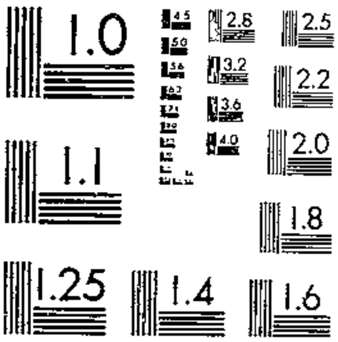
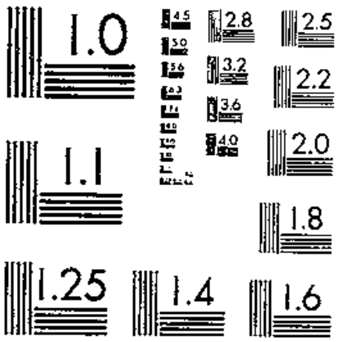
TB 156 (1930) USDA TECHNICAL BULLETINS UPDATA
INVESTIGATIONS IN WEED CONTROL BY ZINC SULPHATE AND OTHER CHEMICALS
WAHLENBERG, W G 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL BULLETIN No. 156 JANUARY, 1930

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

INVESTIGATIONS IN WEED CONTROL BY ZINC SULPHATE AND OTHER CHEMICALS AT THE SAVENAC FOREST NURSERY[1]

By W. G. WAHLENBERG, *Assistant Silviculturist, Northern Rocky Mountain Forest Experiment Station, Forest Service*

CONTENTS

THE WEED PROBLEM AT SAVENAC NURSERY

Savenac nursery, located in western Montana, has a yearly output of about 3,000,000 coniferous tree seedlings and transplants. The annual cost of care during the first two years of seed beds that have not been treated chemically has been about $1.40 per bed of 48 square feet, and of this amount 56 cents, or 40 per cent, has been the cost of hand weeding.[2]

There seemed to be no hope of reducing this expense through the use of any type of cultivator or mechanical device for weeding because of the close stands in which trees are grown in the seed beds—often 100 individuals per square foot of surface. For like

[1] This publication is based upon 10 years of investigation begun in 1916 by P. C. Kitchin (2), who published a preliminary report in 1920. The experiments were continued by the author until the fall of 1925. The author wishes to express his thanks to those members of the Forest Service and others who have assisted in the preparation of this bulletin, with especial recognition of helpful suggestions from the Bureau of Chemistry and Soils, where soil tests were made, and from Carl Hartley, of the Bureau of Plant Industry.

[2] G. W. Jones, superintendent of Savenac nursery, furnished the cost data. The wage basis for all cost figures is $4 per day. Costs are expressed here on an area basis rather than on the basis of each thousand seedlings produced, because the number of weeds and the expense of removing them by any method varies more directly with areas than with density of the crop. No uniform costs per thousand tree seedlings can be given because the number of trees to a bed varies widely with the age class and the species grown.

NOTE.—Italic numbers in parentheses refer to "Literature cited," p. 33.

67453—29——1

reasons no trial was made of the methods of preventing weed growth by laying down strips of heavy paper as in Hawaiian pineapple fields or of spreading paper by machine as in South African sugar-cane fields (*1*).

It is said that the sugar-cane sprouts successfully pierce the paper, but the tops of forest-tree seedlings could hardly be expected to do this. Roots from seeds germinated on top of paper might be able to penetrate, but this was not tried. The Norwegian method of controlling weeds in forest nurseries by laying boards between trees in transplant rows did not seem practicable for a large nursery in a country where labor costs are high. Because physical methods held forth so little promise, the investigations were centered on chemical means of control, keeping in mind the possible injury to tree crops and the soil.

Although what appears to be quite a satisfactory chemical method has been developed at the Savenac nursery, it is to be expected that the reaction of any chemical substance will vary with different soils, weeds, and crops, and that in other places the Savenac weed treatment may possibly require considerable modification before it can yield the best results.

Analysis of the Savenac nursery soil in 1913 by the Bureau of Soils showed that it contained 0.41 part of lime, 0.24 part phosphoric acid, 0.37 part potash, and 0.11 part of nitrogen. In 1921 a qualitative microscopic examination indicated very good physical properties in the soil, a high percentage of granular or "crumb" structure, and highly oxidized soil minerals. There was a very fair amount of organic matter but a large part of it was not well decomposed. The soil contained no lime in the form of carbonate or phosphate and had an acid reaction, attributable to the use of slightly acid irrigation water and to lack of rapid percolation through the subsoil. Potash feldspar (orthoclase and microcline) and potash mica (muscovite and biotite) were fairly plentiful, especially the feldspar. These minerals should slowly yield their potash under the process of weathering. Lime-soda feldspar (plagioclases) were present. These will probably weather and decompose more rapidly than will the potash feldspars.

Of the annual output of 3,000,000 trees 85 per cent are western white pine (*Pinus monticola*), and western yellow pine (*P. ponderosa*). The remainder consists of Engelmann spruce (*Picea engelmannii*), Douglas fir (*Pseudotsuga taxifolia*), western larch (*Larix occidentalis*), and western red cedar (*Thuja plicata*). The experiments detailed here dealt principally with the two pines and the spruce. The trees remain in the nursery from two to five years, but the majority are 3 years old when planted on the denuded mountain slopes. Field peas are used as a green fertilizer crop.

The three most troublesome weeds[3] at the nursery are field or sheep sorrel (*Rumex acetosella*), common timothy (*Phleum pra-*

[3] According to Cox (8) a weed has been defined as a plant out of place or a plant which has not yet found its proper use, but in the minds of most people a weed is simply a wild plant that has the habit of intruding where not wanted. Both are right. Generally weeds are worse than useless when they occur on cultivated soil, but it is only fair to mention certain values which have been recognized as belonging to this class of agricultural pests. Just as a sawmill company would do well to investigate the possible commercial value of its waste material before investing in expensive equipment for its disposal, a forester should consider the possible value of weeds before expending much

tense), and white clover (*Trifolium repens*). These are all very prolific. It is impossible to remove the sorrel by hand and get all of the root system except when the seedlings are very young. The roots send runners far and wide. When roots 2 or 3 feet long are extracted they often do considerable damage by uprooting tree seedlings or disturbing the roots of many trees. The broken sorrel roots remain in the ground to sprout new plants. Clover and timothy are important because of their abundance and their bushy root systems. Although these three weeds deserve especial attention there are many others which in the aggregate give as much trouble.[4]

The source of weed seeds is a point to be considered since it is natural to think that chemical methods might not be necessary or that hand weeding might be made much less of a problem if access of many seeds to the nursery soil was prevented. The principal means by which seeds are introduced are water, manure, mulch, and wind. The water supply for irrigation and sprinkling is obtained from open ditches which carry many weed seeds produced along their borders or in mountain meadow land along the creeks from which the water comes. This is a common source of weed seed in many localities (*12*). Various methods of filtering out this seed have been tried, but so far none has been succeessful. Filters cause much trouble by clogging up with vegetal matter and decreasing the water pressure in the sprinkling system. Manure used as fertilizer contains numerous weed seeds that may not be killed by heat and steam treatments, although a period of one year is generally sufficient to kill weed seeds in compost containing manure. Straw used as mulch usually carries seeds. Sand used as covering for tree seeds after sowing is a river-washed product and should be fairly free from seeds, but probably contains a few. Wind, like water, is a rather constant means of weed-seed distribution. It is improbable, therefore, that weed growth at the nursery will ever be controlled by preventing the access of seeds.

Seeds already in the soil are the next consideration. The operations of plowing and cultivating must bury a great many seeds and unearth others, some of which probably retain their vitality for several years. An experiment started in Virginia by Duvel and reported by Goss (*16*) showed that seeds of most weeds, if ripe when plowed under, will not perish in the soil during the period of any normal crop rotation. Among the many weeds studied were the same species of clover and timothy that are troublesome at Savenac nursery. Of 200 white clover seeds 3 per cent, and of 200 timothy seeds 22 per cent, grew after having been buried 8 inches deep for 10 years. Bit-

---

money in eradication or in studies of methods of control. Campbell (*6*) points out the possibility that deeply leached nitrates can, in part, be returned to the upper surface layers of soil by the growth and decay of certain species of weeds. Early, late, and winter annuals appear to conserve nitrogen at times when no cultivated plants are present on the land. In places, weeds may prevent or retard soil erosion. They may sometimes be utilized in compost or as silage, or serve some other purpose in a minor way as a by-product from cultivated land, but their value seems to be limited to purposes which can be more efficiently served by the use of soiling crops.

[4] Miscellaneous weeds, as follows, have been identified: Woolly yarrow (*Achillea lanu-*
losa Nutt.); rutabaga (*Brassica campestris* L.); blooming sally (*Chamaenerion angusti-*
folium (L.) Scop.), commonly known in the western mountains as "fireweed," but not the
same as *Erechtites hieracifolia*, fireweed); lambs-quarters (*Chenopodium album* L.);
cotton cudweed (*Gnaphalium palustre* Nutt.); Purslane speedwell (*Veronica peregrina* L.);
western stickseed (*Lappula occidentalis* (S. Wats.) Greene.); groundsmoke (*Gayophytum*
ramosissimum Torr. and Gray); red sandspurry (*Tissa rubra* (L.), Britton); phacelia
(*Phacelia heterophylla* Pursh.); Arctic pearlwort (*Sagina saginoides* (L.) Britton);
houndstongue hawkweed (*Hieracium cynoglossoides* Arv.-Touv.).

ter dock (*Rumex obtusifolius*), a broad-leaved species belonging to the same genus as the troublesome sheep sorrel, germinated 82 per cent of its seeds under the same conditions. More extreme cases of longevity of seeds in the soil are occasionally recorded. Brenchley (*5*) in reporting experiments carried out at Rothamsted claims a survival of 60 years for the seeds of certain weeds common on cultivated soil. Enough has been done to indicate clearly that buried seeds should not be ignored as a source of weeds.

Weeds are a problem in many forest nurseries. There is very little hope that the harm done by weeds in competition with tree crops can be offset by any use of weed growth as a by-product of the land. Nor is there much hope of preventing the access of weed seeds from their varied sources. Once in the soil the vitality of some seeds may be retained for long periods. The growth of weeds is natural and seems almost inevitable. Removal of weeds by mechanical means is not only very expensive but also is often injurious to the tree seedlings. Removal by chemical methods, if effective, meets these difficulties very satisfactorily.

PREVIOUS AND FUNDAMENTAL INVESTIGATIONS OF TOXIC SENSITIVENESS IN PLANTS

Much of the work already done on chemical methods of eradicating weeds has been confined to poisoning the tops of weeds already established. For this heavy doses of poison are necessary. Also, the poison is not applied until after considerable damage may have been done by the weeds. The advantage of any practical methods of using smaller quantities of poison in the soil is obvious. By such methods weed seeds would be kept from sprouting or at least the seedlings would be prevented from appearing above the surface of the soil. The consideration of a practical means to this end involves a study of the relation of plant life to toxic materials, such as zinc and copper salts, the materials used in the work reported in this bulletin. Fortunately there is already some literature available on this subject.

Baumann (*3*) experimented with nutrient solutions with the object of determining the safe and the fatal limits in quantity of soluble zinc salts for different plants. He tested the effects of zinc sulphate at the rate of 44 milligrams per liter on plants of 13 species belonging to seven families and found that all except the conifers were killed. *Pinus sylvestris* and *Picea excelsa* stood out above all others as the only plants that grew well in a solution containing 10 milligrams of zinc per liter of water.

Work with soil cultures showed that not only does the sensitiveness of different species vary greatly, but concentrations which stimulate a plant in soil may be toxic in sand. Humus was the most absorbent soil for zinc salts. The absorptive power decreased as the soil grew poorer and apparently was weakest in sand. The presence of carbonic acid appeared to increase susceptibility to injury from certain zinc salts. The avenue of injury seemed to be an effect of zinc on chlorophyll and photosynthesis. If so, a comparison of the dry weights of plants produced with and without zinc should indicate the extent of injury, because the bulk of plant material is a product of photosynthesis. As indicated by the experiments of Storp in 1883 (*39*), the formation and function of chlorophyll appeared to be reduced by zinc compounds. Brenchley (*4*) pointed out that such a hypothesis is supported by the fact that in many fungi and higher plants without chlorophyll the toxic action of zinc is not evident. Javillier (*21*, *22*, *23*) found that zinc was contained in many parts of a large number of plants and that it was particularly abundant in conifers. He concluded that plants which contain chlorophyll are benefited by the action of small amounts of zinc, which act perhaps as a catalytic agent in the metabolic process.

This conclusion does not necessarily conflict with that of Storp, if it be accepted that very small amounts of poison often act as stimulants to plant cells. Evidence in favor of such a view is offered by Rusk (*35*) who, working with leaf cells of *Elodea canadensis*, reports the effect of zinc sulphate on protoplasmic streaming. Brenchley (*4*) reviewed the work of several investigators and concluded that although it was still uncertain whether or not higher plants grown in water cultures are susceptible to stimulation by zinc salts except at exceedingly great dilutions, in soils cultures containing zinc the fact of increased growth seemed to be more firmly established.

