UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

St. Johnswort on Range Lands of California

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BULLETIN 503
DECEMBER, 1930

UNIVERSITY OF CALIFORNIA PRINTING OFFICE
BERKELEY, CALIFORNIA

Berkeley, California,
November 26, 1930

His Excellency
Honorable C. C. Young,
Governor of the State of California,
Sacramento, California.

Dear Sir:

I have the honor to transmit to you a report on Hypericum perforatum or St. Johnswort on Range Lands of California, prepared in accordance with Chapter 639 of the Statutes of 1929, approved June 1, 1929, by Doctor A. W. Sampson, Associate Professor of Forestry and Plant Ecologist in the Experiment Station and Mr. Kenneth W. Parker, Technical Assistant in Forestry, of the staff of our College of Agriculture.

Enough has been accomplished by this study to prove that St. Johnswort is one of the most serious pests found on pasture and range lands in California and to indicate certain control measures which appear to be feasible, but further studies should be conducted to determine definitely the longevity of stands of St. Johnswort—the most practical means of controlling and eradicating the pest; and its replacement by forage vegetation under rational range management.

Yours very truly,
Robert G. Sproul.

ST. JOHNSWORT ON RANGE LANDS OF CALIFORNIA

ARTHUR W. SAMPSON[1] AND KENNETH W. PARKER[2]

St. Johnswort (*Hypericum perforatum* L.), best known to stockmen of California as Klamath weed,[3] is probably the cause of the heaviest financial losses found on pasture and range lands of California. Approximately thirty years ago a few stockmen in Del Norte, Siskiyou, and Humboldt counties first observed an occasional small colony of St. Johnswort on their pastures. A few years later the grass vegetation surrounding these early invasions was practically replaced by this weed pest. Extension of the plant has been conspicuous on pasture areas, until in 1930 it is conservatively estimated that it occupies over 100,000 acres of pasture land in the state. In some localities it has replaced most of the herbaceous plant cover and has caused enormous losses in grazing capacity. Each year the area of infestation increases and the plant secures a firmer foothold. St. Johnswort has no forage value, except, limitedly, for goats, and is poisonous to livestock generally. Furthermore, its presence creates a serious fire hazard to adjoining forage and timber.

In August, 1929, a fund of $3,000 was made available by the Legislature (Assembly Bill 1137) to investigate methods of eradicating and controlling the spread of St. Johnswort.[4] The study, outlined and conducted during the past fifteen months, included consideration of the following points: the geographical distribution of this plant in the state and its occurrence elsewhere; the soil and general edaphic conditions favoring its growth and reproduction; morphological and anatomical characteristics of the species insofar as they appear to influence control methods; the succession or rate at which invasions take place; its period of life, and the reproduction of the species in different range types; control measures, including the uses of sprays and seasons of application; and the effect of different grazing systems on suppression.[5]

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[3] Other common names are herb of St. John, Johnwort, speckled St. John, Doolittle weed, goatweed, goldenwire, goatbeard, Tipton weed, and rosin rose.

[4] Kenneth W. Parker, formerly graduate student of the Division of Forestry, University of California, was appointed to assist the senior author in carrying out the details of this study.

[5] The problem of controlling St. Johnswort in Humboldt County was recognized by the Division of Agricultural Extension of the University of California a number of years ago, and various methods of eradication of the plant were tested under the supervision of the farm advisor, J. W. Logan.

It is the aim of this report to review briefly the facts known of St. Johnswort as it bears on the problem confronting stockmen; to summarize the results of a year's study as above outlined; and, finally, to attempt to apply these results to the problem of control and suppression of the plant.

IDENTIFICATION OF ST. JOHNSWORT

St. Johnswort (*Hypericum perforatum* L.) is a smooth, freely branching, erect perennial herb, with stems 1 to 5 feet high, herbaceous above, but woody at the base, terminating above in a dense cyme of showy yellow flowers. There are numerous sterile shoots at the base, and below there are strong runners and a much branched extensive root system. The younger stems are two-edged, with a pair of lateral leaf-like wings. The leaves are numerous, opposite, light green, somewhat involute—indicating drought enduring characteristics—narrow (linear), ½ to 1 inch long, ⅛ inch wide. They are pointed at the tip and slightly narrowing at the base, and are stemless (sessile), with dark glands appearing as small translucent dots along the leaf margins. The flowers are numerous, in loose cymes, individual flowers being ⅔ to 1 inch broad; petals 5, sharp-pointed, ⅜ to ½ inch long, with margins of dark glands; sepals 5, green, much shorter than the petals; stamens numerous, in 3 to 5 clusters by union of the stalks, the anthers with dark glands; ovary not lobed, bearing 3 spreading styles and developing into a seed pod or capsule to which the stamens and petals adhere, giving the plant an unkempt appearance. At maturity the capsule breaks into three parts, liberating numerous small, cylindrical, pitted, dark brown seeds (fig. 1).

Four other species, two being annuals, occur in the state. *Hypericum perforatum* may be distinguished from these by the numerous short sterile shoots of the stem, the lanceolate sepals, and the non-lobed capsule.

DISTRIBUTION AND HABITAT

The earliest reference in this country to St. Johnswort as a pernicious pasture plant was reported from Pennsylvania by Pursh[21] in 1814, but Muhlenberg[17] as early as 1793 listed this plant as occurring in Lancaster, Pennsylvania. In the same year Barton[3] referred to St. Johnswort as being an introduced species. Similar statements followed, as by Darlington[7] in 1826, by Morrell[16] in

1845, and many others in later years. Although the plant now occurs extensively in Washington, Piper[19] in 1906 stated that Vancouver was the only locality where he had observed it in the Northwest.

Fig. 1.—St. Johnswort (*Hypericum perforatum* L.). Generalized sketch of plant: *A*, flower; *B*, capsule; *C*, seed; *D*, root crown.

Regarding carriers which resulted in the introduction of the species on the Pacific coast, Marsh and Clawson[15] state that "Probably the Oregon Trail pioneers of the forties and fifties carried the seeds from the Northeastern States to the Willamette Valley,

Oregon." This might account for its introduction, but when one considers the aggressiveness of the plant it would not be surprising if its original foothold came about considerably later. Since the earliest infestations in California were in the most northerly counties, it seems probable that seed, and possibly vegetative parts of St. Johnswort, were carried from the Klamath River region, possibly by way of water transportation, spreading from Del Norte County southward.

In California St. Johnswort is now widely distributed over the northern portion, occupying large areas in the counties of Del Norte, Siskiyou, Modoc, Humboldt, Trinity, Shasta, Lassen, and Tehama. Younger and more scattered invasions are found in the counties of Mendocino, Glenn, Butte, Yuba, Nevada, Sacramento, Calaveras, Tuolumne, and Santa Cruz, the last mentioned representing the most southern range known (fig. 2). The most recent invasions observed are in Anderson Valley in Mendocino County, where some 300 acres of grassland have within the last two or three years given way to St. Johnswort, and in Santa Cruz County.

Invasions of very serious proportions occur on pasture lands throughout most of western Oregon and western Washington, and to a lesser extent, although appearing to be increasing rapidly, in parts of Idaho, Montana, and Utah. Aside from the far western states named, the range of the plant in North America is from St. John's, Newfoundland, to western Ontario; south to Virginia and the southern Appalachians; westward to North Dakota, northeastern Iowa, Missouri, and Texas. Although found in the eastern and some of the middle western states many years ago, this plant has never given serious trouble either in cultivated fields or in farm pastures. Likewise in its native habitat of Europe, it has not been a serious menace to agriculture, except on a few restricted pasture areas, chiefly because its spread has been kept in check by certain insect enemies. It occurs commonly in France, Germany, and Finland.

In Australia, where intensive studies are now under way to destroy the stands and control its spread, St. Johnswort has become a serious weed. In Victoria, especially, heavy financial losses are incurred, the infested area being between 250,000 and 400,000 acres. Studies of methods of eradication of this plant constitute one of the major problems of the Division of Entomology of the Commonwealth of Australia.

St. Johnswort occurs most commonly and develops best on open grasslands, where it occupies all slopes and exposures with nearly equal vigor and density. It grows in diversified soil types, occupying rather dry to moist soils; it gives way on water-logged areas. Although

it is not restricted to soils of either acid or alkaline reaction, unusually luxuriant growth and dense stands are nevertheless found on soils of distinctly acid reaction (pH 5 to 6.5). Very vigorous growth has not been observed to occur on strongly alkaline soils. Whether this plant is

Fig. 2.—Distribution of St. Johnswort in California. Stars indicate isolated localities where the weed has obtained a foothold.

likely to occupy soils neutral or slightly alkaline in character might be indicated from artificially prepared cultures. Plants sprouted from runners and grown in nutrient solution of varying degrees of acidity and alkalinity, developed much more vigorously in a rather acid medium (pH 6) than in alkaline cultures. Indeed, in acid cultures (pH 6) the plants flowered profusely, whereas in the alkaline cultures

no flowers were formed and the plants were small and the foliage light green. Plants grown in strongly acid cultures (pH 3 to 4) died. These experiments would appear to indicate that the plant prefers at least slightly acid soils and may not become serious on soils of medium to high alkalinity.

The plant typically secures a foothold on denuded slopes and semi-exposed soils. On eroded areas where the upper, mellow soil horizon has been removed it readily becomes established, produces seed, and reproduces; but it also occupies soils of the highest fertility, such as where the upper soil horizon is well developed (fig. 3). Although

Fig. 3.—St. Johnswort forms a complete cover on fertile soils. The former grazing capacity of this area was high. Now it is of no value for pasture.

stands are quickly established on abandoned plowed fields, untilled or natural pastures are favorable sites.

St. Johnswort requires abundant light for its best development. It never grows vigorously in heavy timber or in dense brush fields. In shaded areas the stands are sparse and of weak growth. On open grassland it competes successfully with all types of herbaceous vegetation, including even sod grasses. Destruction of the grass is caused by shading, root competition, and insufficient soil moisture.

The elevational range is from sea level to about 5,000 feet above the sea. The densest and most extensive stands are usually found only a few hundred feet above sea level. In Humboldt County a fairly vigorous cover occurs along the ocean front, this area, however, being one of the few on record as growing practically at sea level. At elevations of 4,000 feet and higher the stand is open and the growth

distinctly less rugged than at lower altitude. For completion of its life cycle—germination or vegetative reproduction, normal rate of growth, flowering, fruiting, and maturity of seed—a moderately warm and long growing season is required. Under the best conditions for growth seed seldom matures until late in August—indeed, little seed ripens until September and October. Accordingly, this plant is not likely to become established in the higher mountains (Boreal life zone) as on National Forest range, or other such elevated lands of the state.

LOSS FROM LIVESTOCK POISONING

As early as 1787 Cirillo[6] observed that St. Johnswort was poisonous to white sheep and to white cattle or to cattle with areas of unpigmented skin. Since that time numerous observations and studies pertaining to the toxicity of this plant have been conducted in various parts of the world. Many are the reports that domestic livestock feeding upon this plant developed dermatitis or blistering on unpigmented areas and that the animals became sick and often died. Poisoning of domestic livestock was reported in Pennsylvania by Darlington[7] as early as 1826. Since that time other reports of poisoning in the United States have been made, but none of these has been supported by experimental fact.

In northern California a proportion of the sheep grazed on areas heavily infested with St. Johnswort have each year, for a decade or more, been reported as sick animals. These reports have come particularly at shearing time in July, and again at the time of sorting and culling prior to breeding in September, when the animals are closely inspected. The sick animals typically exhibit blistering, and a scabby condition about the nose, muzzle, eyes, and ears. The ears may swell to many times their natural size, portions sometimes actually sloughing off. In more severe cases, the animals lose their sight or their mouths become so sore that they die from starvation (fig. 4). In still other instances they are seriously emaciated, with scabby skin about the legs, face, neck, withers, and back—even to sloughing of wool on affected areas (fig. 5). Immediately after shearing, provided the day is sunny, a goodly proportion of a band will rub, bite, lick, and run as though crazed, the itching sensation apparently being so severe. In three or four days these reactions become less intense.

Although the plant is eaten by sheep, particularly in the spring when the growth is tender, it is never highly relished where good forage is available. And it is grazed even to a less extent by cattle.

