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

THE CHEMICAL CONTROL OF ST. JOHNSWORT

R. N. RAYNOR

BULLETIN 615
November, 1937

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

CONTENTS

THE CHEMICAL CONTROL OF ST. JOHNSWORT[1]

R. N. RAYNOR[2]

INTRODUCTION

THE IMPORTANCE of St. Johnswort or Klamath weed (*Hypericum perforatum* L.) as a pest on range lands in California was emphasized in an earlier publication of this Station,[(19)3] which pointed out that by poisoning livestock and reducing forage this weed has become the greatest single cause of financial losses on range and pasture in the state. At that time (1930), according to estimates, it infested at least 100,000 acres, principally on rough, hilly, and mountainous land in the northern counties. Since then it has spread into new territory and has increased in seriousness in the areas previously infested.

The publication mentioned above reported experiments on mechanical and chemical control. It concluded that digging, cutting, covering, burning, and overgrazing are useless; and that chemical methods, though effective, are economically practicable only on small and scattered infestations. The cost is prohibitive on a large, dense growth, especially since the pest is principally confined to land of low value.

Spraying in early spring or autumn with a 15 per cent solution of sodium chlorate or a 20 per cent solution of Atlacide (a proprietary chlorate mixture) was the chemical method recommended.

After this recommendation, stockmen in northern California used sodium chlorate to control scattered infestations of St. Johnswort on their ranges. The results were not uniformly satisfactory—largely, it seems, because the operators failed to follow the advice as to time of spraying and concentration of solutions. They sprayed when the plants were in bloom, usually in July, since isolated plants were more easily located at that season. To obtain a satisfactory kill from midsummer applications, the concentration had to be increased from about 1¼ pounds per gallon (15 per cent) to 3 or 4 pounds.

Such highly concentrated solutions intensified the fire hazard that always attends application of chlorate sprays in the dry season, and several fires resulted. A few men were injured when their spray-

[1] Received for publication May 13, 1937.

[2] Associate in the Experiment Station.

[3] Superscript figures in parentheses refer to "Literature Cited" at the end of this bulletin.

saturated clothing ignited after drying. Fires started by men or animals walking through sprayed vegetation destroyed valuable dry forage and, besides rendered the spray treatment a complete loss on the burned area.

Several times, cattle and sheep were reported to have died after eating relatively small quantities of St. Johnswort sprayed in summer with concentrated sodium chlorate solutions.

The growers' dissatisfaction with chlorate sprays, and the continued spread of the weed, led to the reopening and extending of the investigations on chemical control. A temporary field station was established in February, 1934, near Fort Seward, in southeastern Humboldt County; and with the owners' permission plot tests were located on several solidly infested areas near Fort Seward and Blocksburg.

This report will present the results of these plot tests, conducted over two years with sixteen different chemicals and six mixtures. The list includes most of the chemicals that have proved satisfactory as herbicides. These fall into four general classes, based on their different ways of affecting plants and soil: (1) contact sprays, which kill only the tops of plants and which are useful against perennial weeds (such as St. Johnswort) only to prevent seeding; (2) translocated sprays, which are absorbed by the tops of plants to which they are applied and which penetrate and kill the underground parts; (3) temporary soil sterilants, which are absorbed from the soil by the roots and rootstocks of plants but which do not permanently injure the soil; (4) permanent soil sterilants, which injure the soil and prevent the establishment of seedlings. Some chemicals may act in two or more of these ways—sodium arsenite, for example, may be either a contact spray or a translocated spray, according to the conditions; and when applied to the soil in larger amounts it is a permanent soil sterilant.

Detailed studies to determine the best rate, season, and method of application were made with the herbicides that preliminary trials showed to be most effective.

EXPERIMENTAL METHODS

The test plots were located in a region of extremely rough topography, with considerable variation in slope and exposure. The soil layer varied in depth, rock outcrops appearing at the surface in places. Variations in slope, drainage, and soil depth have undoubtedly influenced the results, especially for treatments in which the chemical was applied to the soil.

The seasonal precipitation averages about 40 inches, the rainy season extending from September through May. Seasonal distribution by months is given in table 18. The summer season is dry, and temperatures of 100°F and over are not unusual in July and August.

The plots, each 1 rod square, were located in dense stands of St. Johnswort. A 3-gallon knapsack sprayer of the Vermorel type, equipped with a Hummer nozzle with No. 3 disk, was used in applying the sprays. The Hummer nozzle produces a flat fan spray and, when each plot was covered in two directions, gave very even distribution. All spray treatments were made up to 3 gallons, regardless of the actual weight of chemical used or whether it was applied to tops or to soil. This volume sufficed to wet thoroughly all plants in the densest stands encountered and was also convenient for soil treatments. Dry materials were applied by hand broadcasting, the plot being covered in two directions for even distribution.

Top growth was removed either by close mowing or by scalping with a hoe from plots receiving soil treatments in summer. A comparison of plots from which the dead flowering stalks were removed with plots on which stalks were undisturbed showed no significant differences with any soil sterilant. Consequently, winter soil treatments were made on undisturbed plots. In practical control operations, of course, one must remove all vegetation before using poisonous soil sterilants on areas to which livestock have access.

The percentage of kill effected by the various treatments, as recorded in the tables, is a visual estimate of the difference in density of stand before and after treatment. A kill of 90 per cent or over indicates a satisfactory treatment. Because of slight irregularities in application and perhaps also because of greater resistance in a few individual plants, a 100 per cent kill is often impossible unless excess chemical is used. For complete eradication, as data in the tables show, one must sometimes double an application that gives 90 per cent kill.

CONTACT SPRAYS

Certain chemicals kill the tops of plants on which they are sprayed or dusted, but do not directly affect the roots, either by movement within the plant or by absorption through the soil. These are called contact sprays, since they destroy only the tissues to which they are directly applied—that is, the leaves and stems. Killing the tops of annual and biennial weeds with contact sprays indirectly destroys the roots also, since they do not regenerate new tops. Killing the tops of perennial weeds like St. Johnswort, on the other hand, is only a temporary setback, since the rootstocks or roots soon send up new shoots. The principal use of contact sprays is therefore in controlling annual and biennial weeds and occasionally in killing the tops of perennials to prevent them from forming seed.

The seeding of St. Johnswort on range lands is probably most economically prevented by cutting or breaking the tops near the crown and, if seed is nearing maturity, by gathering and burning the severed tops.

TABLE 1

RESULTS WITH CONTACT SPRAYS, SUMMER, 1934

Chemical	Concentration, per cent	Bud stage (May 16)	Early bloom (June 1)	Full bloom (July 2)	Green seed (Aug. 1)
Sulfuric acid	1.0	..	..	–*	+*
	2.5	..	–	+	+
	5.0	+	+	+	+
	7.5	+	+	..	..
	10.0	+	..	..	..
Sodium hydroxide	4.0	–	..	..	..
	5.0	..	–	+	+
	6.0	–	..	..	..
	7.5	..	–	+	+
	8.0	+	..	..	..
	10.0	..	+	+	+
Sodium chromate	5.0	+	+	..	..
	7.5	+	+	–	–
	10.0	+	+	+	+
	12.5	..	..	+	+
Sodium arsenite†	0.5	..	+	..	..
	1.0	+	+	+	..
	1.5	..	+	..	..
	2.0	..	..	+	..
	2.5	+	..	..	..

* The plus sign (+) means the entire shoot was killed down to the root crown, while the minus (–) sign means that at least the lower portion of the shoot survived.

† Percentages given as per cent of arsenic trioxide.

Contact sprays were tested, however, because, since St. Johnswort is easily killed by smothering[19] and cultivation, mowing off the tops or killing them with contact sprays might, at some stage of the growth cycle, weaken the plant sufficiently to cause its death. The tests were repeated at four different stages of the flowering period—in bud, early blossom, full blossom, and green seed. Check plots, on which the tops were removed by cutting, were included. The results were almost entirely negative; only young and weak plants were killed, and they in no case exceeded 10 per cent of the treated stand.

Plants sprayed or mowed in the bud and early blossom stages set seed on the regrowth, whereas those sprayed or cut in the later flowering stages, but before any seed was mature, were prevented from seeding.

The relative effectiveness as contact sprays of sulfuric acid sodium hydroxide (lye, caustic soda), sodium chromate, and sodium arsenite, is shown in table 1. Other chemicals tried but found ineffective at concentrations up to and including 10 per cent were copper sulfate, zinc sulfate, and sodium metaborate. In a single trial with sodium fluoride a suspension containing 0.8 pound of chemical per gallon was effective.

The table indicates whether a given concentration destroyed the tops back to the crowns. Some tops were injured by even the lowest concentrations; but when only the terminal inflorescence dies, the lower lateral branches take over the function of flowering, and so seed continues to form unless the entire shoot is killed.

At the lowest effective concentration sulfuric acid and sodium arsenite are the least expensive contact sprays; on a strictly cost basis there is little choice between them. A 5 per cent solution of sulfuric acid and a 1 per cent solution of sodium arsenite can each be prepared for about one-half cent per gallon, at present prices. Being extremely poisonous, sodium arsenite cannot be used as a contact killer on areas accessible to livestock. As will be shown later, however, it is less hazardous and fairly effective as a control measure when applied to the soil. The hazard involved in spraying vegetation with sodium arsenite is accentuated by the attraction that this poison holds for livestock, probably because of its salty taste.