One compound of zinc was included among the many substances tested as soil disinfectants by Hartley (*18*). At Halsey, Nebr., he applied a water solution of 0.281 ounce (nearly 8 grams) of zinc chloride per square foot. The plot was sown with *Pinus resinosa* 17 days after treatment and 28 days later 5 weeds were counted, 4 of grass, and 1 of Mollugo. In the untreated check-plots grass was abundant and Mollugo predominant among other weeds.

The possible beneficial action of zinc on plants does not seem to have been demonstrated very clearly by the early workers, although Mazé (*27*) furnished some evidence of the indispensable nature of zinc for maize, and more recently McHargue (*26*) spoke of the widespread occurrence of small quantities of zinc in soils, plants, and animals and inferred that it performs important functions in metabolism. The failure of earlier experiments to show definitely that zinc is essential to plants is attributed by Sommer and Lipman (*37*) to imperfections of technic, such as the use of ordinary glass containers from which the culture solutions dissolved out appreciable amounts of zinc. They used boro-silicate (or Pyrex) glass containers in their tests with zinc and employed special precautions to exclude dust and other impurities. Wherever possible the seeds were cut off from the seedlings within a few days after germination so as to deprive the seedling of as much as possible of the stored food material in the seed. By these methods Sommer and Lipman confirmed the results of Mazé and presented striking evidence of the indispensable nature of zinc for dwarf sunflowers and barley. They concluded that zinc, like boron, is absolutely essential to the life and growth of certain higher green plants and probably for all of them. Sommer (*36*) later reported that even where the early development of kidney and broad beans appeared normal on plants lacking zinc the leaves began to fall, few blossoms were produced, and the plants declined rapidly in the flowering stage, producing no seed. Reproduction as well as development was normal in plants provided with zinc.

Soluble copper salts have, on the other hand, been found to be universally detrimental to plants. Haselhoff (*20*) found that these salts injure the soil in two ways. (1) Nutrient salts in the soil, especially those of calcium and potassium, enter into chemical combination with the copper salts, are rendered more soluble, and readily leach away. (2) This double decomposition produces copper oxide which remains as an injurious ingredient.

Chemical weeding of coniferous seedlings in nursery beds had its inception in experiments conducted for another purpose. When sulphuric acid was applied to soil as a disinfectant to control damping-off fungi, marked reduction in weeds was noticed at a number of nurseries, according to Hartley and Pierce (*19*).[5]

Early work in applying chemicals to the soil at Savenac nursery has been reported by Kitchin (*24*) and requires only brief mention here. In the spring of 1916 copper sulphate and zinc chloride were compared with sulphuric acid in various quantities as to effectiveness in weed control. One-half ounce (about 14 grams) of zinc chloride and one-quarter ounce (about 7 grams) of copper sulphate per square foot were found to be much more deadly to weed seed than the acid in any strength tested. These results led directly to more intensive experiments.

THE FIRST TESTS OF GERMINATION OF WEED SEEDS AND WESTERN WHITE PINE UNDER CHEMICAL TREATMENT

METHODS AND PROCEDURE

The first intensive tests of chemical treatment at Savenac were made in the fall of 1918. During the first half of September, the usual period for sowing western white pine, 84 small plots were installed to test the effect of zinc sulphate ($ZnSO_4.7H_2O$ white vitriol), zinc chloride ($ZnCl_2$), and copper sulphate ($CuSO_4.5H_2O$ blue vitriol) in quantities varying from 4 to 12 grams per square foot. A block of 28 plots was devoted to each of the three chemicals. In each block were four units of seven plots each. Two of these units were used for germination counts and root examinations, the seedlings being pulled out, examined, counted, and recorded at approximately 10-day intervals during the season. The other two units in each block were allowed to grow unmolested for observation of thrift and survival. In each unit the plot tests were designated A, B, C, D, E, F, and G. The upper 2 inches of soil in all plots except G was sterilized, in part at least, by heating, and was sown with western white pine, clover, sorrel, and timothy—200 seeds of each species in each plot. All except F and G were then treated chemically.

Bottomless wooden containers, 1 by 2 feet, and 10 inches deep, were sunk in the soil as frames for the plots (pl. 1, A) in order to promote uniform growing conditions in the absence of an "isolation strip" or border of similarly treated seed bed. They served to prevent the loss of soil solutions by capillary transfer in a hori-

[5] The acid treatment was found successful in many places with a variety of soils. An exception occurred near Garden City, Kans., where the acid produced effervescence and did not affect the fungus. This has been attributed to a high carbonate content and consequent alkalinity. The exerience indicates that a chemical treatment found successful on one soil may not serve the purpose on a different soil. At this nursery copper sulphate and zinc chloride were then tried and proved to be successful disinfectants for damping-off fungi.

zontal direction and to prevent the border plants from benefiting by an extension of their roots into the surrounding unoccupied soil space. As a further precaution to avoid the passage of soil solutions from one plot to another, and to allow working space, the frames were separated from one another by at least a foot.

In the process of sterilization the upper 2 inches of soil in each frame was removed, soaked in order to swell any weed seeds it contained, exposed to steam heat for an hour to kill these seeds, and then replaced in the frames.

Pine seed was sown at the depth of one-quarter of an inch and weeds at a depth of one-eighth of an inch. Care was exercised to make these depths uniform by the use of specially constructed sliding eveners.

The chemical applications followed immediately after the sowing. One liter of solution of various strengths was applied to each square foot of soil surface. (Pl. 1, B and C.) Accidental sowing of weed seeds was prevented by filtering the water used. Plots were tightly covered with half-inch mesh wire netting to exclude rodents and birds, and with cheese cloth fine enough to exclude the entrance of further weed seed. The cloth cover was kept throughout the season of 1919 on the series used for germination counts, but was removed from the survival series when germination appeared to be complete.

RESULTS

Seeds of the same species that were not sown but were already buried in the soil of the experimental plots do not seem to have produced sufficient seedlings to interfere with the experiment. This is indicated by a comparison of Plots F and G in Table 1. Of the other native species of weeds the sterilization killed only about half, but the remainder were effectively killed by the chemicals as is indicated by the figures for "other weeds" in Table 3.

TABLE 1.—*Ineffectiveness of unsown seed in experimental plots as shown by weed germination, 1919* [1]

Plots	Treatment	Clover	Sorrel	Timothy
		Number	*Number*	*Number*
F	Sterilized soil; 200 seeds of each species sown	93	45	193
G	No sterilization; no sowing	4	0	1

[1] Each figure is an average of six plots.

As the object of this study was to find a chemical treatment that did not injure pine stock in any way, the degree of injury to root tips of pine seedlings should be reviewed first, in order that the results from seed germination in those plots where pine was injured may receive only the secondary consideration they merit. The system of pulling out newly germinated seedlings at intervals of about 10 days gave an excellent opportunity to observe the roots of a large number of plants. Table 2 and Figure 1 indicate the percentage of pine seedlings with injured root tips. The injurious effect of copper sulphate was most severe. Death of plants resulted from failure of the roots to establish themselves in this soil. What few root tips had penetrated the soil were dark brown, curled, and warty in appearance. The zinc salts did not cause the pine seedlings to produce the dark brown, warty root tips, but the injured growing points were fatally curled and crumpled.

TABLE 2.—*Extent of chemical injury to western white pine seedlings from various chemical soil treatments*[1]

Plot	Salt per square foot	Proportion of germinated seedlings with root tips injured by different treatments			Plot	Salt per square foot	Proportion of germinated seedlings with root tips injured by different treatments		
		$ZnSO_4$	$ZnCl_2$	$CuSO_4$			$ZnSO_4$	$ZnCl_2$	$CuSO_4$
	Grams	*Per cent*	*Per cent*	*Per cent*		*Grams*	*Per cent*	*Per cent*	*Per cent*
A	4	0	0	18.9	D	10	7.1	25.8	80.3
B	6	0	0	53.5	E	12	9.8	35.2	95.0
C	8	0	20.0	67.1	F	0	0	0	0

[1] Each figure based on 1 plot of 200 seeds.

The effect of different soil treatments on the total number of germinations of pine and weeds in 1919 and 1920 is shown in Table 3.

TABLE 3.—*Influence of various chemical treatments on pine and weed seed, as shown by number of seeds germinating in 1919 and 1920*[1]

Plot	Salt per square foot used for soil treatment	Western white pine			White clover			Sheep sorrel			Common timothy			Other weeds			All weeds		
		1919	1920	Total	1919	1920	Total	1919	1920	Total	1919	1920	Total	1919	1920	Total	1919	1920	Total
	Zinc sulphate:																		
F[2]	Control	130	1	137	94	23	117	44	0	44	211	1	212	38	143	181	387	107	554
A	4 grams	139	1	140	66	18	84	26	3	29	169	0	169	0	14	14	261	35	296
B	6 grams	144	5	149	30	15	45	12	7	19	111	1	112	0	11	11	153	34	187
C	8 grams	151	4	155	49	9	58	16	3	19	116	0	116	0	5	5	181	17	198
D	10 grams	148	5	153	14	10	24	6	4	10	70	0	79	0	1	1	99	15	114
E	12 grams	162	3	165	23	15	38	9	8	17	60	0	60	0	0	0	92	23	115
	Zinc chloride:																		
F	Control	115	1	116	97	17	114	31	3	34	191	1	192	26	127	153	345	148	493
A	4 grams	137	4	141	45	25	70	21	8	29	133	1	134	0	15	15	199	49	248
B	6 grams	137	7	144	18	17	35	6	2	8	62	0	62	0	2	2	86	21	107
C	8 grams	137	7	144	4	4	8	0	1	7	72	0	72	0	0	0	82	5	87
D	10 grams	138	8	146	11	3	14	1	7	8	73	0	73	0	0	0	85	10	95
E	12 grams	142	10	152	9	1	10	8	1	9	49	1	50	0	0	0	66	3	69
	Copper sulphate:																		
F	Control	138	1	139	87	21	108	59	2	61	178	0	178	39	251	290	363	274	637
A	4 grams	158	1	159	81	20	101	7	1	8	2	0	2	0	61	61	90	82	172
B	6 grams	144	2	146	34	12	46	4	6	10	0	0	0	0	6	6	38	24	62
C	8 grams	134	3	137	21	7	28	6	2	8	0	0	0	0	1	1	27	10	37
D	10 grams	137	5	142	9	4	13	3	2	5	0	0	0	0	0	0	12	6	18
E	12 grams	124	1	125	1	3	4	1	2	3	0	0	0	0	0	0	2	5	7

[1] Figures are the average germination from two plots each sown with 200 seeds of each species in the fa of 1918.
[2] The presence of more than 200 timothy seedlings in 1 of the F plots and numerous other weeds indicates the germination of native seeds that were in the soil before sowings were made.

The action of zinc sulphate raised the germinative capacity of western white pine in every test. It greatly reduced the germination of clover, sorrel, and timothy seed, although not in direct proportion to the amount applied. In 1919 the sprouting of miscellaneous volunteer weeds was eliminated on all plots, and in 1920 the number of volunteer weeds was less than 10 per cent of the number in control plots.

INSTALLATION AND TREATMENT OF PLOTS

A.—Plots with 10 by 12 by 24 inch bottomless frames installed.
B.—Sprinkling apparatus, with glass bottles containing stock solutions of zinc sulphate, zinc chloride, and copper sulphate, also hose with filter nozzle to retain seeds in the water supply.
C.—Method of chemical treatment, with a wooden "funnel" dividing the plot into two equal areas of 1 square foot each and preventing the loss of the solution from the plot. Treated plots at each side are covered with a cheesecloth and wire screen to keep out weed seeds as well as birds and rodents.

The action of zinc chloride was similar, with more pronounced and fairly regular elimination of the weeds, both sown and volunteer.

Copper sulphate stimulated pine considerably in the 4-gram test, and somewhat less in the 6, but heavier applications slightly reduced the number of germinations. Clover germinations were greatly reduced by applications of more than 4 grams. Sorrel and timothy were hit hard by all applications, especially timothy. Most of the miscellaneous weeds were as much reduced by light applications of this salt as they were by the other salts, and were eliminated by the heavier applications.