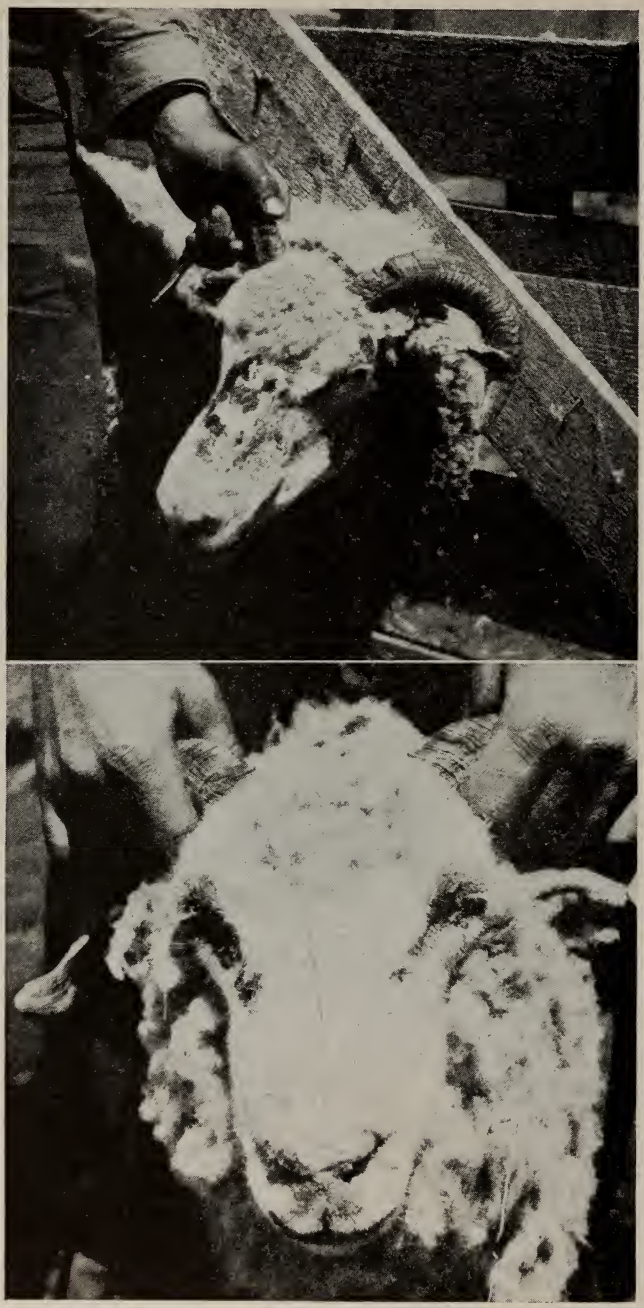

Fig. 4.—Dermatitis is rather common on unpigmented areas of sheep grazed on infested pastures. Upper: the blistering causes the animals to rub and butt, forming heavy scabs and sores. Lower: many animals have sore ears, face, nose and eyes. Blindness occurs in severe cases, resulting in malnutrition and death on the range.

Both sheep and cattle, however, consume varying amounts of the weed where the forage cover has been crowded out. Incidentally, it should be said that the weed is eaten with considerable relish by goats and is taken with even greater gusto by deer. Accordingly, stockmen have been eager to know to what extent it was advisable to guard

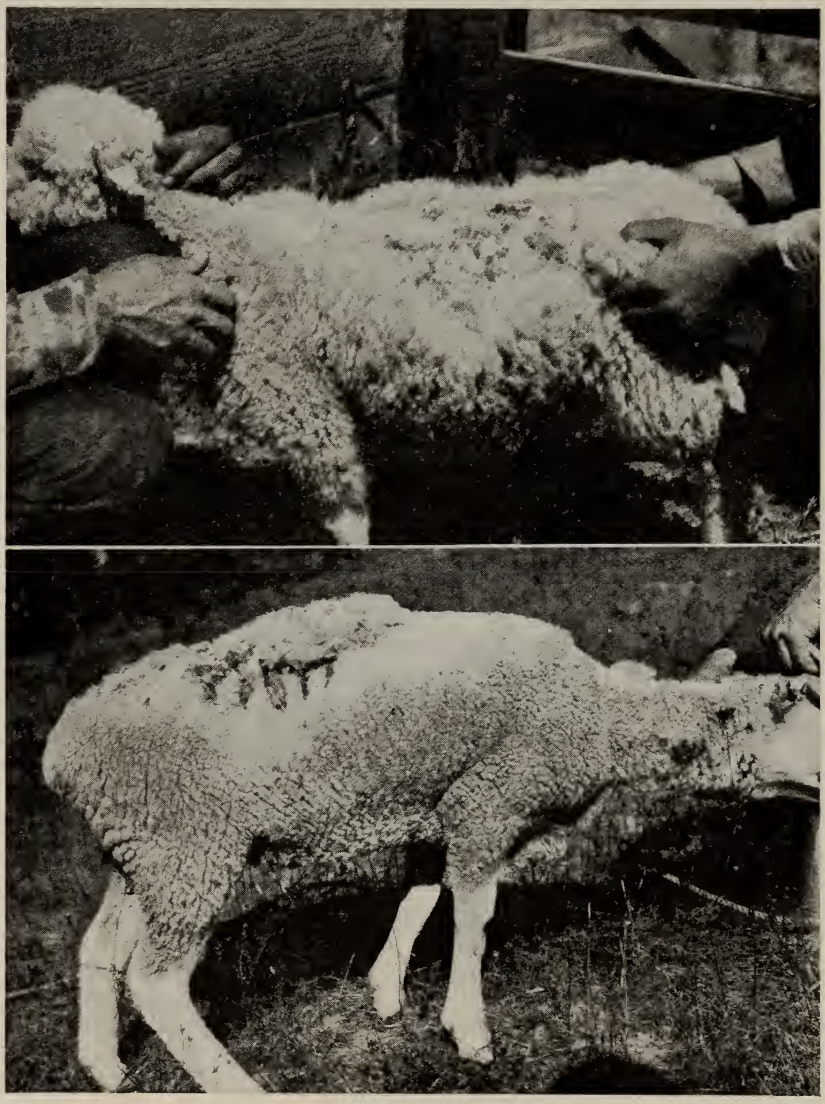

Fig. 5.—Scabby skin over face, ears, neck, withers, and back is accompanied with emaciation, loss of wool, and sometimes death. Removal from the infested area may bring about recovery. Upper: ewe lamb in poor condition and unprofitable to the owner. Lower: three-year-old ewe scabby and too weak to follow the band.

against long periods of grazing on infested areas, both in the interest of the animals and the subsequent yield of palatable, nutritious forage.

Upon inquiry of Dr. C. D. Marsh[6] as to whether his Department, or any other reliable agency known to him, was investigating the toxicity of St. Johnswort in this country, information came to the effect that although this plant has long been recognized in America as producing poisonous effects, there had been little definite experimental work done to determine the characteristic effects or the degree of its toxicity. With a view to clarifying the question of toxicity of the plant, Dr. Marsh and his co-worker, Dr. A. B. Clawson, in 1925 were enlisted to undertake a cooperative study with the University of California using plant materials collected in the northern part of the state.

Results of these feeding experiments, described in detail by Marsh and Clawson,[15] may be briefly stated as follows: both cattle and sheep were affected by feeding them St. Johnswort, the animals typically having high temperature, rapid pulse and respiration, tendency to diarrhea, mild dermatitis, and in some cases salivation. Although 20 cattle were fed varying amounts of the plant, only one—a yearling heifer weighing 550 pounds—died after eating 7 pounds of St. Johnswort, this being equivalent to about 5 per cent (estimated as green) of her weight. All of the cattle fed were either white or had white spots and were kept in sunlight during the feeding tests. The trials with cattle indicated that, in general, about 1 per cent of the animal's weight of the plant in the green state may produce toxic effect, and that about 5 per cent may cause death. The average duration of illness of the cattle that recovered was approximately two days.

Of the 33 sheep fed, all of which were white, only 11 were affected. The toxic dosage varied widely. A 4 per cent dose in one day sometimes produced symptoms—increased pulse rate and rapid respiration, high temperature, and in some instances slight dermatitis. The average duration of illness was 7½ days, being of markedly longer duration than in cattle. These investigators conclude that "As one of the possible forage plants of the ranges of California, St. Johnswort is not likely to be a source of much trouble because of its toxic properties."

The observations of the writers are in agreement with Marsh and Clawson to the extent that deaths among cattle and sheep are not common on the California ranges. As already pointed out, however, several sheep of a band when grazed on infested areas may undergo slight to very serious loss of condition and rustling qualities; there

[6] In charge of the Office of Investigations of Stock Poisoning Plants, United States Department of Agriculture.

may ensue severe dermatitis, resulting in a light clip of inferior wool on the parts of the animal affected. The deaths that do occur are in sick animals not being able to find food or eat it. On the basis of these facts, the writers cannot agree with the conclusion of Marsh and Clawson to the effect that St. Johnswort is not likely to be a source of much trouble in the grazing of livestock, particularly sheep, because of its toxic properties.

LOSS IN FORAGE PRODUCTION

Invasions of St. Johnswort are most rapid where the forage cover has been more or less opened up, as by overgrazing. As would be expected, the grazing capacity of such areas has declined much more rapidly than where this unwelcome invader has had to compete for space and food with a dense forage stand. The all too restricted perennial bunchgrass areas—occupied in northern California chiefly by needlegrasses and oat grasses—are last to yield their foothold, evidently because of their strong, deep roots and their dense stem bases. Many forage grasses and other palatable herbs, including annual and perennial plants, are killed because of the shade cast by the weed. On reasonably heavily infested areas two factors in particular combine with that of deficient light in killing out the grass vegetation, namely, insufficient moisture and root competition.

Beginning growth, as St. Johnswort does, late in the autumn, and continuing through the winter, spring, and most of the summer, the period of growth (hence demand for water and soil nutrients) is practically identical with that of the much esteemed perennial grasses, and is many months longer than the growth period of the annual grasses. Being much taller than most of the forage plants, with abundant foliage and inflorescence displayed on the spreading branches, this weed screens out most of the direct sunlight which would otherwise be available to the understory of grasses. Simultaneously the loss of moisture throughout the soil mass occupied by the roots of this robust weed is very large. Proof of this is the fact that the soil of the upper 6 inches in those areas is near the wilting point from late spring, as in April, throughout the summer. When the earliest flowers appear, late in April, the moisture in the upper soil layer has been exhausted and moisture is then drawn almost entirely from depths of 10 to 35 inches.

In order to determine concretely the influence of varying densities and ages of stands of St. Johnswort on the grazing capacity of the different grass types, a cross-section, represented by a plot 2 inches

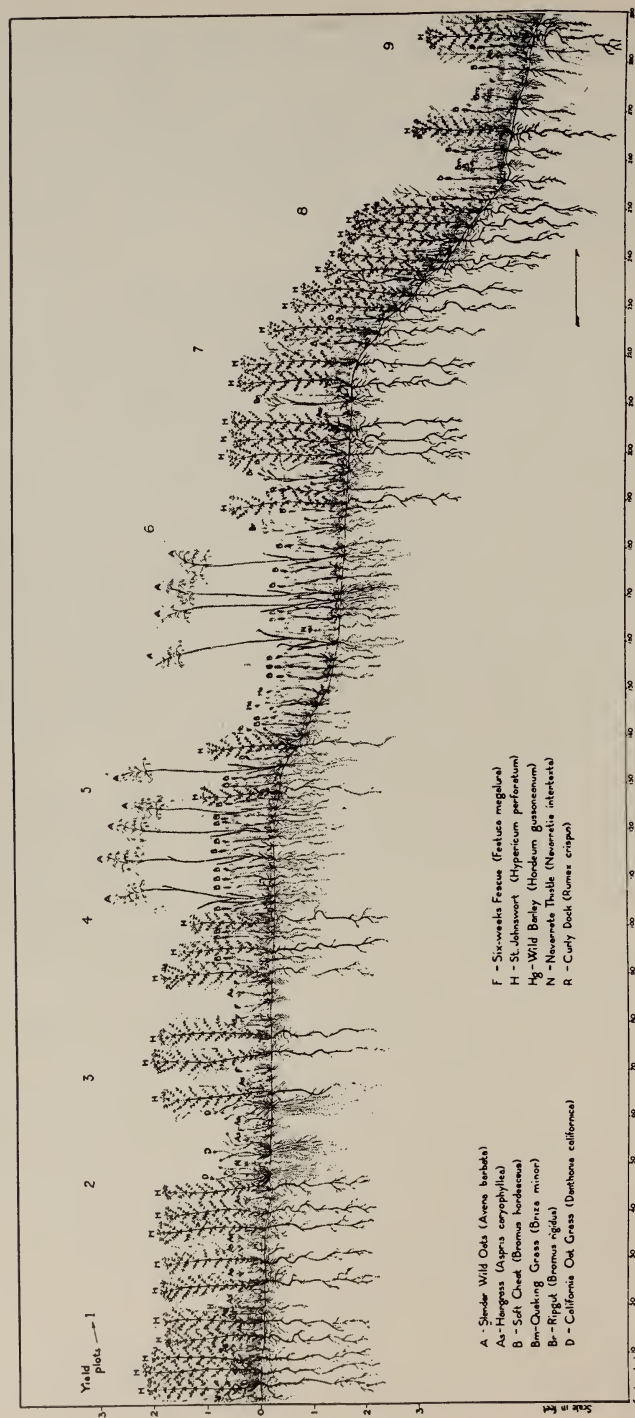

Fig. 6.—Typical invasion of St. Johnswort on a formerly productive range, showing the effect on grazing capacity. Location of yield plots is indicated by the number in the square.