Although, in general, seeding is most easily and economically prevented by cutting, and although this method is preferable when seeds are approaching maturity since the tops may then be gathered and burned, situations may arise where the operator prefers a contact spray. In such cases 5 per cent sulfuric acid is recommended, as prepared by pouring 1¼ pounds of concentrated sulfuric acid (66° Baumé) into 3 gallons of water, stirring constantly while pouring. Larger amounts may be prepared by adding 43 pounds (approximately 3 gallons) of concentrated acid to 97 gallons of water. The plants should be thoroughly wet with the spray. Dense stands will require 3 gallons per square rod or 480 gallons per acre.

The dilute spray solution is extremely corrosive to some metals and to clothing. Parts of the sprayer, such as tank, pump, and nozzle, should be of bronze, brass, or other acid-resistant metals, and even these are subject to slow corrosion. Equipment of iron or steel or that which is porcelain-lined should not be used. Power-sprayer equipment recently designed eliminates many mechanical difficulties formerly encountered in handling acid sprays.[4] The new equipment obviates the need for acid-resistant tanks and pumps, as these parts handle water only, the acid entering through a side tube into an ejector placed between the pump and the boom.

TRANSLOCATED SPRAYS

Translocated sprays, unlike contact sprays, not only kill the leaves and stems of perennial plants but also, under rather specific conditions, penetrate and kill roots and rootstocks to a considerable depth. The term *translocation* describes this movement of the herbicide within the plant.

The mechanism responsible for downward translocation of herbicides depends upon a water deficit in the plant.[(6, 15)] Translocated sprays should be applied in summer or fall to mature plants with well-developed foliage, growing in soil practically depleted of available moisture. Spraying after dark, when the evaporation rate is low, permits greater penetration and deeper killing.

The depth of penetration varies between species, and is probably related to the plant structure. For example, a spray containing ½ per cent arsenic trioxide (added in the form of sodium arsenite) and 5 per cent sulfuric acid has killed roots of Russian knapweed (*Centaurea repens*) and bindweed (*Convolvulus arvensis*) deep enough to prevent regrowth; but on other species, including hoary cress (*Lepidium draba*), the root-kill is insignificant.

Arsenic compounds ordinarily surpass sodium chlorate as an active ingredient of translocated sprays because of their greater toxicity. The small volume of spray solution translocated into the roots is further diluted by sap from the killed cells of leaves and stems; the material, therefore, must be toxic when present in low concentration.

Although arsenical top sprays cannot be recommended when they effect only a contact kill, since the equally satisfactory and nonpoisonous sulfuric acid spray is available, their low cost offsets the poison hazard when root-kills are obtained. Enough translocation to effect good root-kills would probably never occur in scattered stands, since under those conditions soil moisture may never be sufficiently depleted. Still, conceivably, arsenical sprays might provide an economical chemical method for the large areas of dense infestations. The acid-arsenical spray effective on Russian knapweed and bindweed costs about one cent per gallon at present prices and when used at the rate of 3 gallons per

[4] Directions and precautions for handling and mixing dilute sulfuric acid for weed control are given in detail in reference No. 3 cited at the end of this bulletin.

square rod the expense is less than $5.00 per acre for spray materials.

Tests during the summers of 1934 and 1935 to determine the degree of control attainable with sodium arsenite top sprays on St. Johnswort are reported in table 2.

The sodium arsenite used in these tests was prepared by mixing 4 parts arsenic trioxide (white arsenic), 1 part sodium hydroxide (lye, caustic soda), and 3 parts water. This makes a concentrated stock solution of sodium arsenite equivalent to 50 per cent by weight of arsenic trioxide. Spray was prepared by diluting this stock solution; and the concentrations in the table are calculated on the basis of arsenic trioxide, though the compound was actually sodium arsenite. The sprays headed "acid" contained sulfuric acid in a concentration of 5 per cent (approximately 1 normal hydrogen ion), whereas those headed "alkali" contained sodium hydroxide in a concentration of 4 per cent (approximately 1 normal hydroxyl ion). No acid or alkali was added to the "neutral" series. Sodium arsenite prepared by the above-mentioned formula is an acid salt and is practically neutral in dilute solution.

TABLE 2

Percentage of Plants Killed by Translocation of Arsenical Sprays

Reaction of solution	Concentration of As_2O_3, per cent	Date treated			
		July 6, 1934*	Aug. 7, 1934*	July 11, 1935†	Aug. 5, 1935†
Neutral	1	10	..	30	50
	2	15	..	25	75
	3	30	50	75	70
Alkaline	1	0	10	50	75
	2	0	20	75	85
	3	25	..	99	75
Acid	1	0	30	20	10
	2	10	60	40	15
	3	20	60	80	40

* Per cent kill recorded for plots treated on this date is as observed December 10, 1934.

† Per cent kill recorded for plants treated on this date is as observed January 22, 1936.

In 1934, applications previous to July 1 acted as contact sprays, killing the tops only, and are not shown in table 2. The contact effect of the neutral series was reported in table 1. As the summer progressed, the air temperatures increased and the soil moisture decreased in availability; and some translocation obviously occurred.

Neutral arsenite sprays apparently equaled those containing acid or alkali as penetrating agents. The percentage of plants killed increased with the increasing concentration of arsenic up to the highest concentration tried, namely, 3 per cent arsenic trioxide. Crafts[6] has shown that on bindweed there is no increase in effectiveness above ½ per cent arsenic trioxide. Since higher concentrations are required on St. Johnswort, evidently the volume of spray solution penetrating the roots is smaller than in bindweed. The subterranean parts of the St. Johnswort plant—particularly the root crown—are woodier than the similar parts of the bindweed plant; and this difference in the relative proportions of woody elements, and hence in elasticity of the conducting elements, may explain the differing amounts and depths of translocation in the two species.

In the summer of 1934 the August applications were more effective than those in July, whereas in 1935 the opposite was true. This discrepancy is explainable on the basis of rainfall distribution. Soil moisture and atmospheric humidity were maintained by late rains in 1934, with the last rain of the season on June 27, whereas in 1935 the last spring rain was on May 16. Soil and atmospheric conditions influencing translocation were even more favorable in July, 1935, than in August, 1934. In 1935, lack of moisture hastened the maturity of that season's growth so that by August the plants had lost most of their leaves, and the stems were fairly hard and woody. There was a smaller, and at the same time less penetrable, surface through which to absorb the sprays; and less translocation occurred than in the previous month.

In these tests, incidentally, spraying was done in the daytime. Although better control would probably have resulted from spraying at night, such a procedure is impracticable on range lands. The results therefore represent the control attainable by practical applications in dense stands.

As Crafts[6] has pointed out, isolated plants and plants at the edges of dense stands never reach the proper stage for spraying as do those in dense stands. Furthermore, differences in exposure, slope, and depth of soil commonly occurring within short distances in St. Johnswort-infested regions also cause considerable differences in the condition of plants even in dense stands. Differences were observed, for example, within the square-rod area of the test plots, because of such small variations as slight depressions, a few inches deep and only a yard or two in diameter; or on similarly slight elevations on land of otherwise even grade. Plants on the elevations were more easily killed than plants in the depressions, presumably because of dissimilar moisture content of the soil in the two situations.

Evidently, therefore, the percentage of root-kill due to translocation of arsenical sprays applied to the aerial parts of St. Johnswort plants is not high enough, considering the extreme poison hazard to livestock, to justify such sprays in any practical control program.

TEMPORARY SOIL STERILANTS

Perhaps the most successful chemical method of killing the deeper roots of perennial weeds is to apply certain chemicals to the soil surface, with subsequent leaching into the root zone by rain or irrigation. This process is called soil sterilization.

The rate of application of soil sterilants to kill a given species of weed or to sterilize for any given period varies considerably among soil types. In general, all chemicals are more toxic in light soils (sands) than in heavy-textured soils (clays).[4,8] The differences are explainable in part by the concentration of the solution available to the plant roots.

The percentage of water in a sandy soil at field capacity (the greatest amount of water held against gravity) is less than for a clay soil. A given number of pounds of chemical distributed through a given mass of soil is therefore dissolved in a smaller volume of soil solution in a sand than in a clay.

Another effect correlated with soil texture is the retention of a chemical against leaching; and here the effect is greatest in clays and least in sands.[8]

Because the chemicals are thus held by the soil particles, they tend to be concentrated in the surface horizon. Among the sterilants discussed in later sections the effect is most pronounced with arsenic compounds, considerably less with borates, and least with sodium chlorate.

Besides the effects of texture, soil fertility influences the toxicity of chlorates but not of arsenic or borate compounds; and the effects of fertility overshadow those of texture in most soils. Toxicity of chlorates is greatest in poor soils, least in fertile ones.[4] Chemicals such as chlorates, held only slightly by the soil particles and therefore soon reduced to a nontoxic concentration by leaching, are called temporary sterilants because the soil is soon restored to its original productivity. They are termed temporary in contrast with permanent soil sterilants, such as arsenic compounds, which react with the soil and render it unproductive for more extended periods.

