in mixing. A heavy coat of this preparation seemed to depress growth and definitely caused roughening of the bark, an indication of injury to the epidermal layer. Too thin a consistency caused the material to run down the trunk, giving chance for injury at the point of accumulation at the base.

Neilson (*60*) found indications that four preparations he considered to be effective repellents caused injury to trees, but this was not definitely established. Cardinell and Hayne (*16*) observed, however, that trees treated with Neilson's resin-linseed oil mixture showed definite evidence of restricted growth. Coker (*20*) reported that repellent 96a caused injury to cut surfaces of tree wounds and slightly damaged certain 2-year-old clonal apple stocks.

These records of the search for a satisfactory rabbit repellent, continuing through more than 130 years, indicate the importance of such a material to growers of woody plants. The wide variety of treatments reported as effective prove that a great many substances possess repellent properties to some degree. However, the many instances in which a repellent was found satisfactory by one investigator only to be reported useless by another show that conditions greatly influence what rabbits will eat. Apparently it is easy to protect trees from these pests when the stress for food is not great, but as Patterson (*65*) remarked "much is required to repel a hungry rabbit."

REQUIREMENTS OF A RABBIT REPELLENT

When experiments on protecting trees from rabbits were undertaken by the Cheyenne Horticultural Field Station it was decided that a satisfactory repellent should meet the following requirements:

(1) Protect woody plants from significant injury by rabbits.
(2) Be noninjurious to trees and shrubs when applied at any season.

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[6] Schrader, A. Lee. Personal correspondence, January 1954.

(3) Adhere to plants in all kinds of weather.
(4) Retain repellent power at least through an entire winter.
(5) Be nonpoisonous to farm animals in the amounts which they would be likely to get from treated trees and shrubs.
(6) Be suitable for application either with a brush or as a spray.
(7) Be cheap enough so that farmers and ranchers can afford to use it liberally in large plantings.

EXPERIMENTAL PROCEDURES

Tests with Rabbits in a Corral—Materials on Young Elm Trees

Most of the tests were conducted in a rabbit-tight corral after the methods of Maney (*52*, *53*), Harvey (*38*), and Neilson (*60*). The enclosure was about twice as long as wide and covered approximately 1.7 acres. A fence was constructed of standard woven wire, 5 feet high, fastened on the sides of the posts facing into the corral. Over this wire was stretched 6-feet-wide poultry netting, extending 1 foot below the ground surface. The fence was made dog- and coyote-proof on the outside by an overhanging projection carrying three strands of barbed wire.

The land inside the corral was clean-tilled to eliminate all vegetation and then planted to young Siberian (Chinese) elm trees spaced 2 feet apart in rows 10 feet apart. Experience had shown this species to be a favorite rabbit food. Materials to be tested were painted on the trunks to a height of about 30 inches. The tests were conducted between growing seasons which, in the climate of Cheyenne, gave a long period for experimentation. With the coming of warm weather the tests were suspended, as it was impractical to control all growth of weeds and grass during the growing season and rabbits ate such forage in preference to the trees.

In preliminary trials rabbits were caught by various methods and put into the corral. After the first few years the animals were driven into the corral by the personnel of a Civilian Conservation Corps camp. Generally by such a drive about 100 rabbits would be impounded. This number soon would be reduced by deaths due to exhaustion or excitement of the drive, to injuries caused by frightened rabbits bumping into the fence, to vicious fighting among themselves, or to natural causes, so that within a few weeks only about 40 would be remaining. At best, corralled wild rabbits have a high mortality and there was a continual reduction of the number within the enclosure. When the population declined to less than 10 rabbits, another drive was made.

The corralled rabbits were predominantly white- and black-tailed jackrabbits but occasionally a few cottontails were included. After the first shock of impounding was over the animals seemed content. They were not starved but always had available hay, water, and block salt. However, the trees were the only succulent feed inside the corral. Rabbits usually started eating the trees the first night after being impounded. Within a few days they barked the untreated control trees and those coated with the less repellent materials.

Records were taken at intervals to determine the order of preference in eating, the extent of injury, and the length of time the materials retained their repellent properties. When successive readings showed no significant increase in damage, the experiment was terminated and the trees were pulled out. By replanting and by repeated rabbit drives it was possible to complete two or three experiments from fall to spring. Thus, within a few years a large number of materials were screened.

In the early years of the experiments no statistical treatment of data was necessary. Most of the materials failed to give protection and were promptly discarded. Later, materials showing appreciable repellency were given more critical comparison. For these experiments the randomized block design was employed. Usually five replications were used and each treatment was applied to five trees in each replication. Data were taken on the individual tree basis. Extent of damage was judged by the amount of gnawing within the treated area of bark.

Tests With Rabbits in the Open—Materials on Carrot Pieces

In later years it became necessary to develop some other procedure for evaluating repellents, because personnel of the Civilian Conservation Corps were no longer available for rabbit drives. A simple method was devised, whereby pieces of carrots were coated with the materials to be tested and exposed in places frequented by rabbits. Carrots are relished by rabbits and are eaten much more readily than trees. It was found, therefore, that about as critical a test could be obtained with carrots in the open as with trees and rabbits enclosed in a corral, provided that rabbits were plentiful in the test area and that testing was done at a season when succulent herbage was deficient in the locality. This method eliminated any unnatural reactions resulting from confinement of the test animals, such as change in food preferences. Both jackrabbits and cottontails were present in the test areas.

The carrots were cut into cylindrical pieces of fairly uniform size. It was found that the pieces should be small; otherwise, the rabbits satisfied their appetites by eating only the controls and did not bother the treated carrots. It was learned, also, that too many treatments should not be set up at one location, as the rabbits got their fill of carrots by eating those treated with less repellent materials and left those that would have been eaten by hungrier rabbits.