wide and 290 feet long, was located on an area of variable topography and exposure for special study. Each plant that occurred within this narrow strip was recorded, and the character and depth of the root system, as well as the height of each species was sketched (fig. 6). Following the mapping of this area nine yield plots, each 3 feet square, were located at points along this bi-section where rather conspicuous change occurred in density and in plant species. The vegetation on each of these plots, the exact locations of which are shown in figure 6, was clipped 1 inch from the ground surface to simulate grazing. The

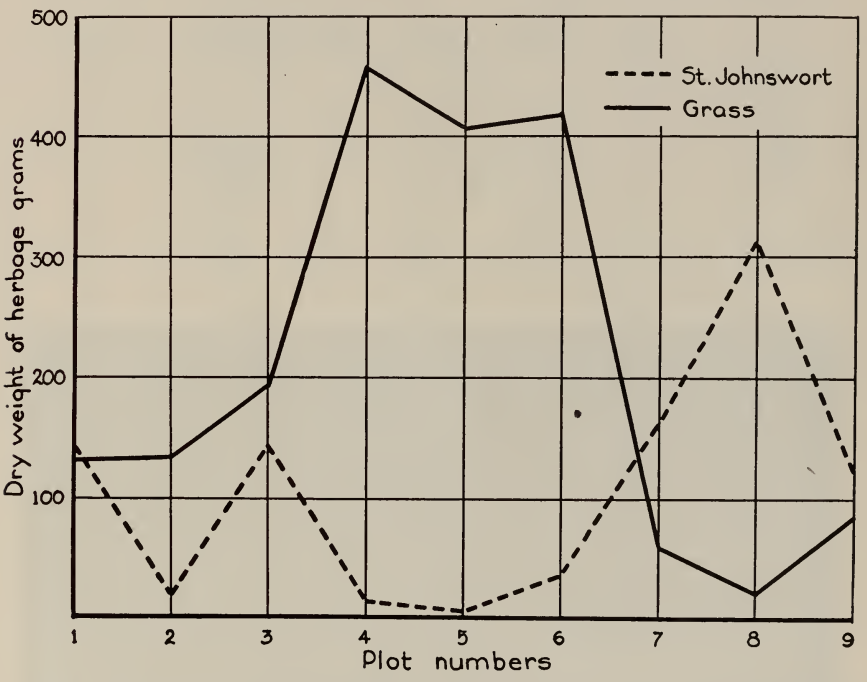

Fig. 7.—Influence of St. Johnswort on forage yield. The grass species that grow beneath St. Johnswort are grazed little or not at all by livestock, even when green and succulent.

vegetation was segregated into forage on the one hand and St. Johnswort on the other. The yields of each plot are given in table 1, and the comparative results are shown graphically in figure 7.

Figures 6, 7, and 8 show that in the denser stands St. Johnswort occupies the ground almost to the exclusion of other vegetation. The dense surface feeding roots not only draw the readily available water from the soil, but also bind the soil so firmly as practically to prevent other plants from getting a foothold. Where the invading weed pest has not attained great density, grass vegetation generally grows

luxuriantly and yields heavily. Such excellent forage plants as California oat grass (designated as "D" in figure 6), although eventually crowded out, are among the last to be replaced. It will be noted that the root system of California oat grass is deeper and the crown much denser than are those of any other grass occurring in the plot.

TABLE 1

WEIGHTS OF PLOT HARVESTINGS OF GRASS AND OF ST. JOHNSWORT AT DIFFERENT INTERVALS ALONG A NARROW PLOT TYPICAL OF AN INFESTED RANGE

Plot number	Weight of grass, grams	Total yield, per cent	Weight St. Johnswort, grams	Total yield, per cent
1	131.9	47.5	145.8	52.5
2	136.3	87.5	19.3	12.5
3	193.2	57.0	145.3	43.0
4	457.1	96.9	14.4	03.1
5	411.7	98.3	6.9	01.7
6	421.4	96.0	17.9	04.0
7	60.8	26.9	164.8	73.1
8	23.9	06.9	319.5	93.1
9	86.5	41.4	122.0	58.6

Fig. 8.—The yield of St. Johnswort is commonly so heavy that practically nothing else can occupy the soil. The dry weight of the weed on this area amounted to 3,900 pounds per acre.

Beginning with plot 1, located at the extreme left of the bi-section strip, the yield of grass constitutes 47.5 per cent of the total; yet there is almost no grass vegetation to be seen. The most common of such plants as nit grass, Navarrete thistle, quaking grass, hairgrass, and annual fescue (fig. 9). They are called "winter annuals" for

Fig. 9.—Plants commonly found growing in stands of St. Johnswort. *A*, nit grass (*Gastridium ventricosum*); *B*, Navarrete thistle (*Navarretia intertexta*); *C*, quaking grass (*Briza minor*); *D*, hairgrass (*Aspris caryophyllea*); *E*, annual fescue (*Festuca megalura*).

the reason that they grow so rapidly in winter and early spring as to complete their development while light and moisture are abundant, thus reaching maturity before St. Johnswort has attained conspicuous growth. Unfortunately these plants have almost no forage value, even when green. When the soil is moist and these plants are succulent their palatability is low because livestock tend to pull out the roots with the leafage. After maturity this vegetation becomes woody and tough and is not grazed unless the animals are forced to subsist upon it.

Figures 6 and 8 show convincingly that increased density of St. Johnswort causes a somewhat proportionate decrease in palatable forage. Very early invasions of the weed pest, as seen in plots 4, 5, and 6 (fig. 6) appear to influence the grazing capacity but little. In a few seasons, however, St. Johnswort may have replaced the wild oats, bur clover, soft cheat, California oat grass, cinquefoil, and other such choice forage plants, leaving the unwelcome invader with only an understory of diminutive unpalatable winter annuals.

Although no definite data are yet available as to the permanency of St. Johnswort, it is evident that once it has come in it will remain for many years. Methods of shortening the life of the stands will be discussed later.

NATURAL ENEMIES OF THE WEED

Among the natural enemies of St. Johnswort, the following might be expected to be of greatest importance—fungi, insects, birds, foraging animals, rodents, and climate. In some countries one or more of these are so adverse to its growth as to hold it distinctly in control.

Although a few leafspots and minor stem infections caused by fungi have been observed, they are of no consequence in growth and regeneration of this plant. Moreover, no fungal enemy has been reported elsewhere that would appear worthy of introduction with a view to controlling or destroying the stands.

No insect damage of consequence to the plant has been reported in the United States. Close observation has been made of this point for the reason that certain insects in European countries are credited with feeding so vigorously on St. Johnswort as to prevent its becoming a pest of economic proportions. Among the insects known in Europe to be confined to the St. Johnswort (*Hypericum*) genus as a food plant, are the following: a Buprestid beetle (*Agrilus hyperici*), which is a stem borer; certain gall-midges (*Cecidomyiidae*); two species of Geometroid moths (*Anaitis*), and a Tortricid moth (*Lathronympha*

hypericana), the larvae of which feed mainly on the young shoots and growing tips; and lastly, a group of closely allied beetles of the genus *Chrysomela* (*C. varians, C. didymata,* and *C. hyperici*).

In Australia, Tillyard[25] in attempting to destroy St. Johnswort by means of insects experimented with certain of the above-named species. He found that *Chrysomela hyperici* fed aggressively upon St. Johnswort but did not attack some forty different kinds of plants of economic value in any stage of its life cycle. Imms[11]

Fig. 10.—Spittlebug and his work on St. Johnswort. Left, detailed view of the insect. Right, insect feeding on stem of St. Johnswort. The spittle protects him from his enemies.

recently reported that some 29,000 specimens of *Chrysomelid* beetles were shipped from the Imperial Institute of Entomology, Bucks, England, with a view to attempting to control St. Johnswort.

An insect called rhubarb spittlebug (*Aphrophora permutata*) (fig. 10), named from the fact that the nymphs are typically surrounded with a mass of white froth or spittle, commonly feeds on St. Johnswort in California. The froth surrounding the nymph conceals and protects the insect from parasites and predacious enemies. The insect bores into the stem at almost any point between the crown and the inflorescence, being found most commonly near the stem base, extracting the juices. The wounds inflicted are slight, however—hardly

of sufficient consequence to injure the plant or to serve as lodgment of spores of fungi which might be the actual agents of destruction. Most of the infested plants were robust and apparently healthy.

The introduction of insects such as those in Europe which feed upon St. Johnswort may well be given serious consideration as a measure of control in California. Such measures, however, should not be undertaken except after extended study, and every precaution should be taken to safeguard the general agricultural interests. Often insects have been introduced to destroy a certain plant and have been found to feed so extensively upon more valuable crops as to offset the benefits to be derived from the destruction of the host plant.

Birds do not appear to feed extensively upon the foliage or fruiting parts of St. Johnswort. A few birds that nest in grassland, however, consume some seed, but this is probably negligible. The gelatinous seed coat doubtless adheres more or less to the feet and body of birds that commonly inhabit infestations, and birds are thus a medium of some importance in seed dissemination.

Domestic livestock are apparently also carriers of seed into new territory. Often heavy stands spring up along roadsides and driveways where livestock have been trailed. Such growths soon spread to adjacent clean lands.

Rodents, such as rabbits, squirrels, rats, and gophers have little effect either on destruction or on local spread of the weed. Occasionally a gopher mound is found in a heavy cover of St. Johnswort, but the plants show no effect of such habitation. Because of the network of runners and surface feeding roots which bind the soil firmly, and the fact that the plant does not furnish palatable food, gophers and other burrowing rodents are few on heavy infestations as compared with their numbers on adjoining relatively clean grasslands.

Climate—notably temperature and precipitation—is of great importance in influencing the spread of the plant on local areas, and in determining the elevational range. In many localities well defined patches have increased little or not at all, except by runners, for several years, when suddenly—indeed, sometimes in a single season—an enormous acreage adjacent to the original patches becomes infested. This is accounted for by the fact that a large amount of seed is produced each year which finds lodgment over the adjoining uninfested area; but the conditions favorable to seed germination are apparently exacting, and the resulting seedling plants appear in large numbers only occasionally. Delayed germination may also be caused by the nature of the seed coat. In this connection the structure of the seed and the stages concerned in its germination are significant (see fig. 18).

Considering the large amount of seed produced, conservatively estimated at 15,000 seeds on one fully developed plant, it is important to know what percentage may be expected to germinate. Accordingly, many seed samples were collected in diversified localities. The germination results are given in table 2 which follows.

TABLE 2

Germination of Seeds of St. Johnswort Collected in Many Localities

Locality	Per cent germination and time concerned			
	20 days		40 days	
	Seed sample A	Seed sample B	Seed sample A	Seed sample B
Blocksburg, Humboldt County	58	61	62	65
Alderpoint, Humboldt County	4	5	8	11
Fort Seward, Humboldt County	48	49	57	59
Bald Mountain, Humboldt County	8	7	8	9
Redding, Tehama County	41	46	41	49
Sonora, Tuolumne County	3	5	4	7

The wide difference in the viability of the seed from the different localities may be caused by difference in moisture, temperature, or other climatic conditions during the period of growth. In all cases a higher per cent of germination was procured after 40 days than for the 20-day period. Possibly even more seed might have germinated had the tests extended over a longer period.

MECHANICAL METHODS OF CONTROL

Among the mechanical methods more commonly used in controling weeds, the following have been included in this investigation: (1) digging; (2) cutting; (3) covering; (4) flooding; (5) burning; (6) overgrazing. Because of the evident loss caused by St. Johnswort recognized several years ago, the senior author engaged in certain cooperative control tests with farm advisors and stockmen as early as 1925, the results of which are also herewith included.