Decomposition, resulting in nontoxic residues, hastens the removal of the temporary soil sterilants, sodium chlorate, and ammonium thiocyanate. Chlorates decompose most rapidly in moist soils at high temperatures.[17]

Some temporary soil sterilants may kill the roots by contact. Others are not sufficiently toxic at the concentration present in the soil solution to cause immediate death. They are absorbed from the soil solution by the roots, along with the mineral nutrients, and are carried into the plant. Because of continued absorption a lethal concentration accumulates within the cells. Once this latter type of sterilant has been leached into the root zone it must remain there, without further leaching, long enough for a lethal quantity to be absorbed. Rainfall distribution is therefore the greatest single factor influencing this type of treatment in a given soil type. First, there must be enough rain to leach the chemical from the surface down into the root zone; then no more rain until the plants have absorbed a lethal dose; and, finally, if the soil must be used for a crop, enough additional rain to leach the residue on down and beyond the reach of the crop plants.

Since most St. Johnswort infestations in California are in regions of at least 30 inches annual rainfall, there is no difficulty in getting temporary sterilants into the soil. The difficulty is that the heavy and prolonged storms of winter leach them down past the root zone so rapidly that the plants fail to absorb a lethal dose. On the flat agricultural lands of the interior valleys, measured irrigation may be used to put the herbicide to the proper depth;[7] and if this work is done early in the dry season the material can act before being removed by the succeeding winter's rainfall. The same effect is realized if the applications are made during the winter rainy season on a date such that the amount of rainfall between then and the dry season just leaches the chemical into the root zone. There it will remain throughout the summer, permitting ample opportunity for absorption.

In the investigation of soil sterilants reported in the remainder of this paper, applications were made at intervals throughout the rainy season in order to determine for each one the amount of rainfall required for optimum results.

One advantage of soil treatments over spraying is that the soil sterilants so applied may be distributed in the dry-powder or crystalline form. The cost of application is considerably reduced,[14] since the equipment needed is usually less expensive; in fact, no equipment at all is required for treating small patches, the material being distributed by hand. More ground can be covered in a given period by such treatment, since no time is lost in hauling water for the solutions and in mixing them. Travel to and from the supply station is less frequent, since a greater weight of active material may be carried on each trip than if it were diluted with water.

Dry application is definitely advantageous in attacking St. Johnswort on range lands in California. Because the broken topography of most ranges renders large-capacity power-spray equipment useless, the less-efficient hand sprayers must be employed. Frequently water for mixing sprays must be carried considerable distances on pack animals.

Considering the advantages of dry application over spraying, the two methods were compared for most of the soil sterilants tested.

SODIUM CHLORATE

Sampson and Parker[19] found that chlorate sprays applied to St. Johnswort in spring or fall brought higher mortality than in summer. They suggested that seasonal variation in spray toxicity might be related to seasonal variation in total sugars of the tops. This theory was in line with the idea, then widely entertained, that chlorate sprays were primarily translocated poisons. More recently, however, it has been amply demonstrated[2, 7, 16, 17] that although chlorates may translocate when the proper mechanism is active, they are primarily soil sterilants.

According to the experiments on arsenical sprays (table 2), translocation of herbicides is not extensive in St. Johnswort even in summer and much less in spring and fall. It cannot explain the superior results of spring and fall applications reported by Sampson and Parker.

Sodium Chlorate Spray Treatments.—Table 3 shows the results of sodium chlorate sprays applied at various times between March, 1934, and May, 1936. The rainfall data show the precipitation in inches between the application date and the last rain of that season. For present purposes, the annual rainfall cycle is considered to extend from the first rain of one autumn to the first rain of the succeeding one.

The first series of plots, treated March 12, 1934, were on a steep slope; and removal of all vegetation with a hoe left them exposed to erosion. Considerable sheet erosion was observed; and part of the chlorate was undoubtedly carried off laterally, so that the actual amount leaching vertically into the soil was less than the amount applied.

The applications on May 4 were exceptionally effective. All plants were destroyed on the plot treated with 1 pound. Rain amounting to 1.84 inches fell between that date and the last rain of the season on June 25. No more rain fell until September 23. The plots sprayed June 8 received the rain of June 25 only, amounting to 0.27 inch—not enough, apparently, for proper vertical distribution of the chlorate, since 1 pound killed but 75 per cent of the plants. Neither were the July 6 and August 1 applications so good as the one on May 4, though complete eradication was secured with 2.5 pounds. Applications during late fall and winter in the 1934–35 season gave very poor results. The rains ceased unusually early in the spring, and the schedule of treatments failed to cover the lower rainfall range satisfactorily. Judging from results of the previous season, 16 inches on the February 9 plots was too much, and 0.84 inch was too little on those treated April 18. The per cent of plants killed on the plots treated April 18, May 20, July 11, and August 15 increased

TABLE 3

PERCENTAGE KILL WITH SODIUM CHLORATE SPRAYS

Rate of application, pounds per square rod	Date of application and inches of rainfall following							
	Season 1933-34, observed December 10, 1934							
	March 12, 8.86 inches	May 4, 1.84 inches	June 8, 0.27 inch	July 6, 0.00 inches	Aug. 1, 0.00 inches			
½	..	20	30	30	30			
1	25	100	75	50	75			
2	95	100	..	...	..			
2½	..	...	90	100	99			
	Season 1934-35, observed September 19, 1935							
	Nov. 22, 33.86 inches	Dec. 7, 31.46 inches	Feb. 4, 17.22 inches	Feb. 9, 16.64 inches	April 18,* 0.84 inch	May 20,* 0.00 inches	July 11,* 0.00 inches	Aug. 15,* 0.00 inches
1	50	0	75	50	25	75	85	..
2	30	30	70	65	60	97	97	95
3	60	40	60	60	90	99	100	100
4	80	60	60	60	92	..	...	...
6	95	50	60	50	97	..	...	...
	Season 1935-36, observed September 7, 1936							
	Oct. 15, 46.66 inches	Feb. 5, 20.06 inches	Feb. 27, 10.71 inches	March 10, 10.64 inches	March 20, 10.64 inches	April 4, 7.64 inches	April 15, 6.02 inches	May 1, 4.29 inches
1	..	30	97	100	100	99	100	99
1½	..	30	99	100	100	100	100	100
2	85	20	100	100	100	100	100	100
3	97	..	...	...	...	...	...	...

* Per cent kill recorded for plots treated on this date is as observed January 22, 1936.

markedly at successive observations after the first rain on September 15; and the maximum per cent reported in the table was not attained until in January, a fact showing definitely the function of rainfall in chlorate treatments. Since the per cent of plants killed by applications on April 18 was lower than for applications later in the summer, there was evidently greater loss in toxicity because of decomposition and fixation over the correspondingly greater period before the fall rains made the chlorates available to the plant roots. In April, 3 pounds was required for satisfactory control; at the later dates only 2 pounds.

In the 1935–36 treatments one should note that those of October 15, after the rainy season began, were more effective than those of February 5, although 46.66 inches of rain fell after the former date as against 20.06 inches after the latter. The superiority of the fall treatment may be explained in that the earlier fall rains were gentle and intermittent, permitting the plants to absorb lethal amounts of chlorate.

The same fact also explains the superiority of the late-summer applications over those in October: because they did not become fully active until fall, they were not essentially unlike fall application, except that the opportunity for loss by decomposition was greater. Presumably the ideal period for fall application would be immediately before the first rain. No decomposition such as takes place in the summer would occur then, and the probability of too-rapid leaching would be less than in late fall and winter. This assumption would explain the excellent results obtained by Sampson and Parker(19) in their September-treated plots.

TABLE 4

PERCENTAGE KILL WITH DRY SODIUM CHLORATE

Rate of application, pounds per square rod	Date of application and inches of rainfall following							
	Season 1934-35, observed September 19, 1935							
	Nov. 15, 37.35 inches	Dec. 8, 31.46 inches	Jan. 30, 17.22 inches	Feb. 2, 17.22 inches	March 30, 7.68 inches	April 11, 2.82 inches	May 20,* 0.00 inches	July 11,* 0.00 inches
1	20	70	0	80	90	60	70	85
2	25	75	20	60	85	60	98	95
3	20	75	40	60	90	60	100	100
4	30	80	40	50	97	60	...	...
6	25	85	75	80	98	90	...	...
	Season 1935-36, observed September 7, 1936							
	Oct. 15, 46.66 inches	Feb. 5, 20.06 inches	Feb. 27, 10.71 inches	March 10, 10.64 inches	March 20, 10.64 inches	April 4, 7.64 inches	April 15, 6.02 inches	May 1, 4.29 inches
1	..	35	97	100	100	99	90	95
1½	..	60	99	100	100	98	95	97
2	80	60	100	100	99	100	99	99
3	95	..	...	...	...	...	..	..

* Per cent kill recorded for plots treated on this date is as observed January 22, 1936.

Beginning February 5, applications were made at approximately two-week intervals, continuing through May 1. Judging from the February 5 plots, 20 inches of rain produced excessive leaching, a finding that agrees with the results on approximately the same date in the previous year, when 16 to 17 inches was excessive. Beginning with February 27, however, after which 10.71 inches of rain fell, 1-pound treatments gave almost perfect control.