A stiff wire about 18 inches long with a loop at one end was run through each piece of carrot, so that when the wire was stuck into the soil the carrot piece was about a foot from the ground, as shown in figure 1. This arrangement kept the carrots above the snow and facilitated labeling and record taking. The best conditions for these experiments were found to be a light snow cover on the ground and fairly mild winter temperature. Subzero weather damaged the carrots, apparently making them less palatable and softening them so that they are difficult to keep on the wires after thawing. Treatments were arranged in a randomized block design.

Before an experiment was set up untreated carrots were exposed for several nights in different locations to determine the places frequented

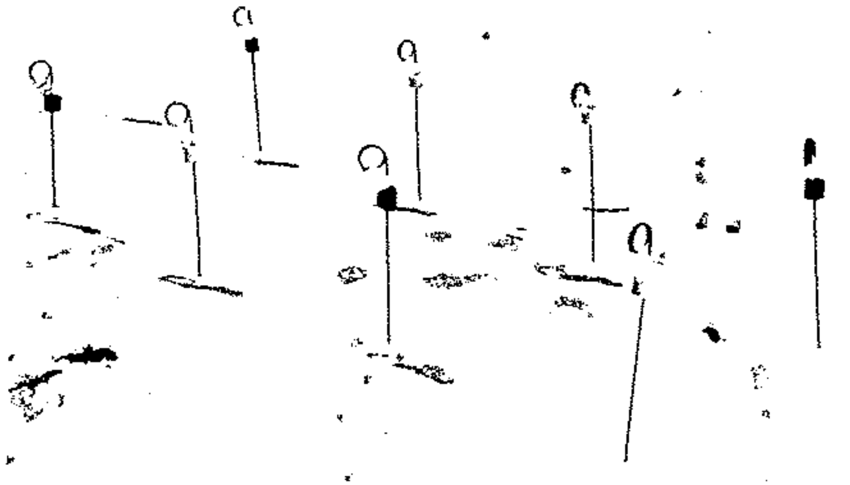

FIGURE 1.—Pieces of carrots coated with materials to be tested for repellency to rabbits.

by rabbits and to get the animals accustomed to eating carrots. The replications of the experiment were then located accordingly. Usually an experiment was completed in less than a week. Data were taken as described for the trees. Figures for the extent of eating (fig. 2) were arbitrarily established and scored as follows:

1. Not eaten.
2. One bite, as though sampling to test palatability.
3. More than one bite but less than half eaten.
4. More than half eaten but not totally consumed.
5. Totally consumed.

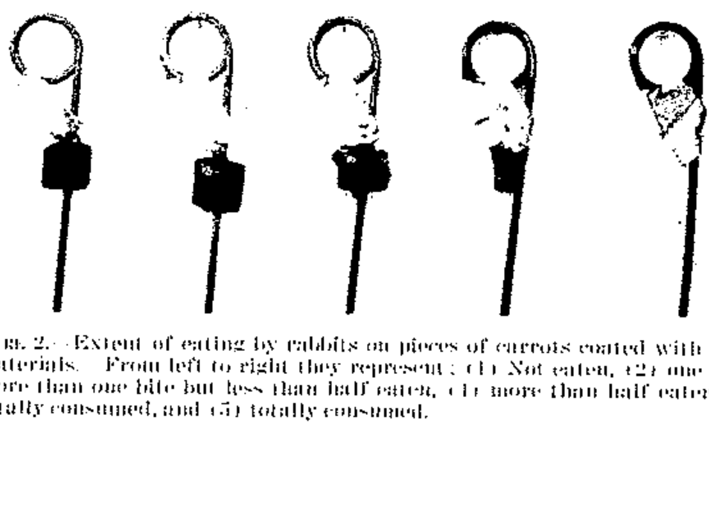

FIGURE 2.—Extent of eating by rabbits on pieces of carrots coated with different materials. From left to right they represent: (1) Not eaten, (2) one bite, (3) more than one bite but less than half eaten, (4) more than half eaten but not totally consumed, and (5) totally consumed.

Phytotoxicity Tests

Materials considered questionable for application to plants and all showing significant repellent properties were tested for toxicity by applying them to stems and leaves of young plants in the greenhouse. At first young sunflower seedlings were used, but later tomato seedlings were substituted because the tomato is generally more sensitive to chemicals. Any injurious tendencies were quickly apparent in reduced growth, stem constrictions or swellings, lesions, leaf withering and dropping, discoloration of tissue beneath the treatment, or death of the plants. This test was perhaps more rigorous than was necessary for materials that were to be used on dormant trees and shrubs; however, repellents with no tendency to phytotoxicity were needed for safe application to all kinds of plants at any season of the year.

MATERIALS USED IN REPELLENT TESTS

During more than two decades of experimenting a great many materials and mixtures in different concentrations were tested for protecting trees from rabbits. Poisons as such were excluded from the beginning, partly because of danger to livestock but mostly because poison applied to trees can destroy rabbits only after they have eaten the trees and, of course, the intent was to prevent such damage.

Oily Substances

Despite frequent reports of damage to plants from oily substances, investigators continued to recommend them in rabbit repellents. Three oils advocated for this purpose during the early thirties were lubricating oil (*60*), linseed oil (*38, 52, 53, 60*), and fish oil (*60*). When tested for toxicity to young tomato plants, all three oils produced injury. The leaves wilted shortly after treatment and later yellowed and died. Stems also were injured, although the different oils did not produce the same effects.