Digging.—The mere digging, grubbing, and hand pulling of St. Johnswort have proven costly and ineffective as a control measure. Such practices were unsuccessful if for no other reason than the fact that the plant typically grows so densely. Sprouting from root runners took place wherever such segments happened to have been left in the surface soil. Destruction by digging adult plants was usually followed by the appearance of numerous seedlings. Also the

operation was costly even on small areas, both on account of the numbers of plants and because they were so deeply rooted.

In the complete excavation of several fully developed plants of St. Johnswort, the roots were found generally to extend 3 feet or more in depth, although this varied appreciably, depending upon the nature of the soil and its moisture content. The roots were well below those of the grasses common to the region (fig. 11).

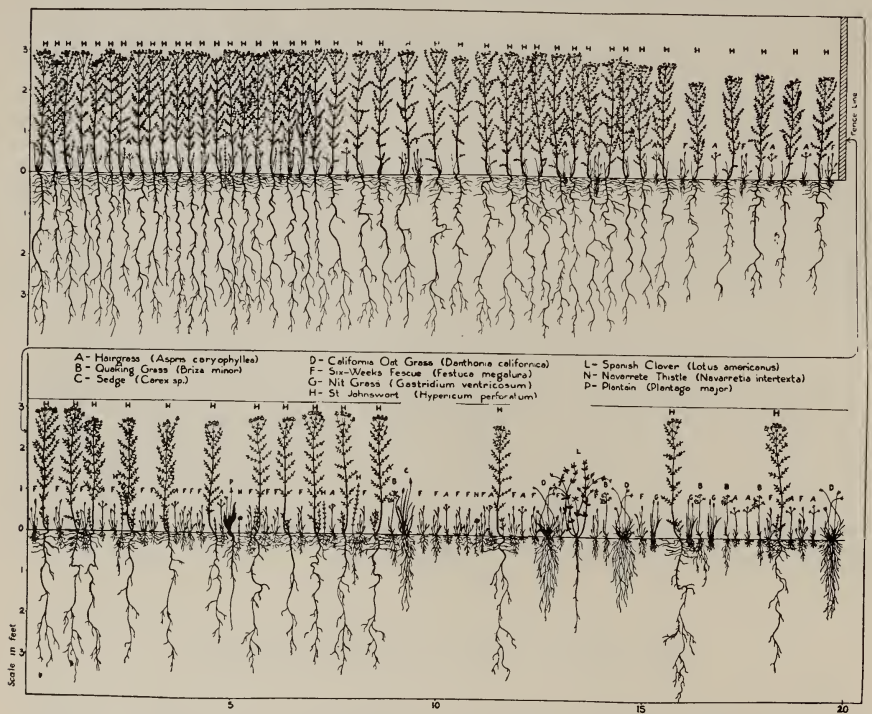

Fig. 11.—Effect of St. Johnswort on grazing capacity. Above: the dense growth of the weed has replaced all vegetation except a few winter annuals which have almost no forage value. Below: an adjoining pasture where St. Johnswort is somewhat scattered, thus permitting space for the better forage cover to grow. Note that the roots extend well below those of the grasses common to the region.

Plants more than one year old were found to have horizontal roots or runners located ½ to 3 inches beneath the surface soil. From these runners young sprouts originated, often being so numerous as to mat the ground near the parent plant. The numerous sprouts which followed the digging or pulling of the plants exclude this operation for practical use.

Cutting.—Preliminary experiments appear to indicate that any attempt to kill the plants by occasional mowing or cutting them to the ground will be unsuccessful. Such a method, however, has some merit

in that it controls the spread of the plant by preventing seed formation and by holding in check somewhat the vegetative reproduction. Repeated mowing or cutting of the tops, as in most plants, tended to starve and weaken the weed; nevertheless some sprouting occurred immediately after cutting. Soon the roots and crown were supplied with ample food and growth appeared normal.

Covering.—Since St. Johnswort does not grow in deep shade, infestations always stopping along the fringe of a forest or a community of brush, the possibilities of killing small patches by excluding sunlight appeared worthy of trial.

Preliminary to such field tests, 30 plants were grown in water cultures in the greenhouse for a period of 50 days, after which 10 of these specimens were transferred to a well ventilated dark chamber. A similar number were simultaneously placed in a shade tent which screened out approximately 50 per cent of the full daylight. The remaining 10 plants were left in the greenhouse in full light and were used as a check.

In 10 days all the plants in the dark chamber had become distinctly pallid and most of the specimens were drooping badly. After 15 days in darkness nearly all these plants had died. In contrast, wheat seedlings after a similar period in the dark chamber were fairly erect and became green when placed in full light in the greenhouse. The plants in the shade tent grew slowly for a time but after 30 days some had died. The remaining were pallid and rather "viny" in form. The control plants grew vigorously and appeared healthy at the end of the 30-day period. From these tests it was evident that St. Johnswort was more intolerant to shade than had been supposed.

The cover test was then applied in the field. The plants were removed by cutting them 2 inches above the surface of the ground and covered with heavy tar (building) paper, laid close to the ground to exclude the light. On the control plots the plants were likewise cut but left uncovered. In a few days the covered plants sent out numerous long white succulent shoots, the leaves of which were reduced to mere scales and devoid of chlorophyll. The covered plants continued to send out shoots until the food reserves stored in the crowns and roots were exhausted. The control plants sprouted vigorously, were leafy, and grew rapidly.

Destruction of St. Johnswort by covering is applicable only to very small patches. Success will depend upon the effectiveness in screening out the light. The cost would usually be high.

Flooding.—Where infestations are so located that they may be flooded, as by irrigation, it has been suggested that they might readily

be destroyed. Some seeds and fruits will not endure immersion in water for more than a few days. For this reason it has been assumed that seed of St. Johnswort will not retain its germination strength when carried in streams or immersed in water for a considerable time.

In order to ascertain whether streams may be a factor of importance in depositing seed of the plant on weed-free territory, pertinent tests were made in the laboratory. Seeds numbering 200 in each lot were kept in vials under water for varying periods, subsequent to which they were immediately placed in sterilized sand and germinated in the greenhouse. The germination results are given in figure 12.

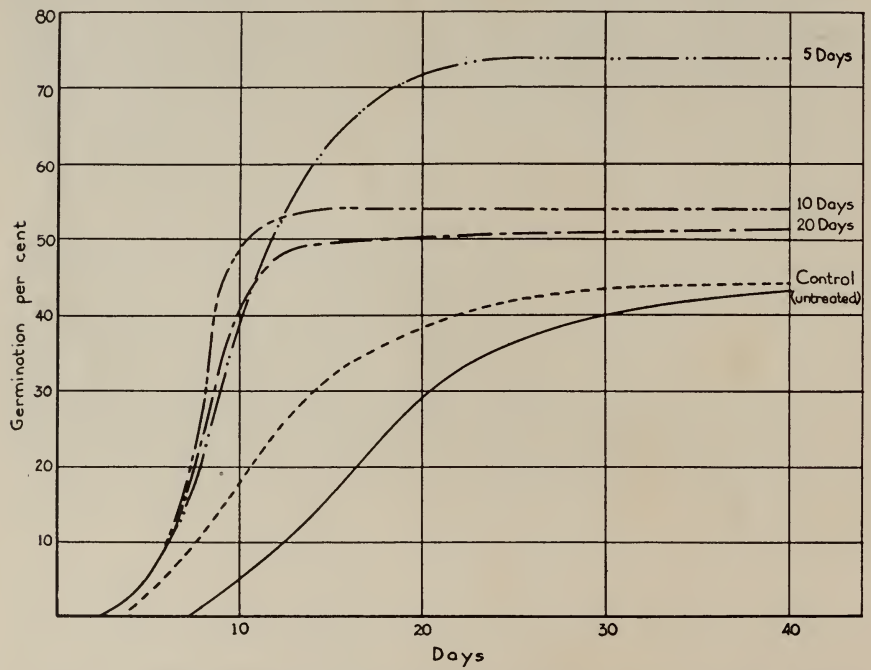

Fig. 12.—Immersion of seed in water and its effect on germination. Since the seed is not readily injured by immersion, water may be an important factor in the distribution of the plant.

After 20 days immersion, the seed was viable, the percentage of germination being considerably higher than that of the untreated lots—it was even higher than that immersed for only 3 days. Also the immersion treatment hastened germination. Evidently, then, streams may be a factor of real importance in bringing the plant into new territory, remote from infestations. Whether well established plants would be readily killed by flooding is not known, but since St. Johnswort does not characteristically grow on water-logged lands, flooding would probably be destructive.

Burning.—Some stockmen have contended that burning infestations of St. Johnswort when the tops are dry in autumn will kill the present cover and destroy the accumulated seed. By burning two or three years in succession it is pointed out that grass may invade the area and crowd out the remaining plants of St. Johnswort.

In order to test the contentions of the proponents for burning, a heavily infested pasture of 300 acres located near Blocksburg was burned closely in October of 1926 and 1927, when the fire completely consumed the tops. Fire was carried to all isolated patches, leaving none unburned. Records were kept as to the density of the stand of the weed on representative areas before the first burn and after the second burn.

Instead of the weed cover being killed or subsequently thinned out by invading grasses, the stand of St. Johnswort was denser and seemingly more vigorous than before. Probably one of the most conspicuous stimuli of the burning operation was the invasion by a large number of seedling plants of St. Johnswort where the fire had been very hot.

These unexpected results suggested heating seed of St. Johnswort in an oven in order to learn what effect this factor might have on germination. Since the surface soil heats up quickly when infestations are burned, and remains hot for only a few minutes, the oven-heated seed was exposed to a temperature of 212 degrees Fahr. for 5 minutes for one series of seed, 15 minutes for a second series, 30 minutes for a third, and 60 minutes for a fourth series. This seed was placed in sterilized sand and germinated in the greenhouse. The results are summarized in figure 13.

It is significant that the unheated or check lots of seed gave the lowest germination, averaging 44 per cent. Next lowest in germination, that of 52 per cent, was recorded for the seed lots exposed to heat for 5 minutes. The seed heated for 30 minutes was highest in germination with an average of 81 per cent, and that heated for 60 minutes gave a germination percentage of 75—higher than the seed that was exposed for only 15 minutes.

Other lots of seed were exposed to a temperature of 260 degrees Fahr. for periods of 1 to 5 minutes, this temperature being the same as that recorded ¼ inch below the surface soil in selected localities during the field burning operation. Even at this temperature the seed gave a distinctly higher percentage of germination than did the untreated seeds.

In addition to the risk of using fire in the destruction of St. Johnswort, this pest appears definitely to increase under burning. Repeated burning of a herbaceous cover is sure ultimately to deplete the soil, for it is through the decay of plant remains that the much desired humus soil layer is formed. With an impoverished soil come weeds, including St. Johnswort, and early-maturing winter annuals of many kinds.

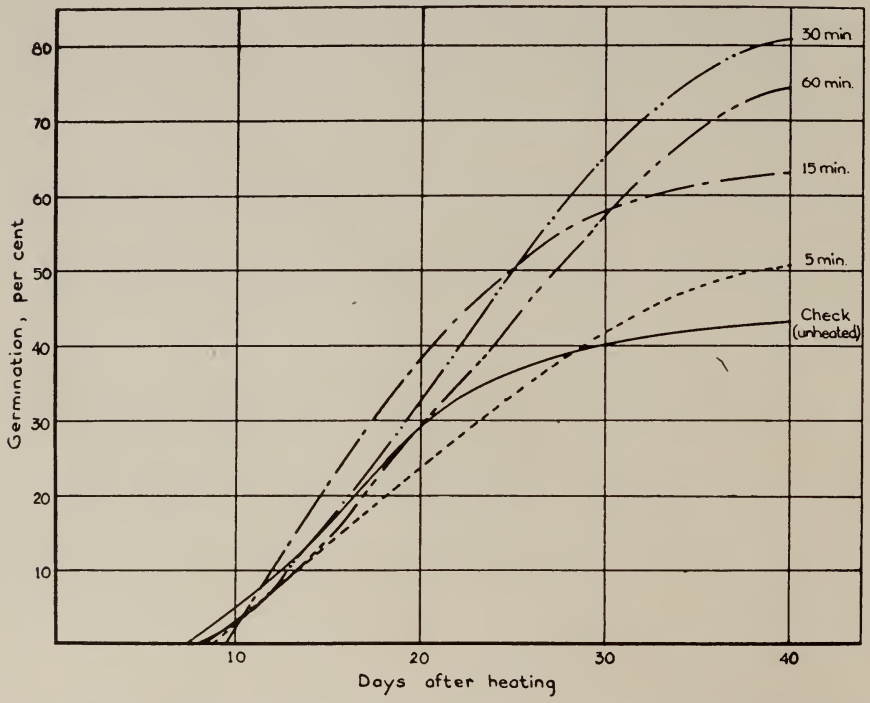

Fig. 13.—Effect of heat on germination of seed of St. Johnswort.