The pine seeds which come up during the season following sowing are the ones which must be depended upon for the crop, for the others, a year younger, do not ordinarly have time to develop sufficiently to be suitable for field planting. It may be seen from the

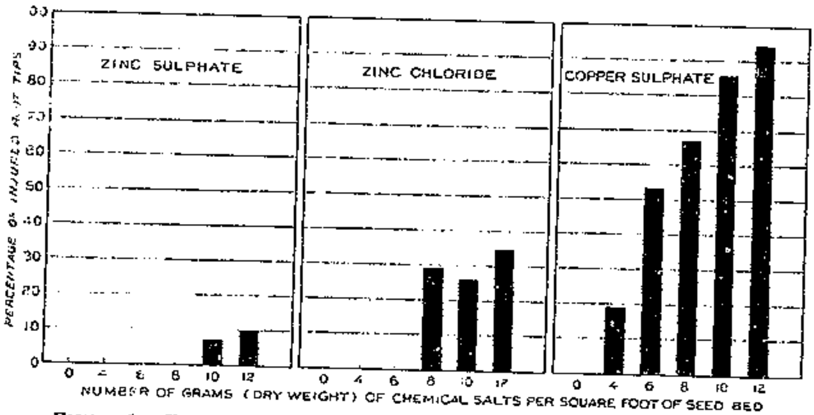


FIGURE 1.—Extent of chemical injury to root tips of western white pine

figures in Table 3 that all of the salts used, and especially the zinc chloride, slightly increased the number of pine seeds which did not sprout until the season of 1920.

It is essential not only that as many as possible of the pine seeds come up during the first season, but that the germination of these seeds should not linger. Prompt and complete sprouting of seeds in the spring months results in regular and satisfactory stands of seedlings. Stragglers are often too weak and tender to withstand the hot summer sun or the fall frosts. The application of shade, which is expensive, may not save these weaklings, and even if it does they are quite likely to be rejected along with those of the following season when field-planting time comes. Therefore this study would not be complete without a consideration of the effect of the chemicals on germination energy or seasonal promptness, as shown in Table 4.

TABLE 4.—*Effect of various chemical treatments of the soil on promptness of germination of western white pine seed*[1]

Salt per square foot used for treatment	Percentage of total germination at successive observations						
	May 7	May 15	May 26	June 6	June 18	June 30	July 14
	Per cent	*Per cent*	*Per cent*	*Percent*	*Per cent*	*Per cent*	*Per cent*
Zinc sulphate:							
Control	0	18.5	93.3	98.5	100	----------	----------
4 grams	0	27.5	97.1	99.3	100	----------	----------
6 grams	.7	16.9	95.8	99.3	100	----------	----------
8 grams	1.3	44.4	98	100	----------	----------	----------
10 grams	1.4	29.3	98	100	----------	----------	----------
12 grams	3.7	40.3	97.5	100	----------	----------	----------
Zinc cloride:							
Control	.9	11.5	94.7	100	----------	----------	----------
4 grams	0	11.8	87.5	96.3	100	----------	----------
6 grams	.7	13.2	90.4	97.3	100	----------	----------
8 grams	1.5	22.2	96.3	100	----------	----------	----------
10 grams	0	34.3	96.4	100	----------	----------	----------
12 grams	1.4	28.6	93.6	99.3	100	----------	----------
Copper sulphate:							
Control	0	13.8	96.4	100	----------	----------	----------
4 grams	.6	18.6	93.6	94.4	100	----------	----------
6 grams	0	8.4	93	100	----------	----------	----------
8 grams	0	3.0	84.9	99.2	100	----------	----------
10 grams	.7	9.5	83	98.4	99.2	100	----------
12 grams	0	2.5	79.1	96	97.6	99.2	100

[1] Figures are based on the average results from two plots each sown with 200 seeds and treated chemically in the fall of 1918.

The copper sulphate in all strengths definitely retarded germination, the apparent stimulation produced by the 4-gram application proving but temporary. On the other hand, both of the zinc salts and especially the zinc sulphate seemed to stimulate germinative energy. In Figure 2 a comparison is made of promptness of seed sprouting under the treatments that did not result in root injury to the pine seedlings. (Table 2.) The criterion of promptness or retardation of germination illustrated in Figure 2 lies in the relative position of the curves above or below the solid-line curve representing the behavior of seeds in the untreated soil. This solid-line curve indicates that without treatment 18 per cent of the germination had occurred by May 15 as compared with 13 per cent under the 6-gram zinc chloride treatment and 44 per cent under the 8-gram zinc sulphate treatment.[6] The apparent superiority of zinc sulphate over zinc chloride stood out in these tests, the seeds from the 8-gram zinc sulphate treatment maintaining their lead as indicated by the uppermost curve of Figure 3.

An interesting point observed in the plots kept covered with cheesecloth during 1919 was the action of zinc and copper salts on the growth of bryophytes. There was as much or even more such growth on the plot treated with 4 grams of zinc sulphate per square foot as on the untreated control, but the growth diminished rapidly through the 6, 8, and 10 gram plots and was practically nil in the 12-gram plot. With the other two chemicals there was some growth in the 4-gram plots, but not as much as in the control plots, and in the plots receiving heavier applications there was no sign of bryophyte growth. Again in the spring of 1920 it was noted that

[6] The evidence that this rather striking increase in germination with the 8-gram zinc sulphate treatment was due to any inherent superiority of zinc sulphate over zinc chloride is weakened by the inconsistent position of the 4-gram zinc sulphate curve between the curves for the 6-gram and 8-gram doses of this salt, and also by the small basis in a single test in which only 400 seeds were sown. If zinc ions are the only active agents, zinc chloride should be found as good in every way as zinc sulphate.

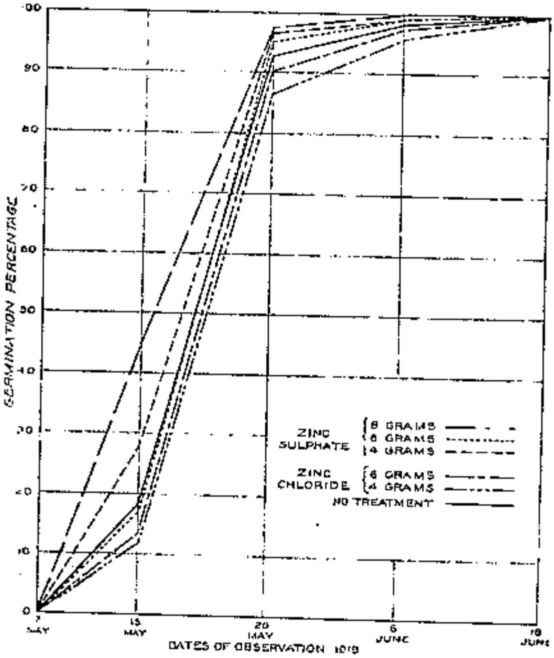


FIGURE 2.—Germinative energy of western white pine seed as influenced by treatment with zinc salts at different rates per square foot of seed-bed surface

zinc chloride, copper sulphate, and zinc sulphate had a restraining effect on bryophyte growth in the order named, and the inhibitory effect appeared to vary directly with the quantity of salt applied.

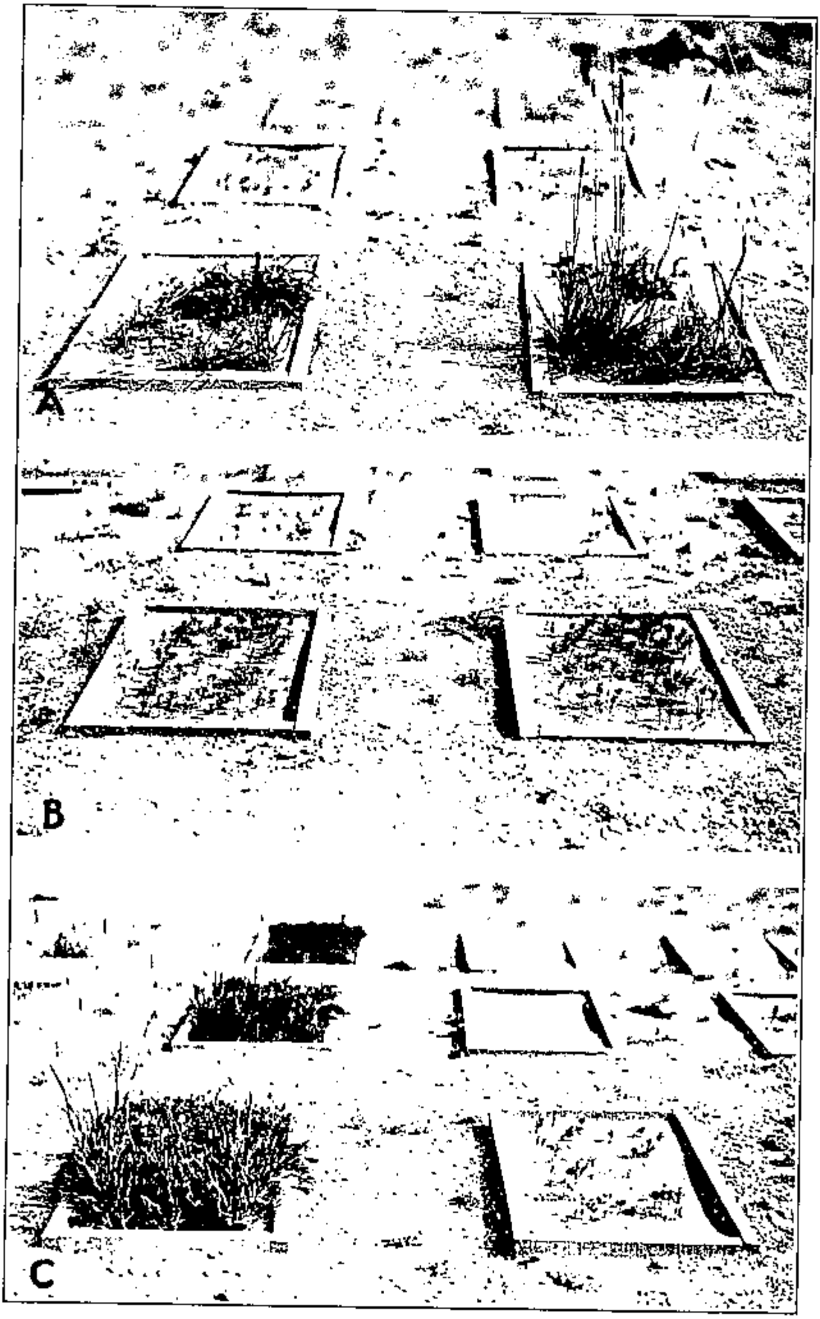
FIGURE 3.—Similarity of survival of planted trees grown on treated (zinc sulphate) and untreated nursery soil

As all the chemical treatments were efficient in reducing the germination of weed seeds, the selection of the most practical treatment depends upon relative effects on the pine seeds and seedlings. Within the range of the doses tested, the effect on the trees may be briefly restated as follows: In increasing the total number of seeds that came up the copper sulphate was least active, the zinc chloride next, and the zinc sulphate most active. Copper sulphate and zinc chloride retarded the rate of seed sprouting during the first year, but the zinc sulphate accelerated germination. All of the salts, but particularly the zinc chloride, slightly increased the number of germinations that were delayed for a whole year. More important than any of these phenomena, however, was the relative extent of fatal injury to growing root tips. In this respect copper sulphate was most harmful, the zinc chloride next, and the zinc sulphate least harmful.

With these general tendencies in mind, an effort was made to select the best treatment from among those which produced no root injury; that is, zinc sulphate at the rates of 4 to 8 grams and zinc chloride at the rates of 4 and 6 grams per square foot. The two zinc chloride treatments were much alike in showing a tendency to reduce the germinative energy of western white pine seed, and were nearly equal in the total tree-seed germination attained; but the 6-gram application was the more effective on weeds. Of the three zinc sulphate treatments in question, all greatly reduced the sprouting of weed seed, the 4-gram application being least effective. All three, but especially the 8-gram application, stimulated the germinative energy and increased the total number of western white pine seeds that emerged from the soil.