Conoco Motor Oil No. 20, a lubricating oil, was least injurious to stems. It killed most of the trichomes and part of the epidermal cells. There was a noticeable increase in the diameter of stems beneath the treatment, resulting from an increase in the number of cortical parenchyma cells. Boiled linseed oil produced brown discoloration and caused a slight constriction of the treated part. All trichomes were killed as were most of the epidermal cells. The underlying cortical parenchyma cells responded by dividing several times as though stimulated by the injury to the epidermal cells. Fish oil produced injury similar to that caused by linseed oil but more severe. The epidermal layer was completely killed and the injury extended through the cortex in places and into the vascular tissue. Interference with the conducting system was indicated by a tendency to put out aerial roots above the treated band.

Considering the results of this test, the injury to sunflower seedlings caused by oils in earlier trials, and the frequent references in literature (*14, 16, 17, 38, 40, 47, 49, 53, 60, 61, 63, 68, 73, 91*) to damage from applications containing greases, oils, tars, and organic solvents, the authors finally decided to discontinue the use of all such materials in rabbit repellents.

Carriers and Stickers

Many materials tried as repellents were concentrated solutions or were in crystalline or powder form, requiring some kind of vehicle with which they could be mixed before they could be painted or sprayed on trees. It was found, also, that some repellent materials did not remain on the trees long enough to provide much protection, being washed away by rain or melting snow, blown off by wind, or abraded from the trees by blowing sand. The need for carriers and stickers became acute after oils and tars were eliminated from all formulas. Eventually it became evident that finding suitable carriers and stickers for repellent materials was as important as finding suitable repellents.

Various waxes, gums, resins, and their emulsions were tried; also glycerol, bentonite, diatomaceous earth, silica gels, rubber latex, and different kinds of glues and pastes. Finally the search led to water emulsions of asphalt. At first these emulsions were made in the laboratory by various methods but later commercial preparations were used.

Asphalt emulsions have many advantages. They are cheap, readily obtainable from dealers in builders' supplies or petroleum byproducts, are generally nontoxic to plants, form tough, long-lasting coatings, can be thinned with water to any desired consistency, and are themselves somewhat repellent to rabbits.

Asphalt emulsions, however, are not ideal vehicles for repellents. Fifty-five brands of commercial asphalt emulsions were tested for miscibility with repellent materials. It was found that all of them were made with alkaline emulsifiers and therefore had a pronounced alkaline reaction. Although they mixed readily with alkaline repellents, the addition of any substance that lowered the pH to the acid side broke the emulsion. Therefore, before being mixed with acid repellents these emulsions had to be stabilized. This was accomplished by adding to the emulsion Carbowax (a polyethylene-glycol preparation) or one of the recently developed household detergents such as Dreft, Surf, Trend, Vel, and others.

Each of 4 nontoxic repellent materials was mixed with each of the 55 commercial asphalt emulsions. The resulting repellent mixtures were tested for toxicity to young tomato plants. Of the preparations, 43 produced no injury, an indication that most commercial asphalt emulsions are entirely safe for use on plants; 12 of them caused slight injury to young tomato foliage. Such slight toxicity probably would not be significant if these repellent preparations were used on dormant trees and shrubs. However, before any asphalt emulsion not known to be safe is applied extensively to growing plants, it should be tested for toxicity on a small scale.

Ordinary asphalt-containing repellents are, of course, black. This color is not objectionable in windbreaks, woodlots, orchards, or plantings for erosion control or game cover, but it is objectionable on ornamental plants and on nursery stock to be offered for sale. Green asphalt emulsions are on the market and would be preferable wher-

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ever the black color is undesirable. However, they are more expensive than the ordinary black product. Experiments have proved that repellent mixtures prepared with green asphalt emulsion are less repellent than those prepared with black emulsions. Therefore, when green asphalt emulsion is used as a carrier, the amount of repellent should be increased to about twice that recommended for use with black emulsions.

Fear has been expressed that dark coatings formed by asphalt mixtures might absorb more of the sun's heat and thereby increase winter sunscald on trees. In treating thousands of windbreak and orchard trees with these preparations during the last 18 years, no such injury has been observed. Any tendency toward increased sunscald, however, could be reduced by covering the asphalt coatings on the south and southwest sides with a reflecting paint made by mixing aluminum powder [7] with water emulsions of vinyl resin or acrylic resin.

During recent years development of water emulsions of synthetic plastics has provided additional nonphytotoxic carriers and stickers for rabbit repellents. Welch (*87*) reported favorable results from the use of emulsions of polyethylene polysulfide, Hycar latex, and Aroclors as adhesives for rabbit and deer repellents. Asphalt emulsions, however, are cheaper and may form more permanent coatings. The chief advantage of the new repellent carriers seems to be their development of thin, nearly transparent films on plant surfaces. Such films do not detract from the appearance of plants and can be used on growing plants without appreciably reducing the sunlight reaching the foliage. Being almost completely transparent, such coatings should not encourage winter sunscald through increased absorption of the sun's heat. Neither should they produce injury such as Mather, Gensch, and Barton (*54*) considered as probably caused from excessive heat absorption by dark-colored sprays on young pine needles.

Emulsions of synthetic plastics that proved suitable as carriers and stickers for repellent materials in these experiments were vinyl resin and acrylic resin.

Repellent Materials Screened

As had been indicated in the literature, most materials applied to trees exerted at least a slightly deterrent effect on rabbits. Unfortunately, slight repellency is of little practical importance in protecting trees from these pests. However, a few materials proved to be attractants, e. g., aluminum paint, glue, and emulsions of paraffin, for trees treated with such materials were eaten in preference to untreated trees. Inclusion of an attractant in a mixture tended to reduce the effectiveness of repellent ingredients.