Overgrazing.—As already pointed out, overgrazing undoubtedly favors the establishment of St. Johnswort. But will heavy overgrazing, as is contended by some stockmen, destroy this weed?

In 1926 and 1927 a heavily infested pasture near Blocksburg was grazed with cattle and sheep far beyond its carrying capacity, the animals being kept on the area from early winter until late autumn. At the end of the second year of pasturing practically all grasses and other palatable vegetation had either been killed or consumed so closely that the animals came off in very poor condition of flesh. The owner would have continued the overgrazing experiment another year had it not been for the financial cost entailed in getting the animals

in condition to endure the rigors of the winter. The following two years the pasture was closed to grazing. The first year of rest was characterized by one of the heaviest stands of St. Johnswort observed. Although it is probable that the weed would have eventually occupied the entire area under moderate grazing, the decreased competition with other vegetation doubtless hastened the spread of the weed over the whole pasture.

Overgrazing, even when goats are held on infested areas, is a serious mistake. Instead the vegetation as a whole should be regenerated in order to curtail the otherwise unhampered growth of St. Johnswort.

CHEMICAL METHODS OF CONTROL

The success obtained through the use of certain chemical herbicides in the suppression of other noxious plants suggested certain experimental trials in chemical eradication of St. Johnswort.

In Europe chemical sprays have long been used in eradicating many different kinds of weeds. Among the earliest experiments are those of Dusserre[8] in France, in 1899. Iron sulfate, copper sulfate, and sodium nitrate were used in the control of mustard in grain fields. The later works of Brenchley,[4] of Rabate,[22] and of Loyer[14] were of importance in demonstrating the practicability of the use of chemical herbicides.

In the United States, Jones and Orton[12] appear to have published the earliest account of the use of chemical herbicides. Working in Vermont, in 1897, they used salt in killing orange hawkweed. Bolley,[5] in North Dakota, is apparently the first to use a spray for the application of chemicals to destroy noxious weeds. He was successful in the use of copper sulfate in controlling weeds in grain fields. Potts,[20] in 1902, successfully used sulfuric acid in killing briers, blackberries, and wild roses by pouring this substance upon the main roots. More recently, Gray,[9] working in California in 1919, found that a dilute solution of sodium arsenite applied to the tops of the wild morning glory (bindweed) destroyed both the top growth and the underground parts to a depth of several feet.

Thompson and Robbins,[26] in 1926, reported experiments in which they tested many different chemicals in an attempt to eradicate the common barberry (*Berberis vulgaris*) in eastern and middle western United States. They concluded that common salt (sodium chloride) was the most satisfactory chemical for killing the barberry plant. Kerosene and sodium arsenite in solution ranked second and third,

respectively. Sodium arsenite, although very effective in killing these plants, is extremely poisonous to livestock, hence it is not suitable for use on pasture lands.

Aslander,[1] in 1927, reported on the uses of sulfuric acid as a herbicide. He found that several weeds, especially perennials, were not injured by sulfuric acid. This was accounted for chiefly because of the waxy surface and the concealment of the easily injured growing point, which protects grasslike weeds as well as certain grain plants. Also dense hairs as well as glandular hairs, protect some weeds against sulfuric acid and certain other sprays when applied on the tops. Moreover, many weeds have a smooth surface to which many sprays do not adhere.

Aslander suggested that it is the high hydrogen ion concentration which is injurious to the plant since protoplasm is highly susceptible to an acid solution. He also observed that rapidly growing plants are most susceptible to sprays.

Within recent years there has been widespread use in the control of weeds by chlorates, particularly sodium chlorate and a chlorate called "Atlacide," which consists approximately of 50 per cent sodium chlorate and 50 per cent calcium chloride. First experimented with in Germany, the work was continued in this country for the eradication of such plants as Canada thistle, field bindweed, or morning glory, quack grass, and wild currants.

Aslander,[2] in 1928, working at the Cornell Agricultural Experiment Station, secured complete eradication of Canada thistle with a 10 per cent solution of sodium chlorate applied in the fall. He found that sodium chlorate applied in the autumn had no influence on the ammonification and nitrification processes in the soil the following spring.

Latshaw and Zahnley,[13] in 1927, at the Kansas Agricultural Experiment Station secured eradication of field bindweed by an application late in the growing season of sodium chlorate spray of 12½ per cent concentration. Cross-sections made of the roots of treated and untreated plants showed important differences in the starch content of the cells and in the condition of the cell wall. The cells of the roots of untreated plants were filled with starch granules and the cell walls were intact. The cells of the roots of plants treated with sodium chlorate were without starch granules and the cell walls in many cases showed unmistakable signs of disintegration. It was also found that sodium chlorate had no permanent detrimental effect on the soil.

Hansen[10] in 1928, in Indiana, secured eradication of quack grass with a spray of sodium chlorate. He suggested that a 10 per cent

concentration of this spray was effective if applied any time after the plants have made their maximum top growth, the early bloom stage being perhaps best. Failures in obtaining results are caused mainly through insufficient saturation of the tops, as in careless application; or they are due to mowing the weeds before using the chlorate, or to applying the spray in immature stages of growth.

Offord,[18] in 1930, after several years of chemical spraying tests of wild currants in the white pine forests of the west, has suggested that the toxic action of sodium chlorate might be explained by the fact that "(1) it is rather passive in the early stages, thus allowing movement of the poison within the plant, and (2) over an extended period a slow decomposition of the chemical occurs, in the superficial layers of the plant catalyzed by sunlight, and within the plant tissue by virtue of reducing elements such as tannins or reducing sugars under the stimulus of life processes."

Anatomy of the Plant.—In order to determine whether St. Johnswort possesses any specialized anatomical structures which might be the cause of failure in the use of chemical sprays, a study of important plant tissues was made. Knowledge of the anatomical structures of leaves, stems, roots, and seeds was obtained by preparing and fixing microscopical sections by the usual standard methods. The toxic action of a chemical spray depends primarily upon its penetration into the tissues of the leaves and stems and its subsequent distribution through the tissues of the plant, culminating in the actively growing tissues of the roots. Penetration of the toxic solution is greatly influenced by injuries to the cuticle of the leaf, such as may be caused by insects or animals, by destruction and permeability of the tissues which form the conductive system (permeability is secured by the death of the cells in a tissue); and by air humidity and temperature.

The leaf of St. Johnswort (fig. 14) is composed of (*A*) a well developed, single-celled, upper epidermis of smooth surface, devoid of stomata; (*B*) palisade tissue of one to two well defined layers; (*H*) spongy parenchyma, 3 to 4 cells deep; and (*J*) the lower, heavy-walled, single-celled epidermis. The stomata (*E*), all of which are located on the lower surface, are numerous and usually open into large stomatal chambers (*F*).

The leaf is typified by the occurrence of glands or secretory cavities in the outer margins of the leaf, which to the naked eye, appear as black, translucent dots (fig. 15, *D*). Actually, they are spherical to elliptical cavities, surrounded by parenchyma cells (*C*). These cavities are commonly filled with a dark colored semi-solid mass. This

material is called *hypericin*. Siersch[24] suggests that it is an organic compound which probably belongs to a group of chemical compounds called anthocyanins, and is thought to possess toxic properties.

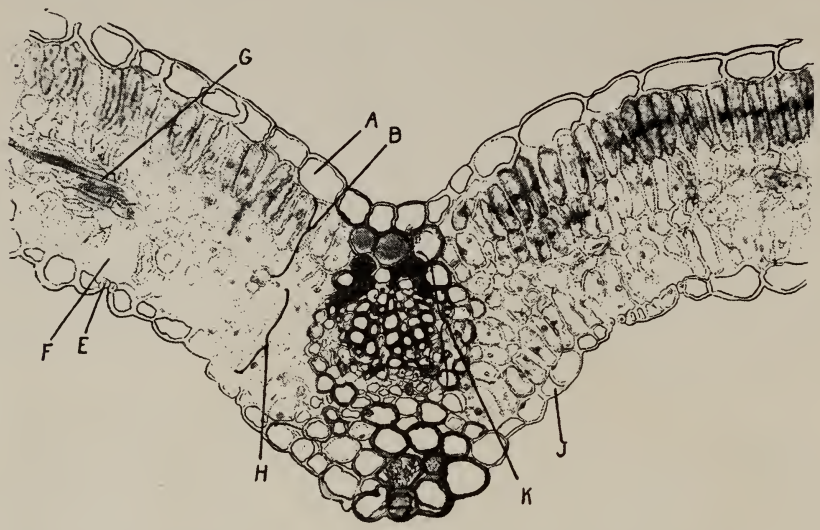

Fig. 14.—Cross section of leaf of St. Johnswort through the midrib. *A*, epidermal cell of upper leaf surface; *B*, palisade cell; *E*, stoma; *F*, stomatal chamber; *G*, bundle ends; *H*, spongy parenchyma; *J*, epidermal cell of lower leaf surface; *K*, conductive tissue.

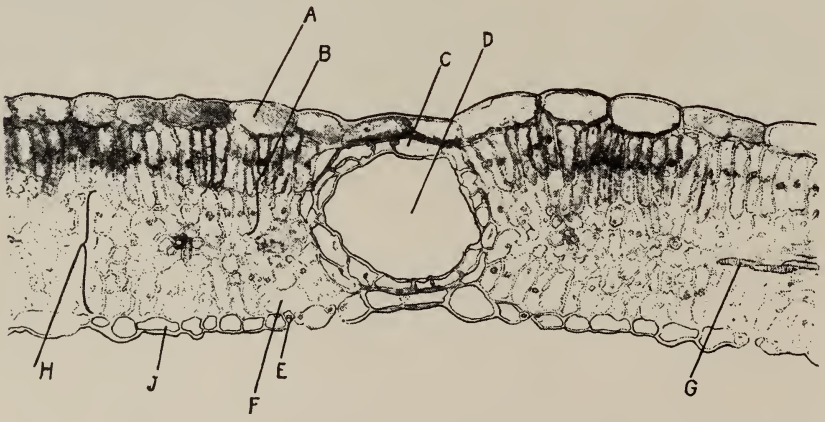

Fig. 15.—Cross section of leaf of St. Johnswort. *A*, epidermal cell of upper leaf surface; *B*, palisade tissue; *C*, parenchyma cell; *D*, secretory cavity; *E*, stoma; *F*, stomatal chamber; *G*, bundle ends; *H*, spongy parenchyma; *J*, epidermal cell of lower leaf surface.

The stem has a well developed conductive system (fig. 16, *C*); a comparatively small amount of cortical tissue (*B*); an epidermis (*A*) composed of a single layer of cells; and two wing-like appendages,

usually composed, as is also the outer portion of the stem, of mechanical or strengthening tissue made up of cells called collenchyma, which are present in all young stems of this genus.

The root has well developed conductive tissues (fig. 17, *C*) with many wide, open ducts. Storage of organic foods, manufactured in and transported from the tops, is mainly in the cortical parenchyma

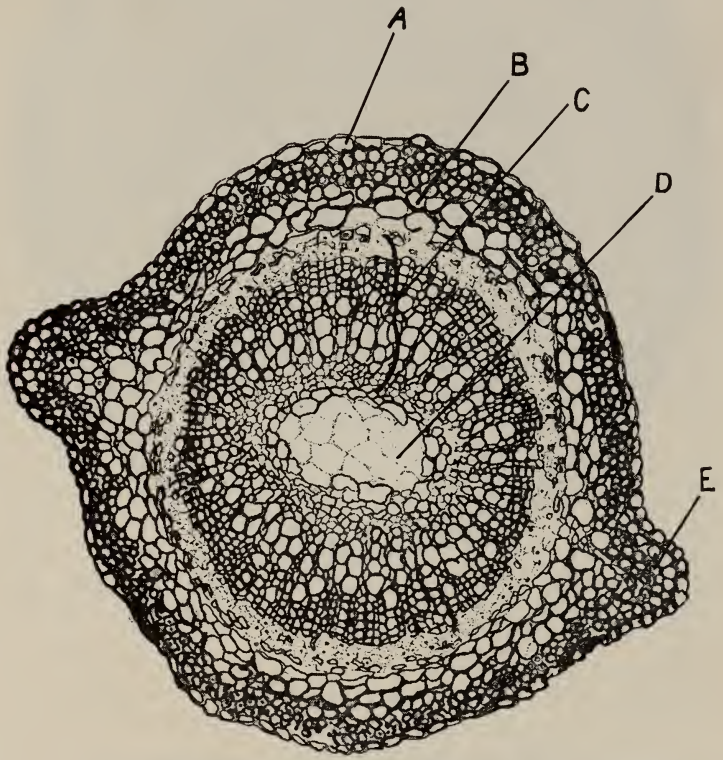

Fig. 16.—Cross section of stem of St. Johnswort. *A*, epidermal cell; *B*, cortical parenchyma; *C*, conductive elements; *D*, pith cells; *E*, appendage, composed principally of collenchyma cells.