Thus, slight advantages narrowed the choice down to two applications—the 8-gram zinc sulphate and the 6-gram zinc chloride treatments. Of these, the latter seemed to be the more effective on weeds, but gave a slightly smaller total number of pine seedlings and failed to hasten pine germination as did the former. Also, the data in Figure 1 suggest that, if through any cause as much as 2 grams more of the chemical than was intended be applied per square foot, greater injury might be expected to result from the 6-gram zinc chloride than from the 8-gram zinc sulphate treatment. The safe and the fatal limits of concentration of these salts were not determined with sufficient precision to establish this point with certainty, but the possibility of extensive damage resulting from irregularities in distribution of the chemical in large-scale treatments had to be considered. The relative cost of these two materials per unit weight of zinc was almost the same at central markets, but freight rates on the sulphate were about twice those on the chloride. On the other hand, zinc chloride is a fused and completely dehydrated salt and hence more hygroscopic and difficult to handle in the nursery than is zinc sulphate. Consequently the 8-gram zinc sulphate treatment was selected as the best.[7]

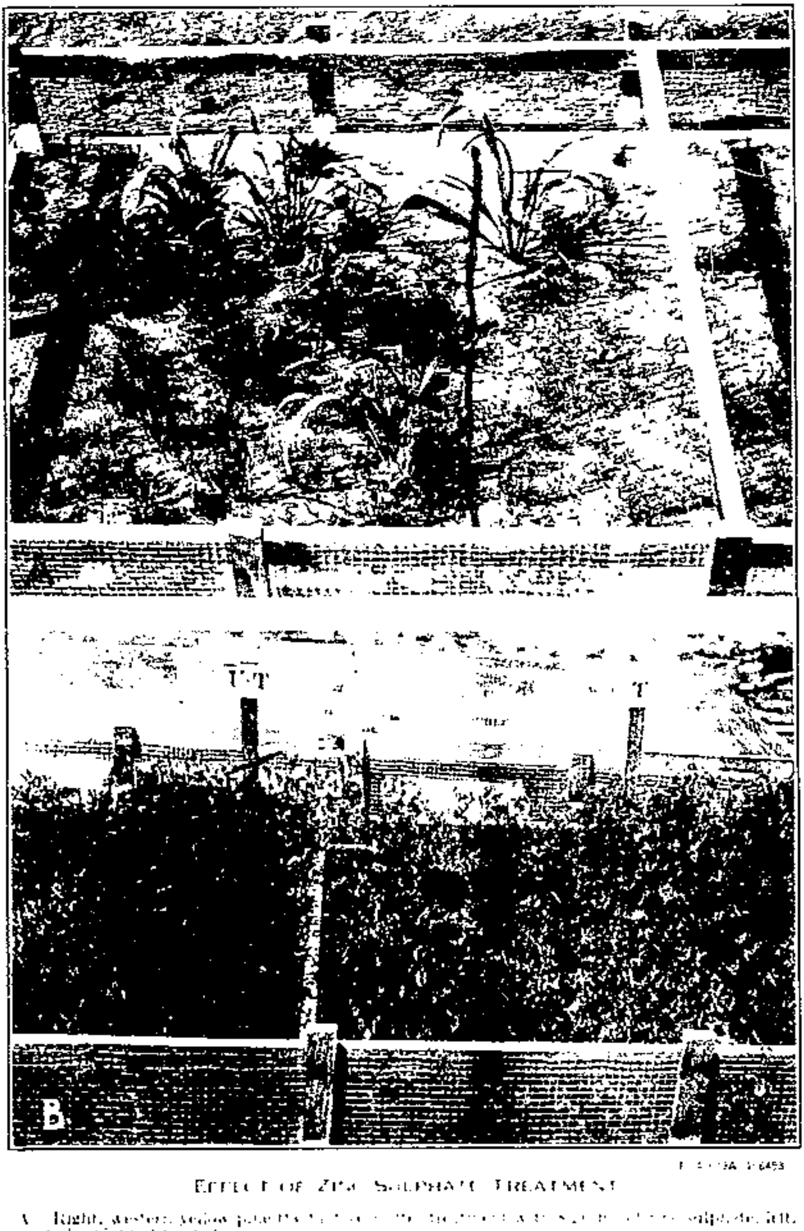
[7] The comparison here of the relative effects of the sulphate and chloride of zinc may appear unscientific because no direct comparisons were made of doses containing chemically equivalent amounts of zinc. This was an oversight in the plans for the work and can not well be adjusted in any way in interpretation of the original data. The author freely admits that because of this weakness in the original plan, the evidence on which zinc sulphate was selected rather than zinc chloride is not convincing. No practical case has been made against the chloride and further research might easily indicate equality or even superiority for the chloride. An attempt is made merely to show the line of thought, possibly a faulty one, whereby the sulphate was singled out for further study.



F-42592A, [illegible]A–42590A

EFFECT OF ZINC SULPHATE TREATMENT

A. Left, the 6-gram plot; right, the 4-gram plot.
B. Left, the 10-gram plot; right, the 8-gram plot.
C. Left, the check plot that received no treatment; right, the 12-gram plot.



F [illegible] 6453

EFFECT OF ZINC SULPHATE TREATMENT

A. Right, western yellow pine [illegible] sulphate; left, similar plot not treated.
B. Field peas [illegible] results on both treated and untreated plots.

It was planned to obtain information on the survival of seedlings from treated plots to substantiate this choice. An early and unexpected snow cover in the fall of 1919 prevented detailed counts in the plots at that time but general observations and photographs were made. Plate 2 shows how the series of zinc sulphate plots appeared. The duplicate series checked very closely with the one illustrated here, particularly in regard to the clean eradication of weeds in the 8-gram plot. The relatively better stand of pine in this plot than in those of stronger treatment agrees with the figures showing that root injury to pine seedlings first became apparent in the 10-gram plot. (Table 2.)

TEST OF 8-GRAM ZINC SULPHATE TREATMENT ON TWO SPECIES OF PINE

In the fall of 1919 and the spring of 1920, 16 test plots of 12 square feet each were established. This time only the 8-gram zinc sulphate treatment was applied, but another tree species was introduced, the western yellow pine. As in the earlier tests, there was a marked reduction in the number of weed seeds that sprouted.

Four treated plots and four untreated plots were each sown in the fall of 1919 with 1,000 seeds of clover. Similar groups of four plots were sown in the same way with sorrel and timothy seed. During 1920 the following germinations occurred, the figures being the average number on each group of four like plots:

	Treated	Untreated
Clover	0	49
Sorrel	0	26
Timothy	0.5	86
Volunteer weeds	1	64
Total	1.5	225

Thus with the same sowing treatment 225 weed seedlings came in on untreated soil and only 1.5 on treated soil. The germinations the following year from viable seeds remaining in the soil and from seeds having been subsequently sown by natural means in these unprotected plots were 2 on treated soil and 21 on untreated soil.

Very similar effects on weed growth were observed from the treatment of duplicate plots in the spring of 1920. No samples of weed seed were artificially sown in these tests but the treated and untreated soil was given equal exposure to natural seeding. During the season the average results from duplicate plots were as follows:

	Treated	Untreated
Clover	0	47
Sorrel	0	19
Timothy	0.5	38
Other weeds	0	19
Total	0.5	123

How these plots appeared at the end of their first season is shown in Plate 3, A. That this relative freedom from weeds on treated soil may be expected to change very little during the second season is indicated by the tests already reported.

It is important to note that the otherwise very satisfactory persistence of toxic effects in the soil during the second year as a result of this chemical treatment seems to be reduced or eliminated if the soil be disturbed. In 1921 many weeds appeared during the summer in scattered places where the soil had been disturbed by the use of a spading fork and the pulling out of the tree seedlings. It may be that in undisturbed plots capillary movement of the soil solution has in some way maintained a higher concentration of the toxic solute at the surface, which forms the germinating medium for seeds, than at deeper levels, and that pulling trees has abruptly destroyed such a condition. Further observation of this phenomenon is needed.

The effects of the zinc-sulphate method on pine seedlings in nursery beds as indicated by these trials are given in Table 5.

TABLE 5.—*Germination, loss, and survival of western white and western yellow pine grown in soil treated with 8 grams of zinc sulphate per square foot*[1]

GERMINATION AND SURVIVAL

Species and plots (1919)	Germination 1920	Germination 1921		Germination Total	Survival in 1920	
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
Western white pine:						
Treated plots	664	10	1.5	674	259	39.0
Untreated plots	532	28	5	560	199	37.4
Western yellow pine:						
Treated plots	572	0	0	572	434	75.9
Untreated plots	501	1	.2	502	371	74.1

LOSSES BY CAUSES, 1920

Species and plots	Fungus	Cutworms	Drought	Miscellaneous
	Per cent	*Per cent*	*Per cent*	*Per cent*
Western white pine:				
Treated plots	41.5	53.1	0.7	4.7
Untreated plots	12.0	80.5	.3	7.2
Western yellow pine:				
Treated plots	57.2	23.2	7.3	12.3
Untreated plots	40.9	32.3	1.5	19.3

[1]Seed beds were sown in the fall of 1919. Figures are averages based on 3 plots sown with 1,000 seeds each. They may be converted into percentage figures based on the number of seeds sown by merely pointing off 1 decimal place. Percentage figures listed in the "germination" section of the table are based on total germination, in the "survival" section on the first-year germination, and in the "loss" section on loss in 1920.

It is important that certain weaknesses in the basic data be explained. An attempt was made to list all fatalities according to the most apparent or major cause of death. Chemical injury is not mentioned in the table as a cause of mortality, because, as in similar tests of the same quantity of zinc in earlier experiments, no positive evidence of the existence of such injury was found. However, the difficulty of distinguishing between deaths from drought, damping-off, and chemical injury at this stage in the life of seedlings may have resulted in inaccurate classification of causes of loss. Chemical injury may, indeed, have been an important contributory cause of death of some seedlings. For example, contrary to expectation, relatively more trees seemed to have been lost from fungous trouble on the treated soil. Even if this observation could be regarded as accurate, it has little significance because it was based on a single trial. Like the smaller ravage from cutworms on treated soil, it may well have been accidental and could not be depended upon to recur.

The element of chance of infection by fungus or infestation by insects may easily outweigh the effects of any special susceptibility to injury. In other words, lack of control has made it impossible to trace these effects to their causes on so small a basis of observation. For similar reasons the relation of the chemical treatment to hold-over germinations can not be definitely stated. The slight tendency of zinc sulphate, evident in the first tests, to increase second-season sprouting of western white pine seeds was not in evidence in 1921. Had the results of water cultures with zinc sulphate been available, they might have aided in the explanation of some of these points by providing a better conception of the relative tolerance of dormant seeds and of growing roots to different quantities of the poison. Such fundamental points as these deserve further investigation.

The zinc-sulphate tests, however, gave some definite results, which are recorded in Table 5. As a result of the treatment, the number of seeds of western white pine sprouting during the first season was increased by 25 per cent, through control of parasites or other means, and of western yellow pine by 14 per cent. The percentage of survival, based on the total number of seedlings emerging from the soil during the first season, was not appreciably affected by the treatment, being for each species about 2 per cent higher in the treated soil. In other words, the rates of loss did not differ greatly in the treated and untreated soil.

In general the results of the zinc-sulphate tests served to corroborate the results of the first series and yielded two additional points of interest. These were that the treatment appeared to be as harmless to yellow as to white pine, and that artificial disturbance of the soil seemed to reduce greatly the latent toxic action of zinc sulphate. This effect of soil disturbance might cause the chemical treatment to be ineffective in transplant fields where the trees are cultivated: but it would in no way lessen the value of such chemical methods when used on seed beds that are not cultivated during the life of the crop. This observation suggests, however, the necessity of a new application of salt to seed beds for each new crop of trees.

OTHER EFFECTS OF THE SOIL TREATMENT

Among the questions that remain to be answered are the following: What is the effect of chemical treatment on the field-pea plants used as a soiling crop? What is the effect on subsequent development and survival of the pines and on other kinds of trees such as spruce and cedar? Will this treatment be useful on transplant beds? What precautions are necessary to successful application of the method? Will it work on freshly fertilized soil? While holding the amount of salt per square foot constant during any one treatment, is it safe to reduce the amount of water used, thus increasing the concentration of solution? Lastly, there arises the fundemental question of the cumulative effects on the soil of repeated doses of salt over the same areas. These questions, in whole or in part, were answered by further experiments.

EFFECT ON FIELD PEAS

Despite its promise of becoming an efficient means of reducing weed growth, the chemical treatment of the soil would be impracticable if it were to prevent the growing of green fertilizers. It was natural to expect such difficulty because the zinc sulphate had so effectively eliminated the sprouting of so many miscellaneous weeds, including clover, a leguminous plant.

In the spring of 1921 a crop of field peas, the usual soiling crop at Savenac nursery, was sown on untreated plots and on similar plots which had received the soil treatment just one year previously and had supported a crop of western yellow pine during its first season. The seeds were uniformly broadcast and covered with sand. Germination was prompt and uniform in all plots. Apparently most of the seeds which were sown germinated on treated as well as on untreated soil. (Pl. 3, B.) No water was applied until the dry season started. Growth was equally rapid in the plots and no unhealthy color of any significance was observed in the foliage. At the close of the season two sample areas were selected, the roots of the plants washed out of the soil, and the plants removed for laboratory examination. Counts showed nearly half again as many pea plants per square foot on treated soil as on untreated soil, indicating better germination of seeds under treatment. The resultant crowding and poorer development of plants on treated soil is not regarded as significant because the plants are unimportant individually. Oven-dry weights in grams of the mass of plant material per square foot were as follows:

TABLE 6.—*Oven-dry weight per square foot of field peas grown on treated and on untreated soil*

Method	Tops	Roots	Nitrogen nodules	Total
	Grams	*Grams*	*Gram*	*Grams*
Treated	80.52	6.28	0.63	87.43
Untreated	81.09	3.91	.47	85.47

The following year another crop of peas was grown on the same plots with equal success. Growth and development of the plants on the treated soil seemed about the same as on the untreated checks, but the foliage was slightly darker green, owing, perhaps, to somewhat greater increases in available nitrogen on treated soil as a result of the previous crop.