Sodium Chlorate Dry Treatments.—A comparison of the dry sodium chlorate treatments in table 4 with the corresponding spray treatments of table 3 shows that a given amount of the salt gives approximately equal results with the two methods of application. The same correlation of results with rainfall is shown by the dry treatments as was pointed out for the spray.

One might expect that where translocation may occur, spraying would be better than dry treatments. This, however, is apparently not the case, as one sees by comparing the dry treatments of May 20 and July 11, 1935, with the corresponding spray treatments. That the translocatory mechanism was active within the plants on July 11 is readily seen from the results (table 2) of sodium arsenite sprays applied on that date. If any chlorate was translocated in the sprayed plants, the benefits were probably at least partially offset by the decomposition of the salt exposed to light and to high temperatures on and in the leaves and stems. When the dry salt is broadcast, little adheres to the plants; most of it falls to the ground, where it is shaded by vegetation.

To summarize the results: 1 pound of sodium chlorate per square rod (160 pounds per acre) controlled St. Johnswort satisfactorily when applied in spring either by spraying or by broadcasting the dry salt, provided 2 to 10 inches of rain fell after the treatments. Spring applications of 1 pound were not satisfactory when leached by less than 1 inch or more than 16 inches of rain. For satisfactory control, 2 pounds per square rod 320 pounds per acre) was required when leached by less than 1 inch of rain in spring, and during summer and early fall. Winter applications leached by over 16 inches of rain were entirely unsatisfactory.

One or two pounds of sodium chlorate per square rod left no injurious residual effect, and seedlings of St. Johnswort and grasses came up on treated plots during the following winter and spring. Where old plants were completely eradicated and a good stand of grasses was quickly established, some seedlings succumbed under competition with the grasses.

BORATES

Work recently published at this Station[10] indicates the suitability of borate compounds as soil sterilants. Borax and the borate ores, colemanite and Kramer ore, are easily leached from the soil, but less readily than sodium chlorate. When unleached they undergo a slow fixation, becoming unavailable to plants. They are nonpoisonous, except in massive doses; also noninflammable, borax having fire-deterrent properties.

Since many crop plants are extremely sensitive to boron and since the yield is depressed by very low concentrations, borate compounds should not be used on cropped areas or on watersheds supplying water to such areas. This objection does not apply to much of the St. Johnswort-infested region in the north Coast Range of California, since underground waters are not used as irrigation supplies and since the grasses that appear after the eradication of St. Johnswort seem relatively tolerant of boron.

TABLE 5

Percentage Kill with Sodium Metaborate Sprays

Rate of application, pounds per square rod of borax	Date of application and inches of rainfall following				
	Season 1934-35, observed September 19, 1935				
	Nov. 22, 33.86 inches	Dec. 7, 31.46 inches	Feb. 4, 17.22 inches	April 18,* 0.84 inch	
2	50	0	20	50	
4	70	20	40	60	
6	70	40	85	90	
8	80	60	99	90	
12	90	75	100	90	
16	99	90	100	..	
	Season 1935-36, observed September 7, 1936				
	Nov. 15, 45.21 inches	Dec. 15, 39.80 inches	Jan. 20, 20.46 inches	Feb. 27, 10.64 inches	March 13, 10.33 inches
6	85	40	70	97	92
8	90	50	85	99	98
10	85	80	98	99	99

* Per cent kill recorded for plots treated on this date is as observed January 22, 1936.

Sodium Metaborate Spray Treatments.—Borax is but slightly soluble in water at ordinary temperatures. To reduce to a convenient amount the volume of solution equivalent to a given rate of borax in pounds per square rod, one must convert borax to the more soluble sodium metaborate by mixing it with sodium hydroxide. A stock solution containing the equivalent of 50 per cent borax by weight was made by mixing 4 parts borax, 1 part sodium hydroxide, and 3 parts water. Spray solutions applied to the plots reported in table 5 were prepared by taking a weight of stock solution double the weight of borax desired on a given plot and diluting to a volume of 3 gallons.

During the 1934–35 season, as table 5 shows, less metaborate was required for satisfactory control in November than in December; but still better control was attained in late winter and spring, when 6 pounds was satisfactory. This is the same relation of toxicity to season found for sodium chlorate. The April 18 series behaved like the sodium chlorate treatments on that date, in that the maximum kill was not recorded before the following January.

In connection with this deferred action of late-spring application, the results of a series of top sprays applied in July, 1934, are significant. The plots in question were sprayed as part of a series to test the

TABLE 6

PERCENTAGE KILL WITH DRY BORAX, 1934–35 SEASON, AS OBSERVED SEPTEMBER 19, 1935

Rate of application, pounds per square rod	Date of application and inches of rainfall following					
	Nov. 15, 37.35 inches	Dec. 8, 31.46 inches	Jan. 30, 17.22 inches	Feb. 2, 17.22 inches	March 30, 7.68 inches	April 11,* 2.82 inches
4	0	50	60	80	60	50
8	0	60	90	99	70	90
12	10	80	99	99	70	75
16	20	85	100	95	75	75
20	70	90	100	95	85	40

* Per cent kill recorded for plots treated on this date is as observed February 1, 1936.

efficiency of sodium metaborate as a contact spray. According to earlier trials, concentrations up to and including 10 per cent borax were not effective; and so in these particular tests the concentrations were increased to 20, 25, and 30 per cent, equivalent to 5, 6¼, and 7¼ pounds of borax per square rod respectively. Even these rather excessive amounts did not effect complete contact killing of the tops.

With the fall rains, however, the material was washed from the tops and leached into the soil, and the percentage of plants thus killed was 75, 99, and 99 on the 5, 6¼, and 7¼-pound plots respectively. This observation suggests that the 6-pound minimum indicated for spring applications would be equally effective at any time during the summer.

In the 1935–36 treatments, toxicity was again fairly high in November, fell off with midwinter applications, and reached a high point in spring when 6 pounds was adequate.

Briefly stated, the data show that 6 pounds per square rod (960 pounds per acre) of borax as a sodium metaborate spray satisfactorily controlled St. Johnswort when applied in spring and leached by 17 inches or less of rain, or in summer or early fall. Midwinter applications leached by more than 17 inches were unsatisfactory.

No seedlings appeared on the 6-pound plots treated in the spring of

1935 until late spring the following year, and then only a very few on each plot. That rate of application, therefore, had inhibited seedling growth for one year. The annual grasses common in that section were

TABLE 7

Percentage Kill with Dry Colemanite and Kramer Ore

Rate of application, pounds per square rod	Date of application and inches of rainfall following				
	Colemanite, 1934-35 season, observed September 19, 1935				
	Nov. 20, 34.57 inches	Feb. 3, 17.22 inches	April 12,* 2.82 inches		
4	20	10	50		
8	20	50	95		
12	20	80	97		
16	70	98	97		
20	70	95	98		
	Kramer ore, 1934-35 season, observed September 19, 1935				
	Nov. 20, 34.57 inches	Feb. 3, 17.22 inches	April 12,* 2.82 inches		
4	30	50	60		
8	30	60	100		
12	70	90	100		
16	95	98	100		
20	95	80	100		
	Colemanite, 1935-36 season, observed September 7, 1936				
	Dec. 15, 39.80 inches	Jan. 20, 20.46 inches	Feb. 5, 20.06 inches	Feb. 27, 10.64 inches	March 13, 10.33 inches
8	60	95	50	98	85
12	40	98	50	99	85
16	40	98	50	100	95
	Kramer ore, 1935-36 season, observed September 7, 1936				
	Dec. 15, 39.80 inches	Jan. 20, 20.46 inches	Feb. 5, 20.06 inches	Feb. 27, 10.64 inches	March 13, 10.33 inches
8	20	90	95	100	85
12	30	80	92	100	95
16	30	40	60	99	95

* Per cent kill recorded for plots treated on this date is as observed February 1, 1936.

retarded less than the seedlings and grew considerably during the winter.

Use of Dry Borax.—Plot tests with dry borax were made during the 1934–35 season only (table 6). Toxicity was low in the fall; increased to a maximum with the applications of January 30 and February 2, which were leached by 17.22 inches of rain; and decreased in the two later applications receiving less rain. Action on the April 11 set of plots was not complete until after further leaching in autumn. Satisfactory control was effected by 8 pounds per square rod at the season of maximum toxicity.

The correlation of rainfall with the results of these treatments differed from that obtained with sodium metaborate. Assuming that the difference in solubility of the two compounds was the principal factor, we may postulate that with the metaborate, the leaching process was essentially a direct vertical displacement of a concentrated solution; with the borax more nearly a true leaching—that is, the percolated solution remained at a low constant concentration until the solid borax particles were entirely dissolved.

A few seedlings were observed on the 8-pound plots in late spring a year after they were treated. The annual grasses common there were also retarded until about February and made less growth than on the corresponding sodium metaborate plots.

Use of Dry Borate Ores.—The crude borate ores, colemanite and Kramer ore, will be discussed together, since they acted similarly throughout the tests.