(*B*). A single-layered covering of epidermal cells (*A*) protects the more delicate inner tissues of the root.

The anatomy of the seed is shown in figure 18. It has a heavy seed coat (*A*) with a single outer layer of thick-walled, heavily lignified protective cells. The innermost layer (*B*) consists of thin-walled parenchyma cells, which in the mature seed are represented by papery layers of empty, collapsed cells because of the food materials having been used up. Further examination shows that the cotyledons, or food storage leaves (*C*), are composed of cells tightly

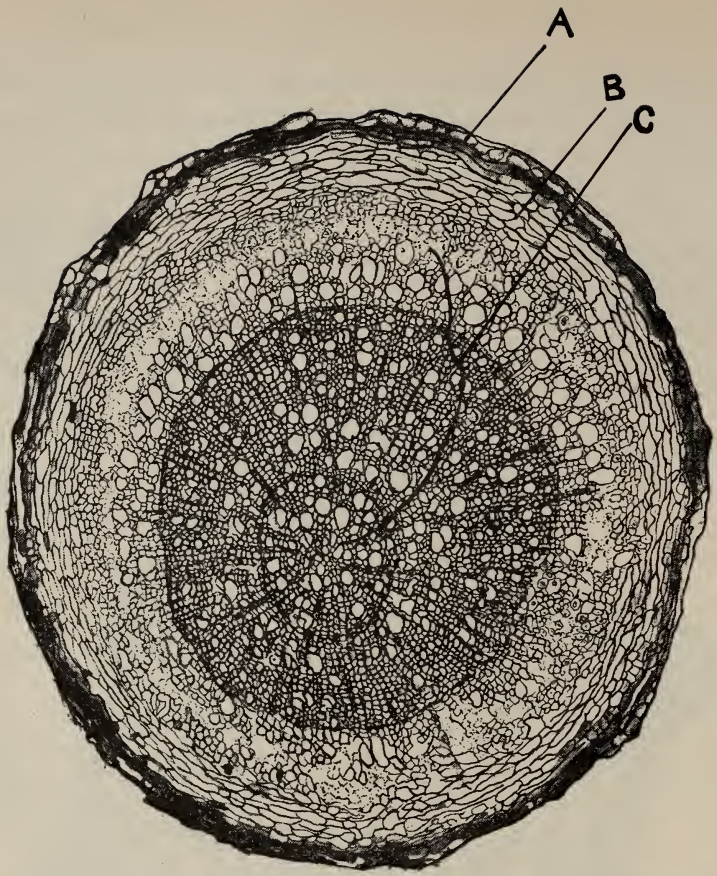

Fig. 17.—Cross section of root of St. Johnswort. *A*, epidermis; *B*, cortical parenchyma; *C*, conductive tissue.

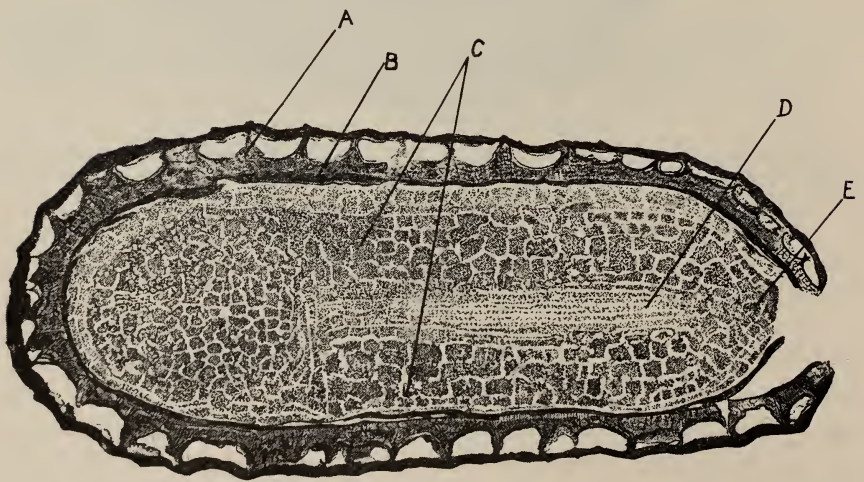

Fig. 18.—Cross section of seed of St. Johnswort. *A*, outer seed coat; *B*, inner integument; *C*, starch cells of the cotyledons; *D*, cells of primary root; *E*, cells of root cap.

packed with starch. Under favorable temperature and moisture the food stored in these cells is released for the nourishment of the entire embryo. At germination the radicle, or primary root (*D*) appears first, and is protected by a layer of cells forming the root cap (*E*) as it pushes into the soil. As the cotyledons appear above the soil surface the protective covering of the seed coat sloughs off.

Requirements of a Satisfactory Spray.—In addition to effectiveness of the spray as a herbicide, the chemical must not be poisonous to livestock after being applied to the plant; the hazard to persons handling it should be low; and, it must not permanently injure the soil.

The cost of the chemical for extensive application obviously must be low, and the chemical should be readily available.

Upon examination of the various chemical herbicides generally recommended, it was decided that sodium chlorate and Atlacide possessed more of these qualities than any others available for use on the range. Accordingly, experiments were undertaken to procure detailed information relative to the eradication of St. Johnswort by these chemicals. A few other materials were tested, but are mentioned only incidentally.

Chemicals Used.—Sodium chlorate is a white, crystalline salt of rather high solubility, 82 parts by weight dissolving in 100 parts of cold water. The salt is a strong oxidizing agent, hence it makes organic material in contact with it inflammable. The solution should not be allowed to dry on clothing or shoes. Therefore, any clothing which has become wet with sodium chlorate spray should be thoroughly washed in water before drying. The use of rubber boots and rubber clothing by those using the chemical is advisable. Crystals of sodium chlorate and concentrated aqueous solutions are poisonous to livestock if taken in fairly large quantities.

A less dangerous herbicide from the standpoint of inflammability is Atlacide, a commercial preparation.[7] It is a mixture of approximately equal parts of sodium chlorate and calcium chloride. The latter salt absorbs water which keeps both salts in solution, thus allowing absorption to continue. Since Atlacide is less effective than sodium chlorate, higher concentrations have to be used in order to obtain the same results.

Laboratory Experiments with Chemical Sprays.—Laboratory experiments with chemical sprays applied in various concentrations to the aerial parts of St. Johnswort plants grown in the greenhouse

[7] Manufactured by the Chipman Chemical Engineering Company, Inc., Palo Alto, California.

in water cultures during the winter of 1929–30, gave the following results: (1) Aqueous solutions of the spray have a tendency to run off the leaf surface or form in large drops upon the leaves so that the efficiency of the spray is materially reduced. This is probably caused by the smoothness of the leaf surface and can be overcome by the use of a chemical spreader. (2) Glue was the most economical and adaptable spreader to use with chlorate sprays. Fish oil soap gave good results, but if improperly mixed with chlorate sprays it has a tendency to form an insoluble scum upon the surface of the solution which interferes with application of the spray. (3) Chlorate spray solutions above a concentration of 30 per cent would be dangerously inflammable and inadvisable for application in the field eradication of vegetation. (4) Chlorate sprays decreased in toxicity with an increase in the alkalinity of the solution. A distinctly alkaline solution (above pH 8) was less effective in killing plant tissue of St. Johnswort generally than solutions of acid reaction. (5) Chlorate sprays were most toxic when made distinctly acid, approaching the acidity of the cell sap, which, under greenhouse conditions, averaged approximately a pH of 4.2.

The results of these preliminary experiments formed the basis for the use of chlorate sprays in the field tests.

Field Experiments with Chemical Sprays.—Field experiments with chemical sprays applied upon St. Johnswort were made in order to obtain information relative to: (1) time of year best suited to the application of chemical sprays to secure effective eradication; (2) pH of spray solution which produced the highest toxicity; (3) concentration of spray solution most advisable to use; (4) necessity of a spreader to be used in conjunction with chemical sprays.

Through the generous cooperation of cattlemen in Humboldt County, permission was obtained to carry on experiments on an area heavily infested with St. Johnswort. The more detailed experimental studies were located near Blocksburg. Areas were located where they were undisturbed by livestock. Plots were staked out with an area each of approximately $\frac{1}{200}$ acre, each plot requiring approximately $\frac{3}{4}$ gallon of spray solution (fig. 19). A tank of about $1\frac{1}{2}$ gallons capacity, and which emitted the solution in a fine spray was used in applying the solutions to the plots.

The plots were treated with chemicals on the following dates: September 4, 1929; April 28, 1930; June 10, 1930; and July 16, 1930. The results were recorded late in the autumn, the individual plants on each plot being closely examined and the per cent of specimens killed determined.

Fall Treatment.—The results of spraying St. Johnswort in the fall with various concentrations of sodium chlorate are given for each plot in table 3 which follows.

TABLE 3

Results of Spraying with Sodium Chlorate in Autumn; September 4, 1929

Concentration of spray, per cent*	Plants killed, per cent
10	98
15	100
20	100
25	100
30	100
40	100
50	100

* Concentration expressed is per cent by weight. No spreader used.

Fig. 19.—View of plots sprayed in spring with various chemicals. This area had a uniform cover of St. Johnswort and was representative of extensive infestation.

At the time the spray was applied (September 4, 1929) the plants had for the most part reached maturity. The table shows that nearly complete destruction of the plant was procured by treatment at this season. Even the 10 per cent concentration of sodium chlorate killed 98 per cent of the plants on the plot. Concentrations ranging from 15 to 50 per cent resulted in killing all the plants. The following spring, however, seedlings of many species had come in, including some of St. Johnswort, thus indicating the need of a follow-up spray. The root crowns of the original plants of St. Johnswort had largely disintegrated and the roots were mostly decayed.

Early Spring Treatment.—Results of spraying with various chemicals on April 28, 1930, are given in table 4. The table shows that sodium chlorate and Atlacide gave highly satisfactory results in that both chemicals were very toxic to St. Johnswort. A sodium chlorate spray with strong acidity (pH 3) was only slightly more toxic than that of a less acid spray (pH 5.6), the latter being the

TABLE 4

RESULTS OF PLOTS SPRAYED APRIL 28, 1930

Chemical	Concentration,* per cent	Spreader of glue,† per cent	Acidity of spray (pH)	Plants killed, per cent
Sodium chlorate	10.0	0.1	3.0	95.0
Sodium chlorate	15.0	0.1	3.0	95.0
Sodium chlorate	20.0	0.1	3.0	96.0
Sodium chlorate	25.0	0.1	3.0	99.0
Sodium chlorate	30.0	0.1	3.0	100.0
Sodium chlorate	10.0	none	5.6	92.0
Sodium chlorate	15.0	none	5.6	93.0
Sodium chlorate	20.0	none	5.6	95.0
Sodium chlorate	25.0	none	5.6	95.0
Sodium chlorate	30.0	none	5.6	95.0
Sodium chlorate	10.0	0.1	5.6	92.0
Sodium chlorate	15.0	0.1	5.6	95.0
Sodium chlorate	20.0	0.1	5.6	96.0
Sodium chlorate	25.0	0.1	5.6	97.0
Sodium chlorate	30.0	0.1	5.6	100.0
Atlacide	10.0	none	.....	90.0
Atlacide	15.0	none	.....	95.0
Atlacide	20.0	none	.....	96.0
Atlacide	25.0	none	.....	96.0
Atlacide	30.0	none	.....	96.0
Atlacide	10.0	0.1	.....	93.0
Atlacide	15.0	0.1	.....	96.0
Atlacide	20.0	0.1	.....	97.0
Atlacide	25.0	0.1	.....	97.0
Atlacide	30.0	0.1	.....	99.0
Pitch oil	Full	.....	.....	25.0

*Concentration expressed as per cent by weight.
†Per cent on basis of dry weight of chemical used.

same as the acidity (hydrogen ion concentration) of the cell sap of the weed. Atlacide was approximately as toxic as sodium chlorate, a 10 per cent solution killing 90 per cent of the plants. These tests also indicated that the efficiency of both sodium chlorate and Atlacide was increased by using an 0.1 per cent solution of glue as a spreader.