The top-root ratios of peas are not of so much interest as are those of trees for field planting, because with peas the main consideration is vegetative matter for the production of humus. The relatively heavier root systems of the peas found in treated soil correspond to results of work by Reimer and Tartar (*34*) indicating that various sulphur fertilizers doubled or trebled the size of alfalfa root systems, and with the findings of Hart and Tottingham (*17*) or Pitz (*32*) that calcium sulphate increased the root development of clover. Although the development of more nitrogen nodules with peas on treated than on untreated soil at Savenac nursery is contrary to the results obtained by Wilson (*42*) and Fellers (*13*) that zinc sulphate as well as calcium sulphate and ferric sulphate depressed nodule formation on soybeans, the finding seems to be supported by the work of Miller (*29*) and Dudley (*11*) with clover.

It might be argued on the basis of such reports as that of Brenchley (*4*) that the favorable results obtained at Savenac nursery with the experiment on peas could be explained solely on the basis of the varying sensitiveness of different plants to zinc poisoning. However, a later test at Savenac confutes this contention. In this test, in which zinc sulphate was applied immediately after the sowing of peas, the sprouting of all seeds, including peas, was almost completely prevented. The loss of poison by leaching or other means when the soil was disturbed by uprooting pine seedlings is the suggested cause of success in the first experiment with peas.

DEVELOPMENT OF PINE TREES FOLLOWING SOIL TREATMENT

Good development of trees in the nursery results in high quality of planting stock and consequently in better chances for survival and more rapid early growth in forest plantations. It is essential, therefore, to study the effect of chemical treatment on the development of trees.

A comparison of averages from various measurements of seedlings is given in Table 7. The trees on which these measurements were taken were mechanically selected by counting out every fifth plant from stock which had been lifted from the nursery and root pruned for transplanting or field planting. As none of the trees were crowded in the seed beds, disturbing influences from variations in density were considered negligible. The measurements sought especially to detect any inferiority of the seedlings from treated soil. The apparent superiority of some of these seedlings may have been caused, at least in part, by the lack of competition with weeds rather than by any direct stimulation from the chemical.

TABLE 7.—*Effect of treated versus untreated soil on the growth and development of pine seedling stock* [1]

Species, age, and condition of seed bed	Length of stem	Diameter of stem at ground	Lateral rootlets				Oven-dry weight of plant	Proportionate weight		Length of needles	Needles measured
			Primary		Secondary						
			½ to 2 inches	Over 2 inches	½ to 2 inches	Over 2 inches		Top	Root		
	In.	*Millimeters.*	*Number*	*Number*	*Number*	*Number*	*Grams*	*Per cent*	*Per cent*	*In.*	*Number*
Western yellow pine:											
1-year seedlings—											
On treated soil	2.41	1.35	7.26	0.95	0.56	0	0.2274	58.0	42.0	0.91	50
On untreated soil	2.24	1.33	8.90	1.28	.08	0	.2272	59.3	40.7	.87	50
2-year seedlings—											
On treated soil	4.56	2.27	11.47	2.54	.04	.01	1.122	83.1	16.9	1.96	57
On untreated soil	4.15	1.72	12.31	1.91	.31	0	.626	80.2	19.8	1.53	54
Western white pine:											
2-year seedlings—											
On treated soil	2.22	1.46	8.45	1.66	.27	0	.284	61.6	38.4	.84	55
On untreated soil	1.98	1.28	7.92	.73	.05	0	.208	59.6	40.4	.70	56

[1] Measurements of 1-year stock (1-0) are averages of 100 representative seedlings in each instance; for 2-year stock (2-0) 110 seedlings were used for length measurements and 100 for weight measurements.

Before interpreting the figures in Table 7, the purpose and the limitations of these figures should be more clearly defined. The general purpose, of course, is the detection of possible differences in plant development due to the chemical treatment of the soil, differences that might not be discernible except in the average measurements of 100 or more plants. The particular purpose is to show differences in what is called balance or the top-root ratio. Balance is the ratio between the capacity of the top to transpire moisture and the capacity of the root to absorb moisture. This ratio can not be directly measured and must be approximated. Although a comparison of the oven-dry weight of tops and roots is inexact as a measure of balance, mainly because volume of wood, which directly affects weight, has no influence on the transpiration-absorption ratio; still, it is the most practical method of getting an approximation of true balance in small plants containing but little wood. The method of counting the number of roots falling into certain length classes yields figures which are also imperfect as a measure of root development, principally because the small rootlets less than 0.5 inch long were disregarded entirely. Although these limitations reduce the precision of the work, the figures still give a better basis for comparisons than can be had from superficial observation.

Table 7 indicates that 1-year-old western yellow pine trees from treated soil compare very favorably with similar trees from untreated soil, except possibly in number of rootlets (primary and secondary). In this respect the untreated trees averaged 15 per cent more rootlets in the short length class and 35 per cent more in the longer class than the treated trees. Because of this and because of the slightly shorter tops of trees from untreated soil, it would be expected that the top-root ratio by weight would be greater for the treated stock, but actually it was slightly less. The discrepancy can only be explained on the basis of what has already been said of the imperfections in methods. The root differences noticed suggest that zinc sulphate in the soil solution, even though too weak to cause visible injury to root tips, retarded the growth of roots. The persistence of such retardation of root growth might well be expected to result in similar reduction in the later growth of tops and in general loss of plant vigor. Largely because this did not happen, the root differences just described were not considered to be serious.

A year later samples from the same lot of trees which were then 2-0[8] western yellow pines, showed what might be interpreted as complete recovery from early symptoms of indisposition. All measured characters, except balance, yielded more favorable figures for the stock from treated soil than for that from untreated soil. (Table 7.) The 34 per cent more rootlets (primary and secondary) in the greater length class for trees from treated soil much more than offset, in value to the trees, the 4 per cent advantage in number of short rootlets belonging to the trees from untreated soil. The treated lot of stock consisted of somewhat taller, sturdier, better-rooted, and generally better-developed trees than the untreated lot.

That the trees from treated soil had 3 per cent more of their total plant weight contained in the tops was not in their favor but was probably due merely to the artificial pruning operation which pre-

[8] As readers familiar with nursery practice will know, this terminology indicates the number of years spent by the plant in the seed bed and in the transplant bed. For example, 2-0 stock are seedlings 2 years old used in the field without previous transplanting, and 2-2 stock has been two years in the seed bed and two years in the transplant bed. Similarly, 1-2 stock and 2-1 stock are both 3 years old, the former having been transplanted at 1 year of age, the latter at 2 years.

ceded the measurements. In this operation all roots more than 6 inches from the ground line were pruned off, thus favoring the smaller plants by the removal of a smaller portion of their total root system.[9] The difference is not, however, great enough to be significant in field survival, and furthermore in similar 2–0 stock examined a year later it failed to appear.

The effects of treated soil on the development of western yellow pine seedlings hold also for western white pine, as is shown (Table 7) by the larger average measurements for the trees grown on treated soil. In other words, treated soil has been as favorable to the development of 2-year-old western white pine as it was to similar western yellow pine seedlings.

The same trees were further observed after removal from treated seed-bed soil to the untreated soil in transplant beds. The western yellow pine stock was transplanted in the spring of 1921 and the western white pine a year later. A comparison of the stock from the two kinds of soil and at different ages is shown in Table 8.

TABLE 8.—*Latent effect on transplants of origin in treated versus untreated seed beds*[1]

Kind of stock and condition of seed bed	Seedlings transplanted	Thrifty	Unthrifty	Injured	Missing	Dead
1–1 western yellow pine:	*Number*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
From treated soil	392	71.1	25.5	2.8	0.3	0.3
From untreated soil	400	66.8	25.8	2.0	.7	[2]4.7
1–2 western yellow pine:						
From treated soil	400	86.8	12.8	0	.2	.2
From untreated soil	400	85.0	8.5	0	6.3	.2
2–1 western white pine:						
From treated soil	577	81.8	17.3	0	.5	.4
From untreated soil	583	83.4	15.4	0	0	1.2

[1] These figures record the result of observations on western yellow pine transplants 1 year after transplanting (1–1 stock), and the same trees a year later (1–2 stock).

[2] Six out of nineteen trees died from injury by a garden hose to which the plants of the treated lot were not subjected.

There seems to have been little evidence of difference in the stock which could be attributed to chemical action. The lots appeared to be in very similar good condition. The only possibly unfavorable sign was the presence among the western white pines of a few more unthrifty trees from treated than from untreated soil, but the difference was hardly sufficient to be significant, and, as will be shown later, it did not persist in the field plantation. For views of transplant rows of this stock see Plate 4, A and B.

For the purpose of observing the relative survival and development of stock in the field, some 3,500 trees from treated and untreated nursery soil were planted by the slit method in 1922 and 1923. In May, 1922, two plantations of 2–0 seedlings were made, one of about 800 western yellow pine on a southeast slope, and the other of an equal number of western white pine on a northwest slope. On the same sites in the spring of 1923 about 1,140 (2–1) western white pines and about 750 (1–2) western yellow pines were planted.

[9] At the time the work was done it was desired to disregard all root development below 6 inches because it would be pruned off in any case in actual planting practice. Since then the planting crews have been planting longer roots in deeper holes, so that were this experiment repeated using the improved methods now in vogue, the slightly superior balance of stock from untreated soil might no longer be in evidence.

The comparative development of the seedling stock planted in 1922 has been considered in detail in Table 7. No laboratory study was made of the transplants set out in 1923. Previous to planting, the western white pine transplants were root pruned in bunches of 50 at a point 6.5 inches from the ground line. The western yellow pines were pruned in bunches of 25 to an 8-inch root length.[19] This removed from 4 to 8 inches of roots from one-third of the number and half as much from the remaining trees. From the appearance of the roots in bunches the plants from treated soil seemed to have a slightly larger number of lateral rootlets.

Trees from treated and untreated soil were set in alternate rows in the field in order to equalize their exposure to slight variations in soil and competing vegetation. Every tree planted in each of the four plantations was marked individually with a lath stake painted white. This facilitated the taking of accurate field notes on the behavior of the trees during the next three years. The plantations were examined monthly during their first season and in the spring and fall of the second and third years.

TABLE 9.—*Latent effect on field-planted seedlings and transplants of origin in treated and untreated seed beds*[1]

Stock planted, year of planting, and condition of seed bed	Thrifty	Unthrifty	Dead
Western white pine:	*Per cent*	*Per cent*	*Per cent*
2-0 stock, planted 1922—			
From treated soil	55.0	1.3	43.7
From untreated soil	50.0	1.0	49.0
2-1 stock, planted 1923—			
From treated soil	93.5	.9	5.6
From untreated soil	95.6	.9	3.5
Western yellow pine:			
2-0 stock, planted 1922—			
From treated soil	16.2	0	83.8
From untreated soil	19.5	.5	80.0
1-2 stock, planted 1923—			
From treated soil	77.2	3.1	19.7
From untreated soil	79.9	1.7	18.4

[1] Figures are percentages of the number planted—400 or more in each lot, 3,490 in all.

The results were watched with interest because it was thought that the treated soil might have caused some injury that escaped detection in the nursery observations and laboratory studies. By September of the first year the majority of the unthrifty plants had either died or recovered and by the third year the losses in all plantations were small. The condition of the trees in the fall of their third field season is shown in Table 9, and stages by which this degree of survival was attained are shown graphically in Figure 3. The differences in survival between plantations were marked, the transplants being superior to the seedlings and the site on which the western white pine was planted being more favorable to plant life than that on which the western yellow pine was planted, but for each class of stock the survival trends were very similar and differences in survival were too small to be significant when some allowance is made for experimental error. The 2-0 western white pine stock

[19] Numerous seedlings in a bunch may be quickly and satisfactorily root pruned at one stroke if the plants themselves are small. When large and bushy seedlings are pruned in this way the plants on the interior of the bunch are cut shorter than the others. Because the western yellow pines were larger than the western white pines in this experiment fewer plants could be uniformly pruned at once.

from treated soil was 5 per cent higher in survival than that from untreated soil, but for each of the other classes of stock the trees from untreated soil survived best by amounts from 1 to 4 per cent.

In the fall of 1925 after the transplants had been three years in the field, measurements were made of total height and of the length of the growth made by terminal shoots during the year. No attempt was made to select trees for measurement except that all injured, abnormal, or very unthrifty plants were excluded. The results are given in Table 10.

TABLE 10.—*Height growth in the field three years after planting of trees from treated versus untreated nursery soil*

Kind of stock and condition of seed bed	Total height	1925 growth	Basis, trees
	Inches	*inches*	*Number*
Western white pine, 2-1 stock:			
From treated soil	5.1	1.2	301
From untreated soil	5.1	1.2	302
Western yellow pine, 1-2 stock:			
From treated soil	7.8	2.0	200
From untreated soil	7.3	1.6	200

From the observations made, it appears that the survival and development of pines from treated and untreated nursery soil are very similar.