As shown in table 7, the effects of colemanite and Kramer ore resembled those of dry borax. They were not effective when applied in the fall, either in 1934 or in 1935. The winter applications receiving 17.22 and 20.06 inches of rain were better; but they did not definitely show whether 8 pounds per square rod gives satisfactory control, since those receiving 20.06 inches in 1936 were very erratic. With the spring applications, leached by about 10 and 3 inches of rain, respectively, 8 pounds appears satisfactory. The final kill on the plots receiving 3 inches was not completed until further leaching by the fall rains.

Apparently, 8 pounds per square rod (1,280 pounds per acre) of either colemanite or Kramer ore effects satisfactory control when applied in spring and leached by up to 10 inches of rain, and perhaps up to 20 inches. As with borax, this rate inhibited germination of seedlings for approximately one year.

MIXTURES OF BORATE AND SODIUM CHLORATE

Although borates and chlorates are physiologically antagonistic,[9] their toxic effects being mutually counteractive in mixtures for soil sterilization, such combinations have certain advantages in field practice. If the ratio of chlorate to borax or borate ore is kept low, the antagonism is minimized, the cost reduced, and the fire hazard practically eliminated.

Mixtures of borax or of borate ore with sodium chlorate are advantageous from the standpoint of distribution. An even distribution of sodium chlorate at the rate of 1 pound per square rod is difficult because of the small bulk; on the other hand, 8 pounds of borax or borate ore is unnecessarily bulky. If, however, 4 pounds of the borate material is combined with ½ pound of sodium chlorate, the resulting volume is

TABLE 8

PERCENTAGE KILL WITH SPRAY MIXTURES OF SODIUM METABORATE AND SODIUM CHLORATE, 1934–35 SEASON, AS OBSERVED SEPTEMBER 19, 1935

Ratio of borax to sodium chlorate	Rate of application, pounds per square rod	Date of application and inches of rainfall following				
		Nov. 25, 32.50 inches	Dec. 7, 31.46 inches	Feb. 5, 17.19 inches	Feb. 9, 16.64 inches	April 22,* 0.84 inch
2:1	3	85	60	0	..	..
2:2	4	85	70	10	..	..
4:1	5	90	70	40	25	30
4:2	6	95	75	70	10	60
6:1	7	..	..	75	30	60
6:2	8	..	..	70	50	95
8:1	9	100	60	..	70	85
8:2	10	100	80	..	70	97

* Per cent kill recorded for plots treated on this date is as observed January 22, 1936.

optimum. Furthermore, the residual effect of such mixtures is greater than for sodium chlorate alone.

Sprays of Sodium Metaborate and Sodium Chlorate.—The percentage of plants killed on plots sprayed with mixtures of sodium metaborate and sodium chlorate is shown in table 8. In these treatments the mixture responded to rainfall just as the components did in that season (1934–35); toxicity was high in the fall, dropping off during the winter. Because no plots were treated during the 2-to-10-inch interval in spring, no upward swing was observed, as occurred with the components the following season. Again, the late-spring treatments required further leaching in autumn for the maximum effect.

The fall treatments achieved satisfactory control at lower cost than when the components were used independently. Although 1 pound of sodium chlorate killed 50 per cent of the plants (table 3), 4 pounds killed only 80 per cent. Similarly with sodium metaborate, 2 pounds killed 50 per cent (table 5); 8 pounds, only 85 per cent. But by mixing the lower amounts of each and by applying them together, the same control was achieved (85 per cent) as with the higher amounts applied independently. If sodium chlorate costs 8 cents per pound, borax 1½ cents, and sodium hydroxide 4 cents, the relative expense per square rod of the treatments is 32 cents for 4 pounds of sodium chlorate, 20 cents for 8 pounds of sodium metaborate, and 13 cents for a 2-to-1 mixture. Where small quantities of either chemical applied alone are effective, as in spring, the mixtures would be the least economical. The mixtures are therefore most valuable for treatments under the more unfavorable conditions.

Since sodium chlorate is so readily removed by leaching, the residual effect of the mixtures is probably due to sodium metaborate; and mixtures containing less than 6 pounds postpone seedling growth only a few months.

TABLE 9

PERCENTAGE KILL WITH DRY MIXTURES OF BORAX AND SODIUM CHLORATE, 1934–35 SEASON, AS OBSERVED SEPTEMBER 19, 1935

Ratio of borax to sodium chlorate	Rate of application, pounds per square rod	Date of application and inches of rainfall following						
		Mar. 8,* 8.86 inches	Nov. 15, 37.35 inches	Dec. 8, 31.46 inches	Jan. 30, 17.22 inches	Feb. 2, 17.22 inches	March 30, 7.68 inches	April 12, 2.82 inches
4:1	5	98	0	60	60	50	98	20
4:2	6	98	30	60	50	40	98	30
6:1	7	98	..	..	75	60	92	50
6:2	8	99	..	..	80	40	97	80
8:1	9	98	35	50	90	40	97	50
8:2	10	99	60	70	90	50	97	60

* Percentage kill recorded for plots treated this date in the 1933–34 season is as observed December 10, 1934.

Dry Mixtures of Borax and Sodium Chlorate.—Mixtures of borax and sodium chlorate applied dry were less effective in late fall and winter than in spring (table 9). This result agrees with the fact that the toxicity of each one separately followed that same course. The best spring applications were those receiving 7.68 inches of rain. This confirms the results obtained from the preliminary trials in March, 1934, also reported in the table. This point corresponds more nearly with the peak of chlorate toxicity than with the peak of borax toxicity, which was somewhat earlier, with 17.22 inches.

The low amount of rainfall (2.82 inches) received by the plots treated April 12, 1935, was insufficient to bring all the borax into action; and apparently antagonism prevented the sodium chlorate from being fully effective.

Residual sterilization against seedlings of St. Johnswort and grasses was greater with these dry mixtures than with the spray mixtures. This

TABLE 10

Percentage Kill with Dry Mixtures of Borate Ore and Sodium Chlorate

Ratio of borate ore to sodium chlorate	Rate of application, pounds per square rod	Date of application and inches of rainfall following			
		Colemanite and sodium chlorate, 1934-35 season, observed September 19, 1935			
		Nov. 20, 34.57 inches	Feb. 3, 17.22 inches	April 17,* 0.84 inch	
4:1	5	20	70	97	
4:2	6	65	50	97	
6:1	7	..	40	97	
6:2	8	..	50	97	
8:1	9	50	50	99	
8:2	10	70	60	99	
		Kramer ore and sodium chlorate, 1934-35 season, observed September 19, 1935			
		Nov. 20, 34.57 inches	Feb. 3, 17.22 inches	April 17,* 0.84 inch	
4:1	5	50	85	95	
4:2	6	70	40	95	
6:1	7	..	70	98	
6:2	8	..	70	98	
8:1	9	50	85	98	
8:2	10	50	90	99	
		Colemanite and sodium chlorate, 1935-36 season, observed September 7, 1936			
		March 13, 10.64 inches	April 14, 7.64 inches	April 15, 6.02 inches	May 1, 4.29 inches
4:½	4½	99	98	95	95
4:1	5	99	99	90	98
6:½	6½	99	99	90	95
6:1	7	100	99	90	98
8:½	8½	100	99	90	95
8:1	9	100	99	95	97
		Kramer ore and sodium chlorate, 1935-36 season, observed September 7, 1936			
		March 13, 10.64 inches	April 4, 7.64 inches	April 15, 6.02 inches	May 1, 4.29 inches
4:½	4½	98	97	85	90
4:1	5	90	99	92	97
6:½	6½	90	99	90	95
6:1	7	99	99	99	95
8:½	8½	97	99	99	97
8:1	9	97	100	99	98

* Per cent kill recorded for plots treated on this date is as observed February 1, 1936.

result might have been predicted from the somewhat greater residual effect of dry borax over sodium metaborate sprays.

In these experiments, satisfactory control was achieved with a mixture of 4 pounds of dry borax plus 1 pound of sodium chlorate per square rod, applied in spring and receiving about 8 inches of rain. Applications receiving more rain were less effective than dry borax alone; and those with less rain were less effective than sodium chlorate alone.

Dry Mixtures of Borate Ore and Sodium Chlorate.—As the data in table 10 show, these combinations behaved like the ones containing dry borax, in that toxicity was low with the higher amounts of rainfall and increased with successively later applications. They differed from the borax combinations, however, in being effective over a wider rainfall range, being decidedly more effective with small amounts of rainfall.

Mixtures of borate ores and sodium chlorate in the proportion of 4 pounds of ore to ½ pound of chlorate gave as good control as 1 pound of chlorate alone over the period of greatest toxicity in the spring—that is, with rainfall of 4 to 10 inches. The application of 4-to-1 mixtures on April 17, 1935, with only 0.84 inch of rain, was much more satisfactory than sodium chlorate applications on that date, although the plants were not completely killed until after further leaching the next fall. This was true also for the straight borate-ore treatments.

As the data show, mixtures of either borate ore—colemanite or Kramer ore—and sodium chlorate (4 pounds of ore to ½ pound of chlorate) satisfactorily controlled the weed when applied in spring and leached in by 4 to 10 inches of rain; and 4-to-1 mixtures were satisfactory with less than 4 inches of rain. Seedlings appeared by the following spring on plots treated at these minimum rates, but the numbers were much smaller than where sodium chlorate alone was used.