Pitch oil, containing a high per cent of phenol, although effective in destroying the tops of all plants, actually killed only 25 per cent of the plants upon the plot. The top growth of St. Johnswort at this time was about 10 inches in height.

Late Spring Treatment.—At this season plots were treated with several chemicals, the list of which is given in table 5.

TABLE 5

Results of Plots Sprayed June 6, 1930

Chemical	Concentration, per cent	Spreader of glue, per cent	Acidity of spray (pH)	Plants killed, per cent
Sodium chlorate	5.0	0.1	3.00	22.0
Sodium chlorate	10.0	0.1	3.00	35.0
Sodium chlorate	15.0	0.1	3.00	44.0
Sodium chlorate	20.0	0.1	3.00	50.0
Sodium chlorate	25.0	0.1	3.00	60.0
Sodium chlorate	30.0	0.1	3.00	80.0
Sodium chlorate	5.0	0.1	8.00	10.0
Sodium chlorate	10.0	0.1	8.00	15.0
Sodium chlorate	15.0	0.1	8.00	20.0
Sodium chlorate	20.0	0.1	8.00	50.0
Sodium chlorate	25.0	0.1	8.00	75.0
Sodium chlorate	30.0	0.1	8.00	77.0
Atlacide	5.0	0.1	.....	12.0
Atlacide	10.0	0.1	.....	15.0
Atlacide	15.0	0.1	.....	20.0
Atlacide	20.0	0.1	.....	40.0
Atlacide	25.0	0.1	.....	50.0
Atlacide	30.0	0.1	.....	80.0
Sodium chlorate	5.0	none	5.45	10.0
Sodium chlorate	10.0	none	5.45	20.0
Sodium chlorate	15.0	none	5.45	30.0
Sodium chlorate	20.0	none	5.45	50.0
Sodium chlorate	25.0	none	5.45	65.0
Sodium chlorate	30.0	none	5.45	80.0
Atlacide	5.0	none	.....	5.0
Atlacide	10.0	none	.....	10.0
Atlacide	15.0	none	.....	15.0
Atlacide	20.0	none	.....	20.0
Atlacide	25.0	none	.....	30.0
Atlacide	30.0	none	.....	70.0
Sodium chlorate	5.0	0.1	5.45	12.0
Sodium chlorate	10.0	0.1	5.45	20.0
Sodium chlorate	15.0	0.1	5.45	30.0
Sodium chlorate	20.0	0.1	5.45	35.0
Sodium chlorate	25.0	0.1	5.45	60.0
Sodium chlorate	30.0	0.1	5.45	85.0

At this time plants of St. Johnswort were in the early blossom stage. It will be noted that conspicuously low percentages of destruction were obtained with all the chemicals used. An examination of the plots showed the following: Atlacide was much less effective than sodium chlorate; sodium chlorate was more effective when applied in an acid solution than when used in an alkaline solution; increased efficiency resulted when a sticker, or spreader, of glue was used in the spray. The cell sap of the plant at this time was rather acid (pH 5.45).

Summer Treatment.—The results of plots treated in the summer (July 16, 1930) are summarized in table 6.

TABLE 6

RESULTS OF PLOTS SPRAYED JULY 16, 1930

(Spreader of glue, 0.1 per cent of dry weight of chemical used.)

Chemical	Concentration, per cent	Acidity of spray (pH)	Plants killed, per cent
Atlacide	5.0	.....	50.0
Atlacide	10.0	.....	55.0
Atlacide	15.0	.....	75.0
Atlacide	20.0	.....	80.0
Atlacide	25.0	.....	90.0
Atlacide	30.0	.....	95.0
Sodium chlorate	5.0	8.0	75.0
Sodium chlorate	10.0	8.0	80.0
Sodium chlorate	15.0	8.0	88.0
Sodium chlorate	20.0	8.0	90.0
Sodium chlorate	25.0	8.0	94.0
Sodium chlorate	30.0	8.0	99.0
Sodium chlorate	5.0	4.9	70.0
Sodium chlorate	10.0	4.9	80.0
Sodium chlorate	15.0	4.9	85.0
Sodium chlorate	20.0	4.9	95.0
Sodium chlorate	25.0	4.9	99.0
Sodium chlorate	30.0	4.9	99.0
Sodium chlorate	5.0	3.0	75.0
Sodium chlorate	10.0	3.0	85.0
Sodium chlorate	15.0	3.0	90.0
Sodium chlorate	20.0	3.0	95.0
Sodium chlorate	25.0	3.0	98.0
Sodium chlorate	30.0	3.0	99.5

At this time the plant had passed the full blossoming stage and most of the flowers had wilted. It will be noted that Atlacide was not particularly toxic in concentration below 20 per cent, and sodium chlorate was not strongly poisonous below a concentration of 10 per cent. Sodium chlorate was again most effective in killing the plants when used in an acid solution, particularly in decidedly acid solutions (pH 3 and pH 4.9 being most efficacious), the latter being the acidity of the cell sap.

Seasonal Differences in Destruction of the Weed.—Some workers have suggested that weed eradication should be attempted only at certain times in the stage of growth of the plant. Hansen[10] in discussing the use of sodium chlorate as a herbicide suggests that the early bloom stage is the most effective time to apply the spray. Gray[9] found that morning glory is most easily killed with a herbicide applied late in the growth cycle of the plant.

In order to clarify this matter, so far as concerns effective spraying of St. Johnswort in California, and to determine the time of greatest toxicity of applying the chemicals, an organic analysis was made of the top growth—stems and all its parts—in four stages of the growth cycle. This was done to determine whether there was a correlation between mortality and the carbohydrate content. The results of these analyses are presented in table 7.

TABLE 7

Results of Organic Analysis of St. Johnswort

Date of harvest	Stage of growth	Total sugars*, per cent	Starch and† hemicelluloses, per cent	Organic nitrogen, per cent
April 28, 1930	Early growth	1.62	3.64	2.02
May 20, 1930	Shortly before bloom	3.60	5.76	1.29
June 10, 1930	Early bloom	4.74	4.40	1.00
July 19, 1930	Shortly after bloom	3.74	5.96	0.88
September 17, 1930	At seed maturity	2.10	4.66	0.69

*According to iodometric determination of copper and its use in sugar analysis as proposed by P. A. Shaffer and A. F. Hartman in Journal of Biological Chemistry **145**: 349-390, 1921.

†Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists 1924, **21**: 119.

The per cent of total sugars appears to be significant in connection with the toxicity of sprays. An examination of figure 20 shows a rapid rise in per cent of total sugars of the tops in early spring, followed by a maximum percentage in late spring when the plants were beginning to bloom. Thereafter a gradual decline in per cent of total sugars took place up until the close of the growth cycle. The poorest results as regards per cent of plants killed were obtained in late spring when the top growth contained the largest amount of total sugars. The best results at this season, however, were procured with sodium chlorate of a very acid character (pH 3). The results are plotted in figure 20 for concentrations of 10, 20, and 30 per cent solutions of the chemical.

This study indicates that the most favorable time to apply sodium chlorate or Atlacide to St. Johnswort in northern California is either in early spring (April or May) or in late summer (September), before or after blossoming time. The disadvantage of spraying in late summer or fall lies in the fact that the plant has produced seed. One advantage at that season, however, is that St. Johnswort is not confused with other plants and is easily located on the range.

Sodium chlorate and Atlacide, when applied in an aqueous spray to the aerial parts of St. Johnswort, are markedly slow in their toxic

action on the plants. Within a few hours after spraying, depending upon temperature and air humidity, the stems of the plant droop heavily at the tips and the margins of the leaves curl inwardly as if the plant were suffering from lack of water. In a few days the leaves begin to turn brown and the internal (cortical) tissues of the stem darken in color. An aromatic odor like that of new-mown hay is given off by the sprayed plants. Within about two weeks the cortical tissue and pith in the root become dark brown and the plant soon

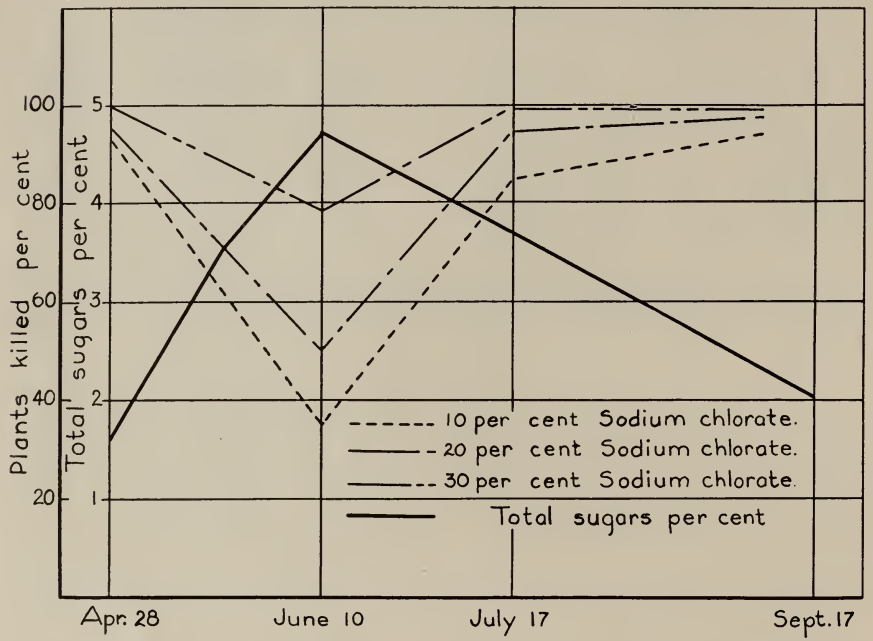

Fig. 20.—Effect of season on toxicity of spray. Seasonal variation in total sugars of tops of St. Johnswort is a possible explanation of the difference in toxicity of sodium chlorate spray.

thereafter dies. Apparently the toxicity of sodium chlorate to plant tissue is enhanced by its slow rate of action upon the living contents of the cells, in that greater amounts of the chemical are carried by the conductive system throughout the plant than would otherwise be possible with a chemical which quickly kills the protoplasm of the cells.

Recommendations for Use of Chemical Sprays.—Upon the basis of the results obtained in the use of chemicals, particularly sodium chlorate and Atlacide, recommendations for their use in the eradication of St. Johnswort are made as follows:

Extreme caution and care should be taken by all workers handling sodium chlorate and Atlacide that the solution be not allowed to dry on their clothing, since organic matter when saturated with this salt is highly inflammable and explosive. Clothing of workers should always be washed thoroughly in water after handling the chemical. The chemicals should never be mixed near farm buildings because of the fire hazard.

A 15 per cent solution (about 1¼ pounds per gallon of water) of sodium chlorate is of sufficient strength to kill the plant. A 20 per cent solution of Atlacide (1⅔ pounds per gallon of water) may be used instead of sodium chlorate to destroy the plant. About a tablespoonful of glue per gallon of solution should be added as a spreader. The glue solution may be made by dissolving overnight in a pint of water a small handful of flake glue. About ¼ teaspoonful of sulfuric acid should be added to each gallon of water.

A suitable portable spray tank costs about $6.00 and holds about 1.5 gallons of solution, which if applied as a fine mist spray will cover an area of approximately 1/100 acre (42 ft. × 10 ft.). Sodium chlorate purchased in reasonably large amounts costs about 8 cents per pound, and Atlacide about 10 cents. At this rate the cost of sodium chlorate to spray an acre would be about $18.00, whereas the cost of Atlacide would be about $30.00. Obviously, then, cost prohibits the use of these chemicals on areas of large size. In the destruction of small patches the cost of the spray is by no means prohibitive. Spray equipment of considerable capacity will be needed if large areas are to be treated with chemical sprays.

Vegetation that has been sprayed with sodium chlorate and Atlacide (although to a lesser degree with the latter) is highly inflammable in very dry weather and may catch fire from friction alone, until the salt has been washed off by heavy dew or rain. Early spring or late autumn, during the non-fire season, therefore, are especially recommended. Livestock should be removed from the area until weather conditions have made it safe to graze.