EFFECT ON TREE SPECIES OTHER THAN PINE

Pines only were used in the experiments so far described. In the spring of 1922 two plots sown to Engelmann spruce, (*Picea engelmannii*), and two to western red cedar (*Thuja plicata*) were given zinc sulphate treatment. The behavior of these plots during the season is shown by Tables 11 and 12. The small difference in survival of spruce on the two soils is considered to be within the limits of experimental error and not significant, but cedar showed lower germination and greater loss on treated soil at each count and resulted in less than half the survival obtained on untreated soil. It seems probable either that the thin seed coats of western red cedar were more easily penetrated by the zinc poison or that the cedar is less tolerant of zinc than are other conifers. The usual effect of practically complete elimination of weeds was attained on treated soil. Four of these plots are shown in Plate 4, C.

TABLE 11.—*First-year germination of Engelmann spruce and western red cedar under 8-gram zinc sulphate treatment* [1]

Species and treatment, 1922	June 16	June 27	July 7	July 18	July 29	August 17
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Engelmann spruce:						
Treated plots	66	58	25	21	7	11
Untreated plots	86	42	13	20	7	11
Western red cedar:						
Treated plots			132	40	5	0
Untreated plots			179	77	16	0

[1] Each figure represents an average number of seedlings for two plots sown with 500 seeds each. *Picea engelmanni* (Lolo National Forest), seed sown May 24, 1922, and *Thuja plicata* (Lolo National Forest), seed sown June 7, 1922. Soil treated with 8 grams zinc sulphate per square foot.

TABLE 12.—*First-year survival and losses of Engelmann spruce and western red cedar under 8-gram zinc sulphate treatment*

Species and treatment, 1922		Survival		Losses from—		
	Seedlings	Based on seed sown	Based on germination	Fungus	Cutworms	Miscellaneous
	Number	*Per cent*	*Per cent*	*Number*	*Number*	*Number*
Engelmann spruce:						
Treated plots	133	26.6	70.7	15	21	19
Untreated plots	149	29.8	83.2	11	11	8
Western red cedar:						
Treated plots	113	22.6	63.8	20	6	44
Untreated plots	246	49.2	92.5	12	1	7

In the fall of the same year a similar test was made with Douglas fir seed. During 1923 the plots received no attention except sprinkling, the weeds being allowed to run riot on the untreated soil. In the fall there were 174 fir seedlings on treated soil as compared with 53 on the untreated soil where they had to compete with weeds, a reduction of 70 per cent on the untreated soil.

These tests were neither so intensive nor were they followed so long as the experiments with pine, but as far as they go the indication is that the chemical treatment may be used with spruce and Douglas fir but not with cedar.

The use of zinc sulphate as a soil treatment was not tested in seed beds of any other species of trees at Savenac nursery, but Darnfelt (*9*), after visiting the nursery in 1924, experimented with *Pinus sylvestris* and *Picea excelsa* in Sweden. He reports no damage to these species from the zinc treatment. In a later paper Darnfelt (*10*) describes further encouraging results from his experiments. He used zinc sulphate at the rate of 60 grams per square meter dissolved in 2.5 to 5 liters of water, and obtained reductions of 50 to 75 per cent in weed growth.

DANGER TO THE SOIL

Some observations made in Germany in the latter part of the nineteenth century are worth recording here because of their direct bearing on the present problem. Sorauer (*38, p. 752*) reports that Konig (*25*) paid especial attention to the effects of waste waters containing zinc sulphate from zinc blend mines. Streams receiving such water were found to contain zinc oxide in solution, and to cause an evident retrogression in the yield on meadows they watered; even in places a very poor growth. Up to 2.78 per cent of the ash of grasses grown on such sterile places, as well as the deformed, bushy beech and maple trees, was zinc, whereas the ash of normal meadow plants contained none of this metal. Only one specific zinc plant, the "white mineral blossom," was found. It contained not less than 11 per cent of zinc oxide in its ash. Two points were brought out, (1) the great difference in the susceptibility of different plants to injury and the high concentrations that sometimes may be endured, and (2) the fact that injury occurred only after a number of years during which the zinc had accumulated from water containing only very small quantities in solution.

The possibility of serious injury to the soil as a result of repeated chemical treatment was recognized early in this work. In 1921 Kelley[11] warned that soil injury might well be expected for two reasons, (1) because zinc in any considerable concentration is a definitely established plant toxin to which different species are susceptible in various degrees; and (2) because zinc sulphate, being a salt of a weak base and a strong acid, will tend to produce acidity in the soil. Other students of plant nutrition doubted if the Savenac treatments would result in sufficient quantities of zinc in the soil at any one time to be injurious to the tree crops and were inclined to believe that injurious acidity would not develop in the near future.

The tendency for sulphur to produce soil acidity, however, has been observed by numerous investigators. Storp (*39*) states that the presence of zinc generates free sulphuric acid in some soils. Olson and St. John (*31*) quote 12 authors who agree that sulphur in various forms increases soil acidity. The relation of acidity in the soil to the metabolism of plants is not thoroughly understood as yet, but coniferous trees are often thought of as preferring acid soil. Wherry (*41*) lists certain coniferous forest trees as preferring acid habitats, although also occurring on soils of intermediate reaction such as other conifers appeared to prefer. Experiments reported by Baker (*2*) indicate that unless acidity or alkalinity reach extreme points they do not limit the survival or growth of western yellow pine. Physical character of the soil had a greater influence on the trees than soil acidity. Other investigators have concerned themselves with the effect of an acid state on soil fertility through the influence of hydrogen ions on nitrogen fixation by certain soil organisms. Meek and Lipman (*28*) observed that, although nitrification proceeded in peat soil of low pH value, organisms from garden soil ceased the production of both nitrites and nitrates at pH values below 5.4. The same men, in studying the resistance of nitrifying bacteria to high salt concentrations, found that the sulphate was less toxic than other sodium salts. As has been pointed out in the present study, zinc sulphate in a single test seemed actually to stimulate the production of nodules on the roots of field peas. The chances for the development of unfavorable soil conditions from the use of zinc sulphate, however, are sufficient to warrant constant vigilance.

In 1924 numerous unthrifty 1-year-old western white pine seedlings were found in one of the principal fields at Savenac nursery. The soil had been treated with zinc sulphate and showed a slightly unnatural color. When the soil surface was air-dry and neighboring untreated soil was light colored, the treated soil appeared darker, as if it were moist. These observations, particularly the unthrifty condition of the trees, brought about a soil-acidity survey by the author, a field inspection by a representative of the Bureau of Soils, and soil examinations in the laboratories of that bureau. The findings of these three agencies agreed that both treated and untreated soils were strongly acid, having an average pH value of about 5.3,

[11] Kelly, W. P., In a personal letter to the author from the agricultural experiment station, University of California, Berkeley, Calif.

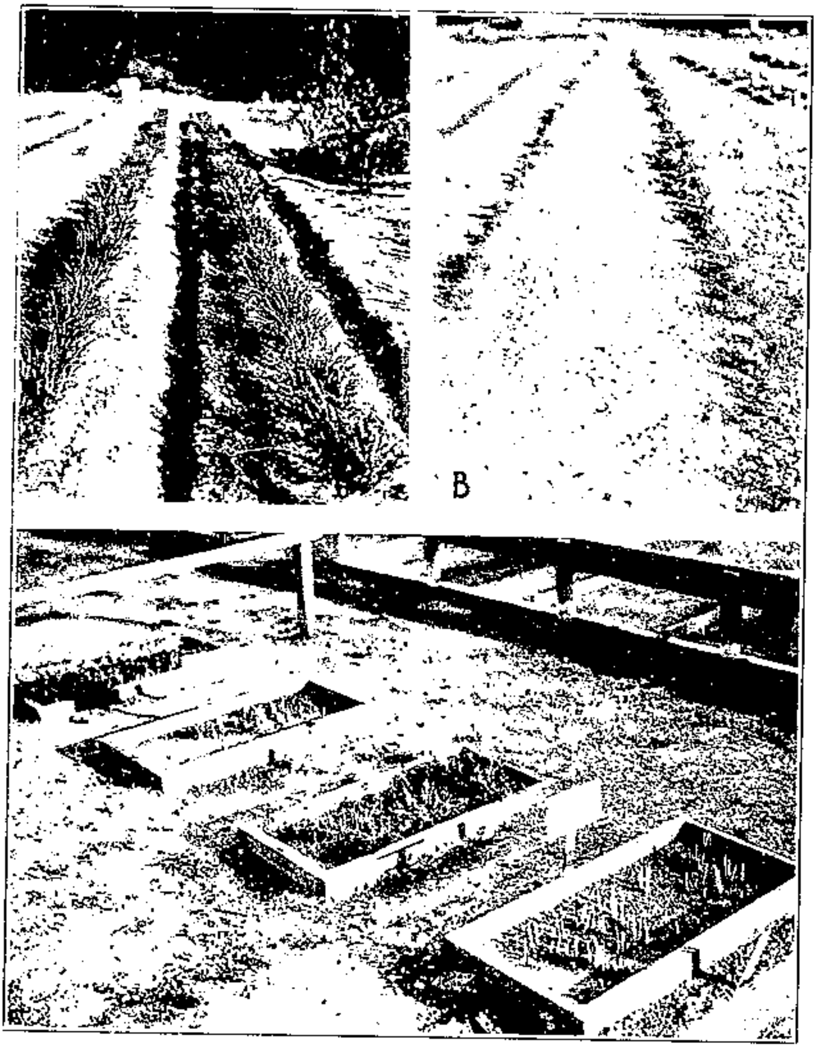
but that as yet this condition showed no connection with the zinc sulphate treatment.

The treated soil in question had received but one application of zinc sulphate and was no more acid than the surrounding untreated soil. Acidity seemed rather to have been caused by irrigation with slightly acid water and by the presence of a somewhat impervious subsoil. The unnatural color of the air-dry soil is attributed to a film of actual moisture on the surface of soil particles and pebbles, due to the hygroscopicity of the salt. Meanwhile the unthrifty color of the foliage on the seedlings disappeared. The next year the trees on treated soil had developed equally well with those on untreated soil and had apparently recovered completely. The investigation did not reveal the cause of the temporary unthrifty appearance of the trees, but it served to remove the suspicion that soil acidity resulting from zinc sulphate treatment was the cause of unthriftiness. Thus the first dose of zinc seemed to have been as harmless in these large-scale trials as it proved to be in the earlier small experimental plots.

In order to estimate the possible injury from a second dose of zinc, an attempt was made to determine the quantity of the first application still remaining within reach of the tree roots. The Forest Products Laboratory at Madison, Wis., tested samples and found no soluble zinc in the untreated soil or in the treated soil two years after the application. In the treated soil 0.30 per cent of insoluble zinc [12] was found. Similarly no soluble zinc was found in the ashes of either white or yellow pine from treated or untreated soil. This was to be expected because wood ashes are so strongly alkaline with potassium carbonate that the soluble zinc would be precipitated as insoluble zinc carbonate. In the ashes of western white pine from treated soil 0.48 per cent of insoluble zinc was found and in the ashes of western yellow pine from treated soil 0.50 per cent. None was found in tree ashes from untreated soil. Thus it seems that soluble zinc had entirely disappeared from the soil in two years, and that which was not lost through leaching was either absorbed by the trees or deposited in insoluble form in the soil.

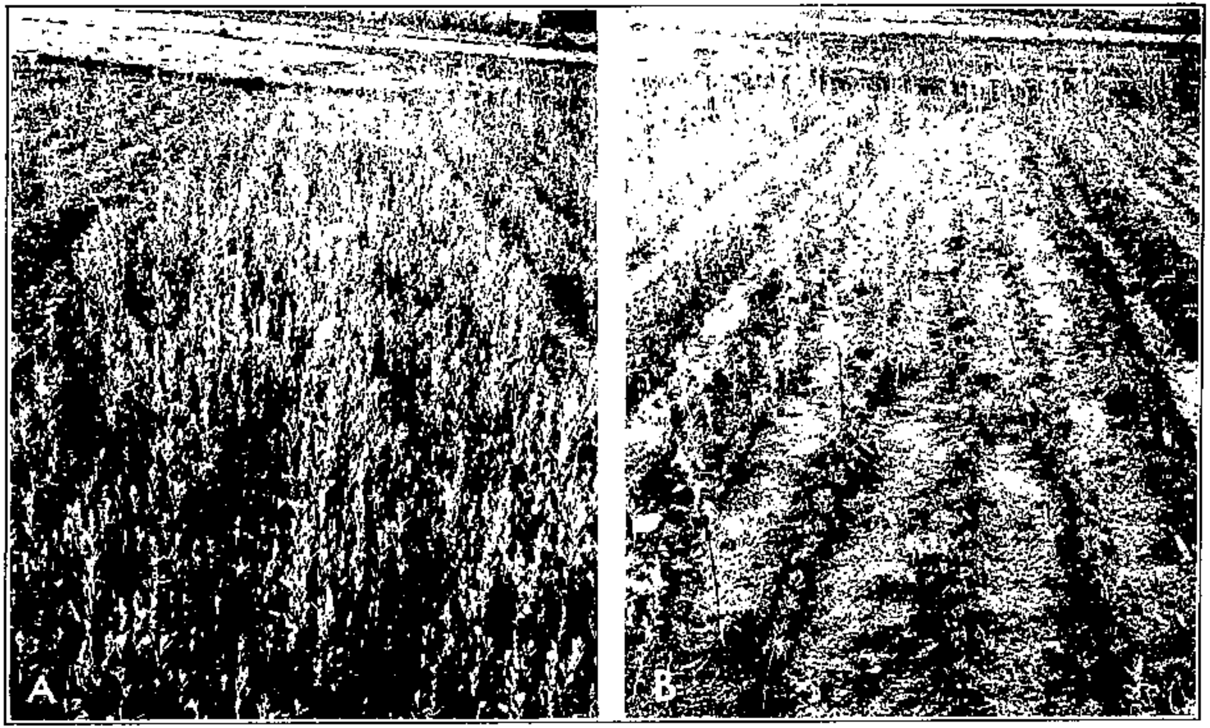
The possibility of some of this insoluble zinc again becoming soluble, either through the action of the roots themselves or other compounds such as ammonium salts, suggested that reduction in the amount of zinc sulphate applied the second time might be advisable. Second treatments were tried in 1924 on plots which had been given the standard treatment for the first time in 1922. In preparing the soil the land was plowed in 1922, but spaded in 1924 in order to keep the same mass of soil for second treatments. Results are given in Table 12.