The principal materials tested, their rating as repellents, and their tendency toward phytotoxicity are given in the appendix (see p. 26). It is impractical to include the data from all the materials tested over the 22-year period. Table 1 shows results of a typical experiment

[7] Commercial aluminum paints having amyl acetate or drying oils as carriers are toxic to plants and attractive to rabbits. Such paints are not recommended for use on trees.

with corralled rabbits in the early years of the investigations, the treatments being applied to young elm trees. There were five treatments and five replications, each treatment being applied to five trees in each replication. Trees were scored on a scale of 1 to 5, a score of 1 signifying no injury and a score of 5 representing serious injury sufficient to cause the death of the tree or its killing back to the ground.

TABLE 1.—*Degree of damage*[1] *on six dates by corralled rabbits to young elm trees treated with different repellents*

Ingredients and treatment number	Jan. 14	Jan. 20	Jan. 27	Feb. 4	Feb. 10	Feb. 17
1, Copper soap, fish oil, resin	1. 14	1. 87	2. 54	2. 63	2. 75	3. 04
2, Sulfonated linseed oil	1. 92	4. 72	4. 99	5. 00	5. 00	5. 00
3, Sulfonal (commercial repellent)	1. 28	2. 43	3. 52	3. 70	3. 85	4. 04
4, Resin, linseed oil (Neilson's formula)	1. 15	1. 62	3. 31	3. 49	3. 63	3. 77
5, Control (untreated)	4. 88	4. 94	4. 97	5. 00	5. 00	5. 00

[1] Differences required for significance:
1 percent level 0. 24
5 percent level . 18

It is evident that treatment No. 1 had the best lasting quality, while treatment No. 2 soon lost its repellency. Treatments Nos. 1, 3, and 4 were not significantly different in effectiveness at the first weekly reading, but after 3 weeks No. 1 was definitely superior to the other treatments. All these materials have since been superseded by better repellents or ones less toxic to plants. These results are presented merely to illustrate the way in which the various materials were compared and evaluated. In later years similiar procedures were followed with data obtained from materials applied to carrots.

Considerable encouragement was given the project in 1936, when the DuPont chemical company furnished some organic sulfur compounds for trial. Among them were preparations containing 80 percent of tetramethylthiuram disulfide in powder form and 50 percent of tetraethylthiuram monosulfide in liquid suspension. Both proved to have pronounced rabbit repellent qualities. For several years after their repellency was discovered there was no commercial source of these two compounds. Consequently there was no way to determine whether they would be practical for use as rabbit repellents. Later, a preparation containing 50 percent of tetramethylthiuram disulfide was put on the market as a fungicide under the name of Arasan. At present there are two additional preparations sold under the names of Arasan SF–X and Tersan 75, each containing 75 percent of tetramethylthiuram disulfide. Their prices make these products practical for use in protecting plantations of trees and shrubs from rabbits. Tetraethylthiuram monosulfide is not yet in commercial production.

In an experiment in which some of the repellent materials were compared by applying them to carrot pieces and exposing them in places frequented by rabbits, the following degrees of damage were obtained:

Ingredients and treatment number:	Degree of damage[1]
1, Copper carbonate, copper sulfate, dry lime-sulfur, synthetic resin, and ethylene dichloride. Formula 96a (*30*)	4.5
2, Rezyl, ethylene dichloride, copper carbonate, lime-sulfur, asphalt emulsion (*2*)	4.6
3, Asphalt emulsion, wood alcohol, copper carbonate (*2*)	4.0
4, Asphalt emulsion, diatomaceous earth, lime-sulfur (*2*)	2.0
5, Resin and ethyl alcohol (*87*)	5.0
6, Nicofume, 1 part: asphalt emulsion, 10 parts	1.0
7, Tetraethylthiuram monosulfide, 1 part: asphalt emulsion, 10 parts	1.5
8, Tetramethylthiuram disulfide, 1 part: asphalt emulsion, 10 parts	2.0
9, Control (untreated carrot pieces)	5.0
Difference required for significance:	
5 percent level	1.84
1 percent level	2.50

[1] Mean of four replications.

Treatments Nos. 1, 2, 3, and 5 were not significantly better than No. 9, the untreated control, while treatments Nos. 4, 6, 7, and 8 were not eaten by rabbits to a significant extent. Toxicity tests showed that treatments Nos. 1, 2, and 4 caused injury to tomato plants. As will be seen from this experiment, as well as from the evaluation of materials in the appendix, most preparations were deficient in some respects as rabbit repellents.

OUTSTANDING REPELLENT MATERIALS

After the tests had eliminated all preparations that showed little or no repellency and those that proved toxic to plants, there remained only four outstanding repellent materials. They were the preparations of tetramethylthiuram disulfide and tetraethylthiuram monosulfide and two commercial nicotine insecticides—Nicofume containing 40 percent of nicotine in solution, and Black Leaf 40 containing 40 percent of nicotine in the form of a nicotine sulfate solution. Each of these four materials when mixed in the proper proportions with a suitable carrier seemed to meet most of the requirements of a satisfactory rabbit repellent. Nicofume, tetramethylthiuram disulfide, and tetraethylthiuram monosulfide mixed readily with emulsions of asphalt and synthetic plastics. However, nicotine sulfate, being acid, broke the emulsions of asphalt. It was found that this difficulty could be prevented by adding to the asphalt emulsion a stabilizer such as Carbowax or one of the household detergents. Stabilizers were not needed when nicotine sulfate was mixed with synthetic plastic emulsions.

Preparations Containing Nicotine

As the repellent action of a nicotine preparation depends upon the amount of nicotine in the application, it was desired to determine the loss of nicotine during mixing and application and after the treatments had aged. Mixtures of Nicofume and of nicotine sulfate were prepared with known amounts of nicotine in asphalt emulsion with and without a stabilizer. These preparations were spread on sticks and exposed in the laboratory. Samples were analyzed for nicotine immediately after application and at intervals thereafter. As nicotine volatilizes readily in alkaline solution the pH of each mixture was determined and the value included in the table. Results of these analyses are shown in table 2.