AMMONIUM THIOCYANATE

Ammonium thiocyanate, a coke-industry by-product, has been recommended as a herbicide.[13] Dilute solutions are used as contact killers; heavier applications as temporary soil sterilants. Not extremely poisonous and is said to repel livestock. Ammonia is a product of its decomposition in the soil, and the residual effect is one of nitrogen fertilization.

Plot tests on St. Johnswort (table 11) showed that late-spring applications surpassed those of summer. About 3 or 4 pounds was satisfactory in the spring on plots receiving 5.18 and 1.84 inches of rainfall. The complete lack of kill on plots treated July 7 suggests that the material decomposed in contact with the tops of the plants, and that the decomposition products leached into the soil by the fall rains were nontoxic.

Plots treated with 4 pounds or more were partially sterile for at least one year, and the 12-pound plot was completely sterile for one year and partially sterile after two years. As toxicity decreased, the surviving plants showed the effects of nitrogen by their dark-green color and vigorous growth.

TABLE 11

Percentage Kill with Ammonium Thiocyanate Sprays, Summer, 1934, as Observed December 19, 1934

Rate of application, pounds per square rod	Date of application and inches of rainfall following				
	April 2, 5.18 inches	May 4, 1.84 inches	June 8, 0.27 inch	July 7, 0.00 inches	Aug. 1, 0.00 inches
1	..	0	50	0	30
2	70	50	..	..	..
2½	..	..	60	0	75
3	..	95	..	..	..
4	99	98	..	..	..
8	100	..	..	..	..
12	100	..	..	..	..

The present price of ammonium thiocyanate (about 17 cents per pound) is entirely disproportionate to the sum of its herbicidal and fertilizer values. At the minimum effective rates it was the most expensive treatment tested.

SALT

Common salt (sodium chloride) has been used in California for controlling St. Johnswort on range lands. It was, in fact, the first chemical to be tried on a practical scale. One method of application practiced by ranchers is to cut the plants below the crowns when in bloom and pour a saturated salt brine into the depression. Another method is to make salting stations for livestock on patches of the weed, spreading the dry salt in a thick layer on the ground. Trampling by livestock on these salt grounds apparently helps to eradicate the weed.

Salt is commonly used in Australia[5, 11] along roads and trails and to form a barrier around infestations. As much as 5 tons to the acre is applied, the expense running over £25 for labor and material where steep slopes are heavily infested.[11]

The results of applying dry salt on different dates in the winter of 1934–35 (table 12) show that spring applications are preferable and that 50 pounds per square rod (4 tons per acre) is the minimum amount effective. Although the spring applications continued to kill plants throughout the next fall, seedlings and grasses came up on all salt-treated plots the following winter and spring.

The salt used was the so-called "morning-glory salt," an unrefined product but entirely suitable. Although salt is inexpensive (the consignment used in the tests being purchased for 60 cents per hundred pounds, f.o.b. San Francisco), the high rate of application necessary brings the cost for a given area above that of the more expensive chemicals for which lower rates are required. The total expense, furthermore, is increased by the greater outlay for transportation and handling. For example, the freight charges on a 1,000-pound shipment from San Francisco to Fort Seward were greater than the original cost of the salt in San Francisco. And finally, the cost of application is greater than with other chemicals because of the greater amount of material handled.

TABLE 12

Percentage Kill with Dry Salt, 1934–35 Season, as Observed September 19, 1935

Rate of application, pounds per square rod	Date of application and inches of rainfall following					
	Nov. 20, 34.57 inches	Dec. 8, 31.46 inches	Feb. 4, 17.22 inches	Feb. 6, 17.19 inches	March 30, 7.68 inches	April 18,* 0.34 inch
25	50	50	75	50	70	90
50	50	50	95	75	95	100
75	75	75	97	95	92	100

* Per cent kill recorded for plots treated on this date is as observed February 1, 1936.

PERMANENT SOIL STERILANTS

In treating St. Johnswort infestations where the plants have not been prevented, by cutting or spraying, from maturing and shedding seeds, one must provide for the control of seedlings that may later germinate from the seeds in the soil under the parent plants. Otherwise seedlings will soon reëstablish the infestation, and the original treatment that killed the parent plants will have accomplished no permanent good.

There is no evidence that any common herbicide injures mature seeds when sprayed on plants which have not yet shed their seeds, nor that any soil sterilant enters and kills the embryos of dormant seed in treated soil. Seeds apparently do not absorb toxic substances from the soil until they begin to germinate; then plant poisons in the soil will be absorbed by the embryonic root (radicle) and so kill the seedling.

To eradicate completely, by chemical methods, infestations where the soil contains viable seed, one may either (1) let the seeds germinate and then treat the seedlings by the method originally used to kill the parent plants or (2) sterilize the soil with some chemical that remains actively toxic until all the seeds have germinated.

Although the longevity of St. Johnswort seeds in soil under natural conditions is not definitely known, observations indicate that they remain viable for several years. A buried-seed experiment now in progress in California[12] includes seeds of this species and should give definite information on this point.

None of the soil sterilants so far discussed remains in toxic quantities for much longer than one year—at least with the minimum rates of application that will kill mature plants. In short, they are temporary sterilants when applied in economically reasonable doses, although heavier applications sterilize for greater periods.

Arsenic compounds, taken pound for pound, sterilize more lastingly and are called "permanent," although they are eventually leached out and the soil will grow plants again. The terms *temporary* and *permanent* are only relative. Except in the most arid regions, temporary sterilants are leached out by rainfall within one year, whereas leaching by two, three, or four years' rainfall may be required to reduce the concentration of arsenic compounds to a nontoxic level.

Sodium arsenite and arsenic trioxide are the compounds ordinarily used as permanent sterilants. Their relative permanence results from the fact that they are fixed in the surface horizons and so held against leaching. Since much of an application is fixed in the surface soil, the concentration of chemical in those few inches is high. As seeds do not usually germinate at depths below a few inches, the situation is ideal for preventing establishment of seedlings.

Fixation renders the chemicals only slowly soluble. The concentration, therefore, in the percolating waters reaching the deeper soil horizons is low—too low, usually, to injure the deeper roots of most noxious perennial weeds.

These deep-rooted perennials may send up shoots from roots or rootstocks that penetrate through the toxic layers into the atmosphere; and so they survive soil treatments with compounds of arsenic. Such treatments have therefore little value for eradicating well-established stands, though extremely useful for seedling control.

Permanent sterilization is, of course, unnecessary for seedling control on agricultural land, since cultivation is effective and economical and does not interfere with crops. In agricultural regions such sterilization is practiced only on uncropped land such as ditchbanks, roadsides, graveled walks, and other areas where vegetation is unwanted but where cultivation is impossible or undesirable.

On range lands, where cultivation is impracticable for controlling St. Johnswort seedlings, there is apparently no great objection to permanent sterilization. The aggregate loss in forage production would not be significant on the small areas sterilized in scattered infestations. The loss, furthermore, would be no greater than where temporary sterilants were used every year, as would be necessary to gain the same degree of seedling control.

Sodium arsenite and arsenic trioxide were included for plot testing. Although they might not, because of too shallow soil penetration, kill

TABLE 13

Percentage Kill with Sodium Arsenite Sprays

Rate of application, pounds per square rod, of arsenic trioxide	Date of application and inches of rainfall following					
	Season 1934-35, observed September 19, 1935					
	March 17,* 8.86 inches	Dec. 7, 31.46 inches	Feb. 9, 16.64 inches	April 18, 0.84 inch		
1	60	..	60	50		
2	..	90	70	60		
4	70	99	90	65		
6	90	99	95	80		
8	96	100	98	80		
12	..	100	99	..		
	Season 1935-36, observed September 7, 1936					
	Oct. 15, 46.63 inches	Nov. 15, 45.21 inches	Dec. 1, 43.49 inches	Dec. 15, 39.80 inches	Feb. 5, 20.06 inches	Feb. 27, 10.64 inches
1	50	40	70	50	65	40
2	80	50	80	70	75	85
3	85	97	92	95	92	95
4	92	99	95	97	92	92
5	97	99	99	99	100	97

* Percentage kill recorded for plots treated this date in the 1933–34 season is as observed December 10, 1934.

mature St. Johnswort, it seemed possible that they might inhibit reinfestation by seedlings; and if combined with a temporary soil sterilant, such as sodium chlorate, both mature plants and seedlings might be satisfactorily controlled in a single treatment. The tests demonstrated that sodium arsenite would, under Humboldt County conditions, kill mature plants and keep down seedlings without addition of other sterilants.

SODIUM ARSENITE SPRAYS

As table 13 shows, sodium arsenite must be applied earlier in the wet season than the temporary sterilants if mature plants are to be controlled satisfactorily. The fact that the 3- and 4-pound applications were less effective on October 15, 1935, than later suggests that, unless there is heavy leaching soon after application, fixation occurs in a shallower layer than otherwise, and the chemical does not go deep enough to kill. The result is apparently the same with late-spring treatments receiving less than 10 inches of rain. Once fixed, there is apparently no further displacement except a slow leaching.

Aside from the October application just mentioned, 3 pounds per square rod satisfactorily controlled the weed when applied in fall, winter, and spring, with 10 to 45 inches of rain. Within these limitations, the results of all applications were equally satisfactory.