[12] The chemical state of this insoluble zinc was not determined. It is believed to have been the oxide or possibly the carbonate. The quantity was determined by dissolving in acid and calculating back to the original chemical used. Soil samples were composites made up from soil taken at various points throughout the root zone of the nursery trees.



TREATED V. UNTREATED PLOTS OF THREE SPECIES

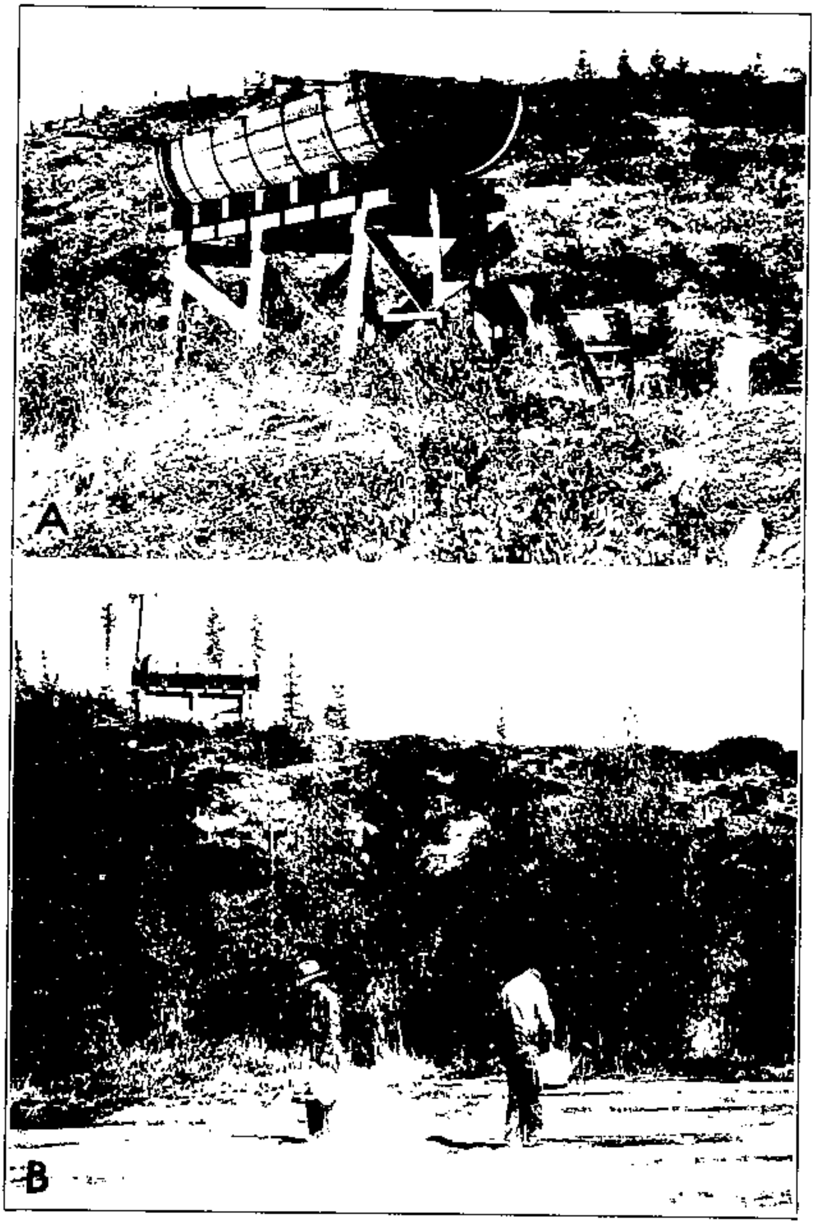
[illegible]



F-200320-200321

EFFECT OF TREATMENT IN TRANSPLANT BEDS

A.—Untreated transplant bed of 4-0 Engelmann spruce showing rank growth of cotton cudweed (*Gnaphalium palustre*) after three months.
B.—Transplant bed of 1-0 western white pine, three months after planting and treatment with 12 grams of zinc sulphate per square foot. Scattered lamb's-quarters (*Chenopodium album*) are conspicuous because of size rather than number. Survival of the pine under this heavy treatment was 77 per cent as against 88 per cent without treatment.



METHOD OF LARGE SCALE TREATMENT

[illegible]

[illegible]

EFFECT OF TREATMENT WITH 8 GRAMS OF ZINC SULPHATE PER SQUARE FOOT

The contrast (A) between treated plots (left) of [illegible] western yellow pine and untreated (right) is further emphasized by a closer, downward view (B) of one of the treated plots, showing complete absence of weeds

Table 12.—*Stand of tree seedlings and weeds on soil twice treated chemically*

Zinc sulphate treatment per square foot in—		Tree seedlings (1-0) per 4 square feet			Weeds per 4 square feet				
1923	1924	Thrifty	Unthrifty	Dead	Grass	Clover	Sorrel	Others	Total
Grams	*Grams*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
8	4	355	7	4	2	0	0	0	2
8	0	310	2	5	7	5	0	4	16
8	8	219	66	48	3	0	0	0	3
0	0	316	2	1	7	2	3	4	16

As was expected from the results of earlier tests the germination of pine seeds was increased slightly (about 5 per cent) in plots treated for the second time in 1924 with 4 grams of zinc sulphate per square foot, and except for some grasses the weeds were eliminated. The superior resistance of many grasses to zinc or acid poisoning has been noticed in several trials. Similarly at the Wind River nursery, at Stabler, Wash., the parallel-veined plants were found more resistant to sulphuric acid treatment than were the net-veined species, and Rabaté (*33*) found that spraying with sufficiently concentrated solutions of sulphuric acid killed all weeds except a few monocotyledonous plants such as grasses and cereals.

In 1924 the repetition of treatment using half the original amount of zinc was as effective on weeds as the repetition of the full amount. The latter treatment alone was injurious to the trees. While a few of the most thrifty individuals showed no apparent root injury, many of the seedlings, including the unthrifty ones, showed strong evidence of injury to the growing points, followed by decay of taproots. This observation points strongly to the conclusion that some of the insoluble zinc residue (probably zinc oxide or carbonate) in the soil had been rendered soluble either by the action of other compounds in the soil or by root action.

According to Freytag (*14*) the soil solution decomposes dilute zinc compounds as they filter through the soil and zinc is retained in the form of oxide. Baumann's (*3*) work indicates that the presence in the soil of such insoluble zinc salts, including the carbonate and sulphide, can not injure plants. But the work of Nobbe, Baessler, and Will (*30*) as reported by Brenchley (*4*) does not seem to agree with that of Baumann in that the insoluble zinc carbonate is included with the compounds that were found injurious. The dry weight of plants grown with small quantities of zinc compounds was less than for the controls, although no other sign of injury was noticed. Sorauer (*38, p. 753*) clearly expresses his view of the nature of the injury caused by zinc sulfate in soil in these words:

Zinc carbonate and zinc sulfate placed in the soil exercise an injurious effect. In themselves, to be sure, they are not injurious although they are soluble in pretty considerable amounts in water containing carbon dioxid, whereby the zinc sulfid is first changed to zinc carbonate. But their dangerous action lies in the transformation which the zinc undergoes in the form of vitriol with the potassium, calcium, and magnesium salts. In this these nutrient substances become soluble and may be wasted away. In poor sandy soils sterility may, indeed, be produced and the injuriousness of irrigation with waste water from the zinc smelters lies especially in this removal of the nutrient substances.

Storp (*39*) observes that the direct action of zinc compounds on plants is largely destroyed when these compounds are mixed in the soil, but suggests injury to soil due to the accumulation of insoluble zinc salts.

The observations of these men seem to be in full accord with the experience at Savenac nursery. Although the zinc residue in the soil may be harmless to plants in its insoluble form, it is nevertheless potentially injurious through its tendency to revert to soluble form. Although such a tendency is a menace to future crops, it may at the same time be the means of preventing permanent injury to the soil, by permitting the removal of injurious quantities of poison through leaching or absorption in the trees. Experiments have indicated that when second treatments are made two years after the original dose of zinc sulphate was applied, the quantity should be reduced to 4 grams per square foot.

Subsequent treatments have not yet been tested. It is hoped that by the time such treatments are needed the natural loss of zinc from the soil will permit of fresh doses in sufficient quantity to be effective on weeds without injuring the trees. Inspection of growing root tips of the trees on treated soil should be made each year in order to detect possible injury to crops. If at any time an appreciable amount of such injury is found it should be considered evidence of soil deterioration from accumulated zinc and the land should be treated with lime and humus or given a rest. The safest policy undoubtedly will be to avoid serious injury to the soil as a result of chemical treatments, but it is reassuring to note that Sorauer (*38, p. 753*) definitely stated the possibility of restoring fertility in these words:

> A soil ruined by zinc sulfate can be improved by the addition of substances which render soluble zinc salts insoluble.

He recommended the use of humus in the form of moor soil or stable manure and under all conditions some form of lime. Although it is possible that zinc treatment for weed control can not be continued indefinitely over the same areas with impunity, future tests of this treatment should aim at balancing the income and outgo of zinc in the soil, avoiding overdosage and accumulation.

USE OF ZINC SULPHATE ON TRANSPLANT BEDS

Although chemical control of weeds in seed beds had been very successful at Savenac nursery, following its adoption as an administrative measure in 1921, no attempt was made to test such control in transplant beds until four years later.

Chemical methods of weeding were not expected to be so efficient for transplants as for seedlings for several reasons. Transplants suffer less in competition with weeds because they are older and larger than most seedlings and because they compete less with each other. Standing in rows, transplants permit the removal of many weeds by cultivation, a process which seems to interfere with the toxic action of the chemical. Also, the open-ditch method of irrigating transplants may cause a greater leaching of the soil solution than the sprinkling method of irrigating seed beds. Nevertheless, some simple tests of zinc sulphate for transplant beds were made.

The last week in April, 1925, five plots were transplanted with 4-year-old Engelmann spruce seedlings and two plots with 1-year-old western white pine seedlings, each plot covering 176 square feet. A week later the spruce plots were treated with 8 grams of dry zinc sulphate per square foot and the white pines were given 12 grams. It was thought that this heavier treatment that had caused injury in seedbeds might not be injurious to transplants because of the larger amount of water passing through the soil. All of the beds were irrigated in the usual way, but not any of them were cultivated or weeded by hand until August.

Late in July, observation of the weed growth on treated soil as compared with that on adjacent untreated soil indicated that clover, sorrel, and cudweed had been almost eliminated, but that many large plants of lamb's-quarters remained. None of the weeds were counted and no significant difference in weed growth between the heavy (12-gram) and normal (8-gram) applications of zinc sulphate was apparent. The profusion of weed growth on untreated soil in contrast with the cleaner treated beds is shown in Plate 5. The lamb's-quarters in the treated bed are conspicuous because of their size rather than their number.

The trees surviving in certain beds four months after transplanting were counted. The survival of Engelmann spruce on treated soil was 81 per cent as compared with 89 per cent on untreated soil. The survival of western white pine was 77 per cent under heavy chemical treatment, 85 per cent under normal treatment, and 88 per cent without any treatment. The lower survival under treatment is attributed to action of the soil solution on roots, because no effect of the chemical on buds or foliage was noticeable. Probably the stumps of roots resulting from pruning at the time of transplanting did not directly increase the absorption of zinc. However, the shock from root pruning and transplanting may have weakened the seedlings sufficiently to increase their susceptibility to chemical injury, especially as the operation left them without their former absorbing rootlets in the deper layers of soil where the concentration of zinc probably was less than it was near the surface.