TABLE 2.—*Recovery of nicotine from mixtures prepared with known amounts of nicotine in asphalt emulsion*

Mixture	pH	Nicotine recovered on—			
		Jan. 5 [1]	Jan. 26	Feb. 16	Apr. 1
		Percent	*Percent*	*Percent*	*Percent*
Asphalt emulsion and water plus—					
Nicofume	9.4	78.3	72.9	64.4	57.6
Nicofume, Carbowax, acid [2]	6.9	97.3	86.5	83.8	73.0
Nicotine sulfate plus—					
Carbowax	5.7	100.0	88.9	77.8	74.1
Dreft	6.8	93.4	67.2	67.2	65.6
Trend	6.8	96.7	95.1	95.1	86.9
Surf	7.6	96.7	68.8	68.8	65.6
Vel	6.8	82.0	78.7	73.8	65.6
Fab	7.4	95.1	62.3	55.7	47.5
Cheer	7.4	91.8	65.6	63.9	59.0
Mixtures above pH 7.0 (average of 4 samples)		90.5	67.4	64.4	57.4
Mixtures below pH 7.0 (average of 5 samples)		93.9	83.3	79.5	73.0

[1] Sampled immediately after being mixed and applied.
[2] Metaphosphoric acid added to lower pH to acid side.

Each of the mixtures initially contained approximately 1 part of nicotine alkaloid to 25 parts of other ingredients. For purposes of calculation the quantity of nicotine in each mixture was considered as 100 percent. As will be seen from the percentages recovered immediately after application (Jan. 5), most mixtures lost appreciable nicotine during mixing and application. All applications showed a reduction in nicotine on aging. Alkaline mixtures generally lost nicotine more rapidly and in greater amounts than did acid preparations. Over a period of about 3 months the loss in alkaline mixtures ranged from 34.4 to 52.5 percent as compared with 13.1 to 34.4 percent in acid mixtures.

It is evident, however, that the kind of detergent used to stabilize the asphalt emulsion may influence the loss of nicotine regardless of the pH of the mixture. For example, with nicotine sulfate, Trend produced a mixture having a pH of 6.8 which, over a period of about 3 months, lost only 13.1 percent of its nicotine. Vel also gave a mixture of pH 6.8, but this preparation lost 34.4 percent of its nicotine in the same period. Again, two detergents Surf and Vel produced mixtures each of which lost 34.4 percent of their nicotine. However, the mixture made with Surf had a pH of 7.6, while the one made with Vel had a pH of 6.8. All the household detergents tested stabilized the emulsions satisfactorily, but the effect on the retention of nicotine in the mixture varied with the detergent used.

Both of the commercial nicotine preparations found to be effective rabbit repellents contained 40 percent of nicotine in solution. Repeated tests with different concentrations showed that 1 part of nicotine preparation to 10 parts of asphalt emulsion-water mixture made a satisfactory repellent. In this proportion the mixture contained 3.63 percent of nicotine, the active ingredient. Repellency decreased rapidly as the concentration was lowered below this percentage. The proportion of water required with the asphalt emulsion to give the desired consistency will vary with the different brands of asphalt emulsion. When Nicofume is used as the source of nicotine without acidification, about 2 parts of the commercial preparation should be used to 10 parts of the asphalt emulsion-water mixture, if a long-lasting repellent is desired.

As previously mentioned, where nicotine sulfate is used with asphalt emulsion it is necessary to add a stabilizer to maintain the emulsion. It was found that 1 part of household detergent to 10 parts of asphalt emulsion gave satisfactory results, when 10 parts of this mixture was combined with 1 part of nicotine sulfate (proportions by weight). It is believed that the ineffective results obtained by Cardinell and Hayne (*16*) with 1 part of the nicotine sulfate preparation to 15 parts of asphalt emulsion were due to the low concentration of nicotine in the mixture and also to the fact that no stabilizer was employed. Without a stabilizer the asphalt tends to separate from the water solution of nicotine sulfate, and thus freed from the protective asphalt film, the nicotine would soon evaporate from the trees.

For the last 18 years nicotine-asphalt preparations have been used by personnel of the Cheyenne Horticultural Field Station and by several cooperators to protect orchards, windbreaks, and ornamental plantings from bark-gnawing by rabbits. No significant rabbit damage has been found on trees properly coated with these materials and one application in the fall has sufficed to give protection over winter.

Preparations Containing Organic Sulfur

Experiments proved that to be effective a repellent containing tetramethylthiuram disulfide should contain 7.27 percent of the active ingredient. Repellency was not significantly increased at higher concentrations but decreased as the content was lowered below this percentage. Repellent mixtures having approximately this concentration of tetramethylthiuram disulfide can be made with the three commercial fungicides as follows (proportions are by weight):

Arasan, 1 part: asphalt emulsion-water mixture, 6 parts.
Arasan SF–X or Tersan 75, 1 part: asphalt emulsion-water mixture, 9 parts.

The Arasan preparation is for application with a brush only. It is not possible to thin this mixture to a spraying consistency without the active ingredient being diluted below the effective concentration. Arasan SF–X or Tersan 75 can be used as sources of tetramethylthiuram disulfide for preparations to be applied as sprays.

The amount of water in the asphalt emulsion-water mixture required to give the proper consistency will depend upon the ingredients used and the method of application. For example, Arasan 1 part to 6 parts of the asphalt emulsion-water mixture will require more water than Arasan SF–X or Tersan 75, 1 part to 9 parts of asphalt emulsion-water mixture. Also, different brands of asphalt emulsion contain different amounts of water. Of course, mixtures to be sprayed require more water than those intended for brushing. It is not possible, therefore, to give exact amounts of water and asphalt emulsion to be used, but only the proportion of the repellent to the asphalt emulsion-water mixture. In order to obtain the desired consistency it will be necessary to do some experimenting with the materials selected.