TABLE 14

PERCENTAGE KILL WITH DRY ARSENIC TRIOXIDE, 1934–35 SEASON, AS OBSERVED SEPTEMBER 19, 1935

Rate of application, pounds per square rod	Date of application and inches of rainfall following				
	Nov. 20, 34.57 inches	Dec. 7, 31.46 inches	Feb. 5, 17.19 inches	March 30, 7.68 inches	April 18, 0.84 inch
4	0	40	0	0	0
6	0	40	20	0	0
8	0	40	40	0	0
12	0	40	60	0	0
16	30	30	50	30	10

The number of years for which 3 pounds per square rod will sterilize is not yet known. The earliest 3-pound plot treated in October, 1935, was still completely sterile when last observed in September, 1936, nearly a year later. At the same time a 4-pound plot treated in March, 1934, was still bare of seedlings, although all the original mature plants had not been killed; but 2 pounds per square rod in the winter of 1934 had begun to wear out. Thus, as far as present information goes, 2 pounds will sterilize for 1½ years; 3 pounds at least as long; and 4 pounds 2½ years or longer.

DRY ARSENIC TRIOXIDE

Although dry arsenic trioxide will sterilize the surface layer of soil in the same manner as sodium arsenite, it has little value for killing mature plants of St. Johnswort. As table 14 shows, 16 pounds per square rod failed to kill over 50 per cent. No seedlings were observed in September, 1936, on the 4-pound plot treated March 8, 1934. Complete control of seedlings was not effected until the winter after the applications. Because of the low solubility of the chemical, considerable rainfall is necessary to leach it into the soil.

TABLE 15

PERCENTAGE KILL WITH DRY MIXTURES OF ARSENIC TRIOXIDE AND SODIUM CHLORATE, 1934–35 SEASON, AS OBSERVED SEPTEMBER 19, 1935

Ratio of arsenic trioxide to sodium chlorate	Rate of application, pounds per square rod	Date of application and inches of rainfall following					
		Nov. 20, 34.57 inches	Dec. 8, 31.46 inches	Feb. 3, 17.22 inches	Feb. 9, 16.64 inches	April 1, 7.68 inches	April 18, 0.84 inch
4:1	5	..	..	..	..	..	75
4:2	6	50	70	85	60	..	97
4:3	7	50	70	80	60	..	..
6:1	7	..	..	..	..	90	95
6:2	8	40	75	80	60	90	90
6:3	9	60	85	85	60	..	..
8:1	9	..	..	..	..	..	95
8:2	10	60	75	70	60	..	95
8:3	11	75	80	70	60	..	..
12:1	13	..	..	..	..	90	..
12:2	14	40	..	90	90	60	..
12:3	15	70	..	90	90	..	..

TABLE 16

RESULTS WITH COPPER SULFATE, ZINC SULFATE, SODIUM FLUORIDE, AND SODIUM CHROMATE, SPRING, 1934

Chemical	Pounds applied per square rod	Date applied	Inches rainfall after date of application	Per cent kill as observed Dec. 10, 1934
Copper sulfate	2	March 12	8.86	0
	4	March 12	8.86	0
	8	March 12	8.86	0.
	12	March 12	8.86	25
Zinc sulfate	2	March 12	8.86	0
	4	March 12	8.86	0
	8	March 12	8.86	10
	12	March 12	8.86	20
Sodium fluoride	2	March 12	8.86	0
	4	March 12	8.86	0
	8	March 12	8.86	0
	12	March 12	8.86	0
Sodium chromate	2	April 2	5.18	0
	4	April 2	5.18	10
	8	April 2	5.18	40
	12	April 2	5.18	60

DRY MIXTURES OF ARSENIC TRIOXIDE AND SODIUM CHLORATE

Mature plants were satisfactorily killed by mixtures of dry arsenic trioxide and sodium chlorate (table 15), applied in spring, the season most favorable for the chlorate; and although the record is less complete than one might wish, apparently a 4-to-1 mixture may be satisfactory. Since arsenic and chlorate are not antagonistic,[9] such a mixture should control mature plants as effectively as does 1 pound of sodium chlorate alone and should inhibit seedling growth as lastingly as 4 pounds of arsenic trioxide alone.

MISCELLANEOUS SOIL TREATMENTS

Tests of copper sulfate, zinc sulfate, sodium fluoride, and sodium chromate applied to bare soil in the spring of 1934 showed these chemicals to have little value as soil sterilants for killing mature plants of St. Johnswort (table 16). Both copper sulfate and zinc sulfate apparently gave some surface sterilization against seedlings. This result agrees with Wahlenberg's statement[20] that they are much more effective against germinating seeds than against older plants and that zinc sulfate at least appears to tie up in the soil.

A series of plots treated with granular calcium cyanamide on February 6, 1935, indicated this chemical to be of little value as a herbicide on St. Johnswort. The results are not shown in the table, but 10 pounds per square rod killed only 50 per cent of the treated plants.

COMPARISON OF SOIL TREATMENTS

The experimental results clearly indicate that soil sterilization is superior to other chemical methods for controlling St. Johnswort. For convenience in discussing the relative merits of the several treatments, the pertinent data for each have been summarized in table 17.

Remembering that the rate figures will not apply directly to all situations, and that the cost-per-pound figures are based on market prices which vary from time to time and which always depend on the quantity purchased, we may still roughly determine whether the cost of a given treatment is at all commensurate with its relative herbicidal value.

We may eliminate from further discussion ammonium thiocyanate and salt, as well as the mixtures of arsenic trioxide and sodium chlorate and those of sodium metaborate and sodium chlorate, none of which has any advantage not possessed by some less expensive treatment. The next most expensive are sodium metaborate and sodium arsenite.

Sodium metaborate has no advantages over dry borax and has the disadvantage of higher application cost—that is, spraying as against dry application. Sodium arsenite has the advantage of a more permanent sterilization than any of the less expensive materials. St. Johnswort seedlings bloom in the second year from germination, so that treatments which do not prevent seedling growth in the following spring must be repeated every other year to prevent increasing the infestation by more seed. But a treatment that sterilizes until the second spring

TABLE 17

COST OF MATERIALS FOR SOIL TREATMENTS AT MINIMUM RATES OF APPLICATION

Chemical	Method of application	Pounds of chemicals applied per square rod	Optimum rainfall, inches	Seedling control, years	Cost of chemicals per 100 pounds	Cost per square rod	Cost per acre
Ammonium thiocyanate	Spray	3	....	1	$17.00	$0.51	$81.60
Salt	Dry	50	1–7	1	0.60	0.30	48.00
Arsenic trioxide, 4 parts; sodium chlorate, 1 part	Dry	5	2–10	2½	4.80	0.24	38.40
Sodium metaborate, 4 parts; sodium chlorate, 1 part	Spray	5	2–10	1	3.60	0.18	28.80
Sodium metaborate	Spray	6	0–17	1	2.50*	0.15	24.00
Sodium arsenite	Spray	3	10–45	2 (?)	5.00*	0.15	24.00
Borax, 4 parts; sodium chlorate, 1 part	Dry	5	8	1	2.80	0.14	22.40
Borax	Dry	8	17	1	1.50	0.12	19.20
Colemanite	Dry	8	0–10	1	1.25†	0.10	16.00
Kramer ore	Dry	8	0–10	1	1.25†	0.10	16.00
Colemanite, 8 parts; sodium chlorate 1 part	Dry	4½	4–10	1	1.99	0.09	14.40
Kramer ore, 8 parts; sodium chlorate, 1 part	Dry	4½	4–10	1	1.99	0.09	14.40
Sodium chlorate	Dry or spray	1	2–10	6–8 months	$8.00	$0.08	$12.80

* Includes cost of sodium hydroxide necessary to convert borax to sodium borate, and arsenic trioxide to sodium arsenite.

† Based on 28 per cent B_2O_3, and on the same price per unit of B_2O_3 as exists for refined granular borax of 36 per cent B_2O_3.

will have to be repeated only every third year. To compare two treatments that sterilize for different numbers of years, divide the cost of each single application by the number of years, and then compare these yearly costs. The yearly cost of materials for sodium arsenite is thus $8.00 per acre; for sodium chlorate $6.40. Thus sodium arsenite, though it lasts longer, is the less economical. Furthermore, the cost of applying sodium arsenite would be greater, since vegetation must be removed from the area to be sprayed and since spraying is more expensive than the dry method that may be used for chlorate.

Neither dry borax nor the mixture of dry borax and sodium chlorate are better in any way than the corresponding colemanite or Kramer ore treatments. As practical control measures, therefore, they may be eliminated in favor of less expensive ones.

Colemanite and Kramer ore are less expensive than borax, but the bulk of material is still larger than necessary for even distribution. Although the residual sterilization is slightly greater than with the smaller amounts used in the less expensive borate ore and sodium chlorate mixtures, the difference is not great enough to balance the difference in cost of materials.

From all standpoints, the most practical treatment seems to be a mixture of 4 pounds of either colemanite or Kramer ore with ½ pound sodium chlorate. The cost of materials is as low as for any of those tested; they may be applied dry; the volume is great enough so that an even distribution can be achieved in hand broadcasting; and yet the weight required for a given area is low. When these mixtures are applied in late spring of one year, a few seedlings germinate on the treated areas during spring of the following year, so that for complete eradication applications must be repeated every other year. The number of seedlings is less, however, than where 1 pound of sodium chlorate is applied alone.