In the eradication of small patches it is advisable to use Atlacide, because of the lesser danger to the worker and the smaller fire hazard.

A second, or follow-up spray, should always be made in order to eradicate plants that are either not entirely killed or were overlooked in the application of the spray. This should take place about three weeks after the first application.

APPLICATION OF THE STUDY TO PRACTICAL CONTROL

Small colonies of St. Johnswort should be eradicated in the season that they are discovered. This can best be done by spraying with sodium chlorate or Atlacide, preferably the latter because of its greater safety, using an inexpensive, portable tank which emits a fine spray. This work should be followed by a second spraying the following spring or autumn in order to destroy any seedlings and sprouts that may have come from the parent plants.

Fig. 21.—Goat grazing tends to control the spread of St. Johnswort. Although the pasture has long been infested, it was not until goat grazing was discontinued that St. Johnswort became conspicuous.

Control and destruction of large infestations is a problem not yet solved. The cost of spraying with the chemicals here used is too high for extensive application. The fact, however, that St. Johnswort comes in most seriously on overgrazed areas justifies the adoption of some grazing system which will increase the general forage cover, thereby checking to some extent at least the more vigorous invasions of St. Johnswort, and incidentally decrease the amount of seed produced.

An encouraging observation is the manner in which the density of infested areas is reduced by goats. Although St. Johnswort appears to be mildly poisonous to these animals, the leafage and tender stems seem as palatable to goats as grass vegetation (fig. 21). It is the belief of the writers that goats should be grazed on all areas infested

by St. Johnswort, their numbers to be determined in general by the abundance of this weed in proportion to that of grasses and browse. On a cover combination largely of grass and St. Johnswort, the number of goats should be such as to keep the weed pest grazed down. Goats seem to do this without taking much of the grass feed. The grass and other such feeds may be utilized moderately by more profitable livestock. The problem, however, of using goats extensively involves new methods in the whole plan of livestock production.

Some stockmen have suggested that bad infestations of St. Johnswort might be pastured heavily by cattle and sheep early in the grow-

Fig. 22.—Grass vegetation usually comes in soon after St. Johnswort is killed by spraying. Left: infested area not sprayed; right: area sprayed in early spring, 1929. The use of sodium chlorate or Atlacide does not interfere with later invasions of a good grass cover.

ing season, for when St. Johnswort is young it may not be poisonous. Seddon and Belschner,[23] however, found that the plant is harmful to livestock in the early stages of growth. They also concluded that grazing the plant when young gave a certain measure of control, but that it could not be entirely eradicated by such treatment.

It is believed that a grazing control experiment would be worthy of trial where St. Johnswort on a portion of the pasture—say one-quarter of its area—would be eradicated by spraying, the eradicated area fenced and permitted to rest until a grass cover is established. Almost invariably grass comes in soon after the destruction of St. Johnswort (fig. 22). During the proposed rest period the animals could graze moderately upon the adjoining infested area.

When the eradicated portion is ready for pasturing, the animals might be alternated from this paddock to the adjoining infested area at such intervals as appear advantageous. If possible, some goats should be kept continuously on the infested portion. The practicability of a test such as this might well be tried on a good-sized scale.

Often only a single field or pasture of a ranch is infested with St. Johnswort. To prevent colonies of this pest from becoming established on clean fields, it is of great importance to observe certain precautions.

Fig. 23.—Public driveway heavily infested with St. Johnswort. Such infestations may be the cause of widespread distribution of the plant and should be destroyed or prevented from going to seed.

The use of seed free from that of St. Johnswort is of the utmost importance, whether it be wheat seed or some other to be sown. Seeds of cereals, clover, or grass grown where St. Johnswort has become established should never be used for seeding purposes. Unclean seed is often the cause of St. Johnswort starting along fence lines and roadsides, from whence it may spread widely.

Hay containing St. Johnswort should never be fed to livestock on pasture or hay meadow that is not infested with the weed. Because the seed of St. Johnswort is very small and readily planted by trampling, the weed may get a foothold. Even seed of this pest that is eaten with infested hay may pass out undigested, like seed of clover and that of many other plants, and ultimately replace the other vegetation. It is probably of equal importance to avoid scattering of infested manure on clean fields. Under favorable growth conditions the weed is almost sure to grow vigorously.

It is probable that the extensive spread of St. Johnswort has come about as a result of driving cattle and sheep along heavily infested public driveways and trails (fig. 23). Seed adheres to hair, wool, and tails of livestock, thus assuring its wide dissemination. Before seed maturity, the plants along driveways should be mowed or otherwise destroyed. This may best be done by community cooperation, as through the Farm Bureau, in cooperation with the farm advisor.

The fact that the seed of St. Johnswort is not injured by long periods of immersion in water, points to the importance of controlling infestations along streams whose waters carry St. Johnswort into weed-free territory. Often these plants get started along dry banks from seed deposited when the water is high. Any rational measures that would destroy the plants whose seed might be transported by water onto new lands should be carried out.

SUMMARY AND CONCLUSIONS

St. Johnswort (*Hypericum perforatum* L.), known to stockmen of California as Klamath weed, is the most serious pest found on ranges and pastures of northern California. The earliest infestations in the state were recognized about thirty years ago. The plant now occupies over 100,000 acres of choice pasture lands of the state.

St. Johnswort is poisonous to livestock, but losses by death are not serious. The heaviest losses are caused by the poor condition of health and flesh of the animals grazed upon infested areas and by the serious decline in grazing capacity. This weed crowds out the clovers and practically all the grasses of high forage value. The few grasses and other plants that typically grow beneath St. Johnswort are of almost no value for grazing.

Among the mechanical methods employed to eradicate and control the spread of this plant, such operations as digging, cutting, covering, flooding, burning and overgrazing have been suggested. None of these methods is effective.

Among the natural enemies that might curtail the spread of St. Johnswort may be mentioned fungi, insects, birds, foraging animals, rodents, and climate. Except for the latter, the aggressiveness of this plant is not hampered. Temperature and precipitation are limiting factors in the rate of spread of the plant on local areas and in determining the elevational range. Periodic extensive invasions of this weed are probably accounted for by the exacting germination requirements of the seed, which are controlled by the climatic environment and soil complex. Introduction of insects that effectively control St. Johnswort in Europe would appear worthy of trial, provided extreme

caution were used to avoid insects that might prove injurious to valuable native or other vegetation.

Of the chemical methods of eradication tested, sodium chlorate and Atlacide are by far the most effective. These sprays should be made reasonably acid for the best results. Spraying in early spring and in autumn is considerably more effective than in late spring when the flowers are in the late bud stage or when the plants are in early blossom.

When a single field or pasture of a ranch is infested, great care should be taken to use clean seed, as for planting, and clean hay, especially if fed in the field. Manure which is likely to have seed of St. Johnswort in it should obviously not be scattered on uninfested ground. Stands of St. Johnswort along roads, community driveways, and trails should be destroyed; or at least the plants should not be permitted to produce seed. St. Johnswort should be eradicated along streams whose waters are carried into weed-free territory.

Small colonies of St. Johnswort should be eradicated in the season when discovered, preferably using Atlacide because it is less inflammable than the more effective sodium chlorate spray.

The control and destruction of large infestations is a problem not yet solved. The cost of extensive spraying with chemicals is prohibitive. Any plan of increasing the forage growth appears to check the rate of invasions of St. Johnswort and decreases seed production. One of the more promising means of holding the invasions in check is through the use of goats. These animals might well be grazed, on all areas infested, with other livestock, their numbers to be determined by the abundance of this weed in proportion to that of grass and browse vegetation. Although St. Johnswort is reported to be mildly poisonous to goats, these animals consume the young growth in preference to that of many grasses.

It would appear that a grazing control experiment might be worthy of trial where approximately one-fourth of the infested pasture would be eradicated of St. Johnswort by spraying, then fenced and permitted to rest until the grass cover is reestablished. With this area available, alternate grazing could be practiced with sheep and goats, the latter to remain on the infested portion of the pasture more or less continuously.

Further studies might well be undertaken to determine the period of life of stands of St. Johnswort on the more extensive soil and vegetative types. Also, it should be determined whether there are any forage plants, native or introduced, that might be used to crowd out St. Johnswort on infested pastures.

LITERATURE CITED

[1] Aslander, A.
1927. Sulfuric acid as a weed spray. Jour. Agr. Res. 34(11):1065–1091.

[2] Aslander, A.
1928. Experiments on the eradication of Canada thistle, *Cirsium arvense*, with chlorates and other herbicides. Jour. Agr. Res. 36(11):915–933.

[3] Barton, B. S.
1793. An inquiry into the question whether the *Apis mellifica* or true honey-bee is a native of America. Am. Phil. Soc. Trans. 3:241–261.

[4] Brenchley, W. E.
1925. Spraying for weed eradication. Jour. Bath and West and South Counties 19(5):1–20.

[5] Bolley, H. S.
1901. Studies upon weeds in 1900. North Dakota Agr. Exp. Sta. Ann. Rpt. 11:48–56.

[6] Cirillo, D. D.
1787. Fundamenta botanicae (Naples), pp. 1–135.

[7] Darlington, W.
1826. Florula cestrica; an essay towards a catalog of the phaenogamous plants, native and naturalized, growing in the vicinity of the borough of West Chester, in Chester County, Pennsylvania (West Chester, Pa.), pp. 1–152.

[8] Dusserre, C.
1899. Destruction des mauvaises herbes par les substances chimiques. Chron. Agr. Canton Vaud, ann. 12:265–268.

[9] Gray, G. P.
1919. Tests of chemical means for control of weeds. Univ. Calif. Publ. in Agr. Sci. 4(2):67–97.

[10] Hansen, A. A.
1928. Sodium chlorate as a herbicide. Proc. Indiana Acad. Sci. 38:139–141.

[11] Imms, A. D.
1930. The biological method of pest control. Nature 126:573–574. (Macmillan and Co., Ltd., London.)

[12] Jones, L. R., and W. A. Orton.
1897. Orange hawkweed or "paint brush." Vermont Agr. Exp. Sta. Bul. 56:1–16.

[13] Latshaw, W. H., and J. W. Zahnley.
1927. Experiments with $NaClO_3$ and other chemicals as herbicides for field bindweed. Jour. Agr. Res. 35:(8):757–767.

[14] Loyer, M.
1923. The use of chlorates for the destruction of weeds. Comptes Rendu des Sciences de l'Academie d'Agriculture de France, pp. 957–960.

[15] MARSH, C. D., and A. B. CLAWSON.
1930. Toxic Effect of St. Johnswort (*Hypericum perforatum*) on cattle and sheep. U. S. Dept. Agr., Bur. Pl. Ind., Tech. Bul. **202**:1–24.

[16] MORRELL, L. A.
1845. The American shepherd; being a history of the sheep with their breeds, management, and diseases (Harper and Brothers, New York), pp. 1–437.

[17] MUHLENBERG, H.
1793. Index florae lancastriensis. Am. Phil. Soc. Trans. **3**:157–184.

[18] OFFORD, H. R.
1930. The chemical eradication of ribes. (Unpublished Bul. U. S. Dept. Agr., Bur. Pl. Ind.)

[19] PIPER, C. V.
1906. Flora of the state of Washington. U. S. Nat. Mus. Contrib. U. S. Nat. Herbarium **11**:390.

[20] POTTS, H. W.
1902. A brier and blackberry bush eradicator. Jour. Dept. Agr. Victoria **1**:27.

[21] PURSH, F.
1814. Flora Americae septentrionalis; or, a systematic arrangement and description of the plants of North America. 2 vols. (Printed for White, Cochrane and Co., London.)

[22] RABATE, M.
1922. La destruction des mauvaises herbes (Paris), pp. 1–170.

[23] SEDDON, H. R., and H. G. BELSCHNER.
1929. The effect of young immature St. Johnswort on sheep. Agr. Gazette of New South Wales **40**:914–916.

[24] SIERSCH, E.
1927. Anatomie und Mikrochemie der Hypercumdrüsen. Planta: Archiv fur Wissenschaftliche Botanik **3**:481–489.

[25] TILLYARD, R. J.
1929. The work of the Division of Economic Entomology for the year 1928–29. Commonwealth of Australia. Pamphlet **15**:1–19.

[26] THOMPSON, N. F., and W. W. ROBBINS.
1926. Methods of eradicating the common barberry. U. S. Dept. Agr. Bul. **1451**:1–46.

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