The tetraethylthiuram monosulfide preparation used in these studies contained 50 percent of the active ingredient. Experiments showed that 1 part of this preparation mixed with 10 parts of asphalt emulsion made an effective repellent. On this basis a concentration of about 4.5 percent of tetraethylthiuram monosulfide is required in a repellent application.

Present retail prices of the ingredients make these outstanding repellent mixtures practical for general use and their preparation is so simple that any plant grower can make a satisfactory repellent. It is hoped, however, that commercial preparations embodying these materials eventually will appear on the market.

SUMMARY

Damage from rabbits is a limiting factor in the growing of trees and shrubs. Probably the cheapest and most effective means of protection from these pests is a chemical repellent that can be applied to the plants either with a brush or as a spray. During the last 22 years the Cheyenne Horticultural Field Station, near Cheyenne, Wyo., has screened a great many materials and mixtures in different concentrations for repellency to rabbits.

At first, comparisons were made with rabbits confined in a corral in which were growing young elm trees coated with the test materials. Later, carrot pieces treated with the test materials were exposed in rabbit-infested areas. Nearly all these materials proved to be unsatisfactory for protecting trees because of toxicity to plants, insufficient repellency, or both.

Four materials were found, however, that met most of the requirements of a satisfactory repellent—nicotine, nicotine sulfate, tetramethylthiuram disulfide, and tetraethylthiuram monosulfide. The first three materials are available in commercial insecticides or fungicides. Tetraethylthiuram monosulfide is not yet in commercial production. Water emulsions of asphalt or of certain synthetic plastics proved to be suitable vehicles for any of these repellents. Formulas for making repellent mixtures are given.

The present cost of the ingredients makes it practical to protect plantings with one of these preparations, and the ease of compounding from readily available commercial materials makes it feasible for a tree grower to prepare his own repellent.

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APPENDIX—EVALUATION OF PRINCIPAL MATERIALS TESTED

Acrylic resin emulsion. Not repellent.

Aloes (Cape), 1 part of powder to 8 parts of asphalt emulsion-water mixture. Not repellent.

Aluminum paint (commercial). Attractive to rabbits, toxic to plants.

Aluminum sulfate, 1 part to 2 parts of asphalt emulsion-water mixture. Slight repellency, toxic to plants.

Ammonium valerate, water. Not repellent.

Amorpha bark (*Amorpha fruticosa fragrans*), infusion mixed with asphalt emulsion. Repellent for only about a week. Powdered dry bark, 1 part to 16 parts of asphalt emulsion-water mixture. Not repellent.

Asafetida, 1 part to 11 parts of asphalt emulsion. Not repellent.

Asphalt emulsion. Various dilutions. Fair repellency, nontoxic to plants.

Asphalt emulsion (green). Less repellent than black asphalt emulsion, nontoxic to plants. Repellents mixed with green asphalt emulsion were less repellent than with black asphalt emulsion.

Beeswax emulsions (laboratory made). Not repellent.

Benzyl disulfide, 1 or 2 parts to 12 parts of asphalt emulsion. Not repellent. Very offensive odor.

Benzyl mercaptan, mixed with asphalt emulsion in many concentrations. Repellent only about a week, a residue being left that was apparently attractive to rabbits, slightly toxic to plants. Stench objectionable in handling.

Blood, dried (fertilizer), mixed to painting consistency with water. Not repellent, not adhesive. Mixed with asphalt emulsion, not repellent.

Blood, rabbit, applied fresh. Not repellent.

Bone oil (commercial). Very toxic to plants.

Bordeaux dust (commercial fungicide), mixed with asphalt emulsion and water to painting consistency. Slight repellency.

Bye Bye Blackbird (commercial crow repellent). Not repellent to rabbits.

Carnauba wax emulsion (laboratory made). Not repellent.

Caustic waste (waste product of oil refinery, containing many waste materials washed from gasoline and oils), mixed with asphalt emulsion to painting consistency. Not repellent, toxic to plants.

Cedar oil. Not repellent.

Clove oil. Not repellent.

Coal tar. Good repellent, very toxic to plants.

Copper compound (waste product of oil refinery, containing copper compounds), mixed with asphalt emulsion to painting consistency. Very good repellent, toxic to plants.

Copper soap (copper salt of linoleic or stearic acid). Good repellent, toxic to plants.

Copper soap, 3 parts; linseed oil, 3 parts; resin, 7 parts.[3] Slight repellency, toxic to plants.

[3] Formula developed by the U. S. Fruit Disease Field Laboratory, Hood River, Oregon.

Corona Mouse and Rabbit Repellent (a commercial sulfonated linseed oil preparation). Fair repellency, toxic to plants.

Crystal No-Dry (commercial wax emulsion). Not repellent.

Cupric carbonate, 7 parts: asphalt emulsion, 4 parts: water to painting consistency. Slight repellency, nontoxic to plants.

Cupric carbonate, mixed to painting consistency with linseed oil. Good repellent, very toxic to plants.

Cupric carbonate mixed with asphalt emulsion and water to give a preparation containing approximately 10 percent of copper. Slight repellency. Nontoxic to plants.

Cupric chloride mixed with asphalt emulsion and water to make a preparation containing approximately 5.5 percent of copper. Fair repellency, very toxic to plants.

Cupric oxide mixed with asphalt emulsion and water to make a preparation containing approximately 10 percent of copper. Good repellent, toxic to plants.