These mixtures, though slightly more expensive than sodium chlorate alone, should prove more reliable in field operations because of better distribution, at least in comparison with dry chlorate. An even distribution is attained in chlorate-spray treatments, but the cost of application is greater.

APPLICATION OF RESULTS TO FIELD PRACTICE

It should be emphasized that the minimum rates of application as determined for the region tested may not, and probably will not, apply equally to all St. Johnswort-infested regions in California. Soils and rainfall will influence not only the minimum rate of application for each chemical, but also the optimum season of treatment. As pointed out previously, borax, sodium chlorate, and sodium arsenite react differently in soils of different textural grade; and the reaction of sodium chlorate is influenced by soil fertility as well.

In regions other than the location of the test plots, the results should serve only as the basis for further tests by local agricultural officers to determine more exactly the requirements on those particular soils.

These experiments have shown that for greatest economy of material, soil sterilants must be applied during definite seasons, which are not calendar periods, but rather depend on the amount and distribution of precipitation. The calendar period, therefore, during which a chemical should be applied in one region may not be the same as in another, because of differences in total seasonal rainfall or differences in distribution, even though the totals are similar.

The average calendar dates of application for any particular region may be calculated from rainfall records. Table 18, for example, gives rainfall data for the Fort Seward-Blocksburg region. The data were calculated from unofficial records from several stations, but all within a radius of about 8 miles. As the extreme difference in altitude of the stations was several hundred feet, the data give only a general picture of conditions within the area.

TABLE 18

RAINFALL AVERAGES FOR THE FORT SEWARD AND BLOCKSBURG REGION, JULY 1, 1915, TO JULY 1, 1936, AND MONTHLY TOTALS, JULY 1, 1933, TO JULY 1, 1936

Month	Average for month	Average from July 1 to first of month	Average from first of month to July 1	Number of years with no rain in this month	Monthly totals		
					1933-34	1934-35	1935-36
	inches	*inches*	*inches*		*inches*	*inches*	*inches*
July	0.02	39.88	39.88	19	0.00	0.00	0.00
August	0.09	0.02	39.86	15	0.00	0.00	0.00
September	0.84	0.11	39.77	2	0.48	0.76	1.07
October	2.39	0.95	38.93	1	3.09	5.66	3.07
November	5.92	3.34	36.54	1	0.05	11.32	2.67
December	7.35	9.26	30.32	0	13.17	5.97	10.70
January	6.92	16.61	23.27	0	3.75	8.30	12.59
February	6.15	23.53	16.35	0	3.92	4.07	9.82
March	4.78	29.68	10.20	1	4.08	5.44	2.85
April	3.36	34.46	5.42	0	2.52	7.53	3.40
May	1.39	37.82	2.06	1	1.69	0.15	1.97
June	0.67	39.21	0.67	6	0.27	0.00	2.22

Monthly totals for the three seasons of the experiments are included in the table to indicate the variability in seasonal distribution to be expected around Fort Seward and Blocksburg.

Returning to table 17, it is apparent that 8 to 1 (4 pounds to ½ pound) mixtures of borate ore and sodium chlorate require between 4 and 10 inches of rain. Referring to table 18, in a normal season about 10 inches is expected after March 1; 4 inches after about April 15. In a normal season, then, the mixtures of borate ore and sodium chlorate should be applied between March 1 and April 15.

Because of variation in distribution of rainfall, more satisfactory control is probable if applications are made about the middle of the proper period rather than near the beginning or end. For combinations of borate ore and sodium chlorate, in the region under consideration, this is about March 20. As shown by inspection of the original records from which table 18 was derived, more than 10 inches of rain fell after March 1 in five out of the twenty-one years, and after April 1 in only one of the twenty-one years.

SUMMARY

A 5 per cent solution of sulfuric acid was the cheapest effective contact spray tested. That concentration, applied at the rate of 3 gallons per square rod, killed the tops of St. Johnswort down to the root crown at all stages between bud and green seed.

Translocation of sodium arsenite sprays occurs to a limited extent in St. Johnswort. The percentage of plants killed by this method did not constitute satisfactory control.

Soil treatments were the most reliable and most effective type of chemical application. Sodium chlorate, borax, and mixtures of borax and sodium chlorate were effective when applied either as sprays or as the dry salt.

The borate ores, colemanite and Kramer ore, were effective when applied dry, either alone or combined with sodium chlorate.

Sodium arsenite sprays not only killed existing plants but also prevented seedling establishment for some time. Mixtures of dry arsenic trioxide and sodium chlorate effectively prevented reinfestation by seedlings, besides killing existing plants.

The most satisfactory treatments as to cost and ease of application were mixtures of 4 pounds of either colemanite or Kramer ore with ½ pound of chlorate per square rod. This rate is equivalent to 720 pounds of the mixture per acre, costing around $14.40. At this rate, the dry materials are easily distributed by hand; and in such scattered infestations as are feasible to treat, this method should be considerably less expensive than the spraying methods now used in treating with sodium chlorate. Although slightly more expensive than straight dry sodium chlorate, the mixtures are more easily applied and have a greater residual effect against seedlings of St. Johnswort. The fire hazards incident to handling chlorate materials are even less than with dry sodium chlorate, and much less than with sodium chlorate sprays. Although not confirmed by test, it is reasonable to presume that the material may be applied on range land in the presence of livestock without danger of poisoning.

ACKNOWLEDGMENTS

The writer is indebted to Dr. A. S. Crafts for assistance in the organization and conduct of the work herein reported. Thanks are also due to Mr. D. H. Prior, Mr. F. H. Boehne, the Russ Investment Company, and the M. and T. Company for permission to use land for plots; and to Mr. W. D. Pine, Farm Advisor, and Mr. Earle Mills, Agricultural Commissioner, for numerous courtesies which facilitated the work in Humboldt County.

LITERATURE CITED

[1] Åslander, Alfred.
1926. Chlorates as plant poisons. Jour. Amer. Soc. Agron. **18**:1101–2.

[2] Åslander, Alfred.
1928. Experiments on the eradication of Canada thistle, *Cirsium arvense,* with chlorates and other herbicides. Jour. Agr. Research **36**:915–34.

[3] Ball, W. E., and O. C. French.
1935. Sulfuric acid for control of weeds. California Agr. Exp. Sta. Bul. **596**: 1–29.

[4] Ball, W. S., A. S. Crafts, B. A. Madson, and W. W. Robbins.
1936. Weed control. California Agr. Ext. Cir. **97**:1–87.

[5] Carn, K. G.
1936. Control work of the Eastern Revering County Council. Agr. Gaz. N. S. Wales. **47**:312–14.

[6] Crafts, A. S.
1933. The use or arsenical compounds in the control of deep-rooted perennial weeds. Hilgardia **7**(9):361–72.

[7] Crafts, A. S.
1935. Factors influencing the effectiveness of sodium chlorate as a herbicide. Hilgardia **9**(9):437–57.

[8] Crafts, A. S.
1935. The toxicity of sodium arsenite and sodium chlorate in four California soils. Hilgardia **9**(9):461–98.

[9] Crafts, A. S., and C. W. Cleary.
1936. Toxicity of arsenic, borax, chlorate, and their combinations in three California soils. Hilgardia **10**(10):399–413.

[10] Crafts, A. S., and R. N. Raynor.
1936. The herbicidal properties of boron compounds. Hilgardia **10**(10):343–74.

[11] Currie, G. A.
1936. A report on a survey of weed problems in Australia. Aust. Council Sci. and Indus. Research Pamphlet **60**:1–38.

[12] Goss, W. L.
1933. Buried seed experiment. California State Dept. Agr. Mo. Bul. **22**:302–4.

[13] Harvey, R. B.
1931. Ammonium thiocyanate as a weed eradicant. Jour. Amer. Soc. Agron. **23**:944–46.

[14] Hulbert, H. W., and L. V. Benjamin.
1935. Dry applications of chlorates. Idaho Agr. Exp. Sta. Cir. **74**:1–8.

[15] Kennedy, P. B., and A. S. Crafts.
1927. The application of physiological methods to weed control. Plant Physiol. **2**:503–6.

[16] Loomis, W. E., Russell Bissey, and E. V. Smith.
1931. Chlorates as herbicides. Science n.s. **74**:485.

[17] LOOMIS, W. E., E. V. SMITH, RUSSELL BISSEY, and L. E. ARNOLD.
1933. The absorption and movement of sodium chlorate when used as an herbicide. Jour. Amer. Soc. Agron. 25:724–39.

[18] MUENSCHER, W. C.
1932. Killing perennial weeds with chlorates during winter. New York Agr. Exp. Sta. (Cornell) Bul. 542:1–8.

[19] SAMPSON, A. W., and K. W. PARKER.
1930. St. Johnswort on the range lands of California. California Agr. Exp. Sta. Bul. 503:1–48.

[20] WAHLENBERG, W. G.
1930. Investigations in weed control by zinc sulfate and other chemicals at the Savenac Forest Nursery. U. S. Dept. Agr. Tech. Bul. 156:1–35.

11*m*-11,'37(232)