Cupric sulfate, 1 part; asphalt emulsion, 1 part; water to painting consistency. Fair repellent, very toxic to plants.

Cupric sulfate, mixed with asphalt emulsion and water to make a preparation containing approximately 7 percent of copper. Good repellent, toxic to plants.

Cuprous oxide, 2 parts; asphalt emulsion, 1 part: water to painting consistency.[2] Good repellent, nontoxic to plants.

Dayton Tree Saver (commercial repellent for dogs and rodents). Not effective against rabbits.

1,3-diphenylguanidine salt with dimethyl dithiocarbamic acid. Not repellent.

Dawg-gone (commercial repellent for dogs and rodents). Not effective against rabbits.

Dog-away (commercial repellent for dogs and rodents). Not effective against rabbits.

Dogzoff (commercial preparation advertised as a repellent for dogs and rabbits). Fair repellency against rabbits.

Dowax (commercial wax emulsion). Not repellent, nontoxic to plants.

Elesar (commercial material, being a waste product in the manufacture of lime-sulfur spray). Mixed with asphalt emulsion to painting consistency. Good repellent, nontoxic to plants.

Elesar, mixed to painting consistency with linseed oil. Not repellent.

Ethyl mercaptan, mixed with asphalt emulsion in different concentrations. Repellency lasted about a week. Stench objectionable in handling.

Fermate (commercial fungicide containing 76 percent of ferric dimethyl dithiocarbamate), 1 part to 10 parts of asphalt emulsion. Not repellent.

Ferric chloride, mixed with asphalt emulsion to make a preparation containing approximately 4.5 percent of iron. Slight repellency, very toxic to plants.

[2] Cuprous oxide-asphalt emulsion mixtures are not practical for spraying, as the copper oxide quickly settles out of the diluted preparation, making it almost impossible to agitate the mixture sufficiently to insure a uniform application

Ferric hydroxide, mixed with asphalt emulsion to make a preparation containing approximately 9 percent of iron. Slightly repellent, nontoxic to plants.

Ferric sulfate, mixed with asphalt emulsion to make a preparation containing approximately 7 percent of iron. Slight repellency, toxic to plants.

Ferrous sulfate, 1 part; asphalt emulsion, 2 parts; water to painting consistency. Good repellent, toxic to plants.

Ferrous sulfide, mixed with asphalt emulsion to make a preparation containing approximately 5 percent of iron. Slight repellency, nontoxic to plants.

Fish and Wildlife Service formula 96a (*86*), containing copper carbonate, powdered copper sulfate, and dry lime-sulfur as active ingredients, asphalt emulsion and a synthetic resin as adhesives, and ethylene dichloride as the thinner. Not effective in repelling rabbits when applied to carrots, although some cooperators report favorable results when applied to trees. Toxic to plants.

Fish and Wildlife Service formula (*35*) containing Rezyl 53, ethylene dichloride, asphalt emulsion, copper carbonate, and lime-sulfur. Slight repellency, toxic to plants.

Fish and Wildlife Service formula (*35*) containing asphalt emulsion, methanol, and copper carbonate. Slight repellency, slightly toxic to plants.

Fish and Wildlife Service formula (*35*) containing asphalt emulsion, diatomaceous earth, lime-sulfur (dry), and water. Good repellent, very toxic to plants.

Fish oil and Duco 246-0091. Fairly repellency, toxic to plants.

Glue (animal). Attractive to rabbits.

Glue (casein), mixed with water to painting consistency. Not repellent.

Hood River Tree Paint[3] (commercial preparation). Fair repellency.

KOR Keeps Off Rabbits (commercial preparation). Not effective in these tests.

Lard. Not repellent.

Lime-sulfur (liquid). Good repellent, but toxic to growing plants when used in concentrations necessary to repel rabbits.

Lime-sulfur and fish oil soap. Fair repellent, toxic to plants.

Lime-sulfur and glue. Slightly repellent.

Lime-sulfur (dry), mixed to painting consistency with asphalt emulsion-water mixture. Good repellent, toxic to plants.

Lime-sulfur (dry), mixed to painting consistency with linseed oil. Slightly repellent, toxic to plants.

Lime-sulfur (dry), 5 parts; copper sulfate, 3 parts; asphalt emulsion, 6 parts. Slightly repellent, slightly toxic to plants.

Naphthalene (moth balls), mixed with various oils and other carriers. Not repellent.

Naphthalene, resin, and linseed oil. Not repellent.

Nicofume (commercial insecticide containing 40 percent of nicotine). Tested in many concentrations: 1 part to 10 parts of asphalt

[3] Hood River Tree Paint was made by the Hood River Spray Company (now defunct), according to the unpatented formula: 140 pounds of resin, 5 pounds of copper carbonate (50-55 percent), 60 pounds of fish oil, 6 gallons of light lubricating oil. This formula was furnished through the courtesy of LeRoy Childs.

emulsion was an excellent repellent but nicotine was volatilized rapidly in alkaline mixture; 2 parts to 10 parts of asphalt emulsion made the repellent longer lasting. Nontoxic to plants.

Nicofume, 1 part; vinyl resin or acrylic resin emulsion, 10 parts. Good repellent, nontoxic to plants.

Nicotine dust (commercial insecticide containing 3 percent of nicotine), mixed with asphalt emulsion and water to painting consistency. Fair repellency, nontoxic to plants.

Nicotine sulfate (Black Leaf 40, commercial insecticide containing 40 percent of nicotine in the form of nicotine sulfate). Tested in many concentrations; 1 part to 10 parts of asphalt emulsion with an emulsion stabilizer added was an excellent repellent; nontoxic to plants.

Nicotine sulfate (40 percent of nicotine) 1 part, plus—

- Vinyl resin or acrylic resin, 10 parts. Good repellent, nontoxic to plants.
- Fish oil, 10 parts. Excellent repellent, toxic to plants.
- Fish oil, 20 parts. Fair repellent, toxic to plants.
- Fish oil, 10 parts; resin, 20 parts. Good repellent, toxic to plants.
- Glue. Not repellent.
- Slaked lime, 14 parts; melted glue, 15 parts; water, 12 parts. Not repellent.
- Linseed oil. Good repellent. Toxic to plants

Nicotine sulfate (40 percent of nicotine) mixed with asphalt emulsion was combined with various other materials in different combinations and concentrations, including benzyl mercaptan, sodium xanthate, tetramethylthiuram disulfide, tetraethylthiuram monosulfide, and fermate, without significantly improving its repellent properties.

No-nibl (commercial preparation containing 22 percent of zinc dithiocarbamate amine complex), 1 part to 1 part asphalt emulsion. Not repellent to rabbits.

Paint (Wyoming Highway Department Road Striping). Slight repellency. Toxic to plants.

Paraffin. Many different types of emulsions were prepared and tested as carriers and attractants. Regardless of repellent added the preparations were attractive to rabbits.

Peanut oil. Not repellent.

Pepper (Cayenne), mixed with asphalt emulsion in various concentrations. Not repellent.

Pick up gum (commercial preparation). Not repellent, not durable as a carrier.

Pine tar. Fair repellent.

Polyethylene polysulfide (P. E. P. S.). Not repellent.

Poppy seed oil. Not repellent.

Resin-ethyl alcohol (*17*). Not repellent when applied to carrots, nontoxic to plants.

Resin and fish oil. Fair repellent, toxic to plants.

Resin-linseed oil (*60*). Fair repellent, toxic to plants.

Resinous materials prepared as emulsions, including balsam of Peru, canada balsam, guaiacum, and rosin. Not repellent.

Rezyl (commercial synthetic resin, not emulsified). Attractive to rabbits.

Rodent repellent (commercial product of Castle Chemical Co.) Slight repellency.

Rosin oil. Not repellent.

Rubber latex (trade name "Natureseal"). Fair repellency, toxic to plants.

Rubber latex and 5 percent of nicotine sulfate solution containing 40 percent of nicotine. Fair repellent.

Sodium silicate solution (water-glass). Ineffective.

Stanley's Crow Repellent (commercial preparation). Fairly repellent to rabbits.

Styrene resin emulsion. Toxic to plants. Not repellent.

Sulphonal (commercial repellent). Lacked adhesiveness. Repellency inconsistent, fair in some cases, ineffective in others.

Sulfonated castor oil. Ineffective.

Sulfonated corn oil. Ineffective.

Sulfonated linseed oil. Many commercial brands tried, also many batches prepared according to the formula of the originator (*30*). Very toxic to tomato plants and many reports received of injury to trees. Repellency inconsistent—sometimes good, sometimes poor. Rated only fair repellent in these tests.

Sulfonated olive oil. Ineffective.

Sulfonated rape seed oil. Slightly repellent.

Sulfur and asphalt emulsion. Fair repellency.

Sulfur, 1 part: rubber latex, 5 parts. Fairly repellent.

Sulfur, 5 lbs.: soap powder, 20 oz.: asafetida, ½ pt.: hot water to make a paste.[1] Not effective in these tests.

Tankage (fertilizer), mixed with water. Not repellent.

Tannic acid in water. Not repellent.

Tetraethylthiuram monosulfide, mixed with asphalt emulsion in various concentrations: 1 part to 10 parts made an excellent repellent, nontoxic to plants.

Tetraethylthiuram monosulfide in asphalt emulsion mixed with other materials in different concentrations and combinations, including benzyl mercaptan, nicotine sulfate solution, sodium xanthate, and tetramethylthiuram disulfide, without significantly improving its repellency.

Tetramethylthiuram disulfide, mixed with asphalt emulsion in various concentrations: 1 part to 10 parts made an excellent repellent, nontoxic to plants.

Tetramethylthiuram disulfide, 1 part: vinyl resin or acrylic resin, 10 parts. Fair repellent, nontoxic to plants.

Tetramethylthiuram disulfide in asphalt emulsion, mixed with other materials in different concentrations and combinations, including benzyl mercaptan, nicotine sulfate solution, sodium xanthate, and tetraethylthiuram monosulfide, without significantly improving its repellency.

Tremco 113 (commercial tree surgery compound). Slight repellency.

Tremco 121 (commercial tree surgery waterproofing compound). Not repellent.

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[1] Formula furnished through the courtesy of D. W. Moffat, Mt. Arbor Nurseries, Shenandoah, Iowa.

Tremco 909 (commercial grafting and budding compound). Little or no repellency.

Trinitrobenzene-aniline complex in asphalt emulsion, 1 part to 10 parts. Fair repellency, toxic to plants.

Vinyl resin emulsion. Not repellent.

Wax (commercial floor wax emulsion). Not repellent.

Wax-Lac (commercial Carnauba wax emulsion). Not repellent.

Wool fat (crude). Not repellent.

Xanthates—sodium, potassium, pentasyl, and butyl—mixed with asphalt emulsion in many concentrations. Not repellent.

Zinc carbonate in asphalt emulsion. Fairly repellent, toxic to plants.

Zinc sulfate mixed with asphalt emulsion and water to painting consistency. Fair repellency, toxic to plants.

Z. I. P. (commercial preparation containing 30 percent of zinc dithiocarbamate amine complex in polyethylene polysulfide). Tested alone and in concentrations of 1:1, 1:2, 1:5, and 1:10 in asphalt emulsion. Concentrations of 1:1 and 1:2 slightly repellent to rabbits.

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