The treated beds of transplants were all weeded by hand in August, but the size of many of the weeds prevented the removal of all the roots. Weeds arising from root sprouts in 1926 were numerous in the treated as well as in the untreated plots. Although during the second year the trees were probably in a better condition to withstand further chemical treatment, it was not applied because it could not be expected to cope with weeds arising from roots. Summer fallowing between crops has since been found to be a fairly satisfactory way of dealing with the weed problem in transplant fields during the second growing season. As this has made the cost of hand weeding about equal to that of chemical weeding, there seems to be small need for any further trials of chemical methods of weed control for transplant beds.

LARGE-SCALE APPLICATION OF THE METHOD IN NURSERY PRACTICE

Chemical treatment was first adopted as a part of the practice at Savenac nursery in the fall of 1921 and has been used every year since then. The zinc sulphate is dissolved in water in a large wooden tank and is applied to the seed beds from ordinary sprinkling cans.

(Pl. 6.) The first year it was tried the treatment was found to be cheaper than hand weeding, but nevertheless fell short of expectations. Weeds were reduced in number, but not eliminated as they had been in the experiments. In large-scale treatments several possible causes of error were recognized and the precautions taken to reduce them in subsequent work have led to gratifying increases in effectiveness of the method.

DIFFICULTIES ENCOUNTERED

Among the more or less obvious causes of loss of the desired effect were the following five:

(1) When not thoroughly dissolved, zinc sulphate in various degrees of suspension following periodic stirring in the tank can not be evenly distributed on the beds, thus resulting in insufficient salt in certain spots to kill weed seeds and enough in other spots to harm the growth of trees. Similar results may be due to irregular distribution of salt from other causes such as careless sprinkling methods.

(2) Too little zinc sulphate may reach the seed-bed soil because of loss by run-off of the solution in paths or because of short weights due to the natural hygroscopicity of the salt. Accurate weights are dependent upon protection of the material from dampness. More about the run-off problem is given later.

(3) The method does not eliminate weeds which have sprouted from seeds previous to treatment nor those which may sprout at any time from broken roots in the soil. The work of Gericke (*15*) indicates that selective absorption by corky root tissue and precipitation of the injurious salt may account for the immunity of older plants from injury. Obviously the soil should be cleared of advance weed growth and broken roots by cultivation or handwork previous to treatment.

(4) Weed seeds from a distance may reach the soil through fertilizer or mulch material and some of these may prove to be highly resistant to, if not immune from injury by the treatment. Many wheat seedlings occured on treated soil following the use of wheat straw for mulch.[13]

(5) The chemical effect of fertilizers or the absorptive action of humus may reduce the effect of zinc sulphate on weeds. Soil containing a large amount of organic matter would undoubtedly require heavier doses of zinc sulphate in order to attain equal effect on weeds because of the retentive capacity of such soil for the soil solution. At the other extreme, sandy soil with its usual very low retentive capacity likewise probably requires heavy doses in order to prevent loss of effect. The formula worked out for weed control on the nursery soil was found ineffective on pure sand used in greenhouse tests at Savenac nursery in 1923. These observations agree with those of Baumann (*3*). He passed zinc solutions through various soils and tested the filtrate for zinc. Much was recovered from the sand, but none from the humus soil. In power to absorb zinc he rates humus first, clay and limerock soils next, and sand last.

Further experimentation was needed to determine the extent of the difficulty due to freshly fertilized soil. Following fertilization,

[13] Javillier (29) states that although wheat is clearly susceptible to zinc poisoning, it can benefit from small quantities of zinc compound.

sowing, and chemical treatment of plots in the fall of 1922, volunteer weed growth was observed in 1923. On unfertilized soil the treatment reduced the number of weeds by 89 per cent, whereas, on soil fertilized with 1 pound of dried blood and ground bone per 48 square feet, the reduction was 71 per cent, and on soil fertilized with 30 pounds of sheep manure per 48 square feet, the reduction was 72 per cent. Thus on fertilized soil the efficiency of chemical treatment was reduced by 17 or 18 per cent. This points strongly to the necessity for using a slightly heavier application of zinc sulphate. Otherwise hand pulling of those weeds escaping death from zinc would be essential because of the relatively more luxuriant growth of weeds which are not eliminated from fertilized soil.

According to Connor (*7*) lime may act upon injurious compounds in the soil in three ways. It neutralizes soil acidity; it precipitates most injurious soluble salts which are found in acid soils; and it antagonizes or opposes the action of excessive soluble salts which may not be precipitated. Among other metals Connor mentions zinc as one which is harmful in a soluble form but is rendered less soluble and less injurious by lime. This is in agreement with the results of True and Gies (*40*) who found that the growth of *Lupinus albus* seedlings suspended with their roots in zinc sulphate solution was retarded, but that when calcium sulphate was present, growth was more than twice as rapid as in the controls. In this case calcium reduced the toxic action of zinc to about one-sixteenth.

At Savenac nursery in 1925 two plots of 12 square feet each treated with hydrated lime, $Ca(OH)_2$, at the rate of 36 ounces per bed of 48 square feet, and the usual zinc sulphate application, produced 12 weeds as against one weed on similar plots receiving zinc sulphate but no lime. In another test, employing the same lime treatment accompanied by a 25 per cent increase in zinc sulphate, three weeds appeared on the fertilized soil and none on the unfertilized. The trees were apparently uninjured. These results are in line with the tests of other fertilizers, indicating the need for heavier doses of zinc, and they conform to Connor's findings concerning lime. The antagonistic action of fertilizers makes it seem desirable that they be mixed as deeply as possible in soil which is to be chemically treated, because the principal action of the weed poison is on or near the surface, whereas the tree seedlings can benefit from soil nutrients drawn from deep in the root zone.

The prevention of loss of zinc sulphate by run-off in the paths is connected with the concentration of the solution used. In the determination of the best amount, or dry weight, of salt to use per unit of area, an obviously safe quantity of water, 1 liter per square foot, was used in the first experiments. This amounted to about 12 gallons of liquid for each seed bed of 48 square feet and was found to be more than the soil could absorb at once. All areas were gone over twice in order to prevent loss from run-off. The additional expense of so doing was eliminated in later work after experiments had shown that such dilute solutions were not necessary. In the tests the original quart of water was halved, quartered, and omitted entirely on certain plots, the amount of salt being kept constant at 8 grams per square foot. Both western yellow and western white pine seeds were sown and their germinations, losses, and survival were closely observed. Developments were much the same in all plots, but survival was slightly lower in those plots that received dry salt, probably because of the lumps of chemical which prevented as uniform distribution as is possible when the salt is dissolved in water before being applied. Root examinations with a hand lens failed to reveal any abnormalities traceable to the chemical treatment. The elimination of weeds by the chemical in these plots was perfect, not a single weed being found during the season on treated soil. Plate 7 shows how the plots appeared. The primary purpose of this experiment, however, was fulfilled by the assurance that the usual quantity of zinc sulphate (384 grams or about 13½ ounces) may be distributed as satisfactorily over 48 square feet of soil surface by 3 as by 12 gallons of water.

FINANCIAL SAVING

The nursery manager reports that chemical methods have materially reduced the annual costs of weeding seed beds.[14] By hand methods the cost during two years for raising 2–0 planting stock is $1.40 per bed of 48 square feet, of which 40 per cent (or 56 cents) is the cost of weeding. Under the zinc sulphate method, similar 2-year costs are $1.02 per bed, of which 17.6 per cent (or 18 cents) is the cost of weeding. This weeding charge, of 17.6 per cent of production costs, consists of 7.8 per cent (or 8 cents) for the chemical, 3.9 per cent (or 4 cents) for the labor of applying it, and 5.9 per cent (or 6 cents) for subsequent hand weeding. Thus the use of zinc sulphate reduces the cost of producing 2–0 seedlings from $1.40 to $1.02 per bed, a saving of 38 cents. However, the usefulness of this chemical method can not be adequately stated in dollars and cents because the value of avoiding extensive injury to tree seedlings from hand-weeding methods has not been appraised.

LIMITED APPLICABILITY

Weed control in coniferous nurseries by the use of zinc sulphate is possible because of the especially high resistance of conifers, such as pine and spruce, to injury by small quantities of zinc. The common angiosperms, to which group almost all agricultural plants and weeds belong, do not possess this specific tolerance for zinc. Hence the method described here can find no application in general agricultural practice. Nor is it adapted for use in destroying weeds along railroad rights-of-way, in lumber yards, in driveways, or for similar problems because its specific effect has no value there. Wherever soil injuries are not important stronger doses of other common herbicides such as sodium arsenite are to be preferred. Even for coniferous seed beds zinc treatment can not be recommended for universal and unrestricted use, on account of the necessity for preserving soil productivity. Chemicals are needed only where the cost of hand weeding is excessive. They should not be used without preliminary small-scale tests in varied quantities and should be repeated only after the effects of the first dose have been determined.

---

[14] Weeding costs in terms of each thousand trees produced are omitted here for the reason already given in footnote 3.

Constant vigilance is necessary in order to avoid injury to crops and soil, or at least to prevent the repetition of any unintentional injury.

SUMMARY

The three most troublesome weeds at Savenac nursery are species of sorrel, timothy, and clover, introduced principally through irrigation water, manure, mulch, and wind. Chemical treatment of the soil to rid the nursery of these weeds has been thoroughly tested in beds of white and yellow pine, which constitute 85 per cent of the annual output of about 3,000,000 trees at the nursery.

The soil at Savenac has good physical properties, a high percentage of granular structure, and highly oxidized soil minerals. Organic matter is present in fair quantity, but not much of it is well decomposed. Lime in the form of calcium carbonate or calcium phosphate is absent. Potash feldspars, potash micas, and lime-soda feldspars are found. The soil tends to have an acid reaction, the irrigation water being slightly acid.

In 1915 various quantities of sulphuric acid applied to plots of soil in the nursery to arrest damping-off fungi were observed to reduce weed growth. In 1916 preliminary tests of chemical weeding were started, in 1918 intensive study of the subject was taken up, and in 1921 a chemical method based on the tolerance of conifers for zinc was put into general use to control the growth of weeds.

The application of the Savenac treatment is simple. It consists in applying 8 grams of zinc sulphate, $ZnSO_4.7H_2O$, known commercially as zinc vitriol or white vitriol, dissolved in 250 cubic centimeters of water, to every square foot of seed-bed area immediately after sowing the seed. This amounts to 1⅛ ounces of zinc sulphate per quart of water applied to every 4 square feet of seed bed. A new application of the zinc salt is needed for each successive crop of trees. The second dose should be only half the quantity of zinc originally applied, and the proper amount for the third dose can only be determined after close examination of the results of the first two doses, or, better still, by actual tests of the effect of applying different amounts of zinc on sample areas.

In the practical use of this treatment it is essential that care be exercised to obtain an even distribution of the chemical. The experiments indicate that if, through any cause, as much as 10 instead of 8 grams be applied to the square foot of Savenac soil, about 7 per cent of the growing root tips of the trees may be injured and that this injury will steadily increase with the overdosage. This observation does not apply equally to soils of different water-holding capacity, and heavier doses may be needed on sandy soils and those rich in humus. At Savenac nursery organic fertilizers reduced the efficiency of the treatment about one-fifth.

Results from year to year have varied a little, but each extensive trial has prevented the growth of at least four weeds out of every five in the seed beds for two seasons following the application. The treatment does not kill advance growth of weeds which may happen to be in the beds, nor pieces of roots or underground stems (runners) left from hand pulling, but it does prevent the germination of most of the weed seeds. They appear to be killed just after breaking their

seed coats in an attempt to germinate. The treatment seems especially efficacious with clover seeds and very effective with sorrel and timothy; most of the native weed seeds are readily overcome. In general the grasses have been observed to be least affected, and wheat seeds appear to be immune from injury, or nearly so.

The value of avoiding the injury to trees incident to hand weeding has not been appraised: but, at least, the use of chemical methods of weeding at the Savenac nursery has effected an annual saving of 38 cents in the cost of weeding each bed of 48 square feet.

The zinc-sulphate treatment for seed beds appears to have a tendency to stimulate the germination of pine seeds not only by reducing the time necessary to complete the germination of all viable seeds but also by increasing the total number of individuals that sprout. This tendency is probably due to the control of parasites or other indirect action, rather than to any direct stimulation of the seeds. Careful comparisons of the behavior of stock from treated and untreated seed-bed soil have been made during the various steps in nursery culture and later for the first three years after field planting, or until the trees were 6 years old. The treatment has been found in no way detrimental to the subsequent development, survival, and growth of western white or western yellow pine planting stock. The germination of Engelmann spruce seed is not injured by this treatment, but that of western red cedar seems to be reduced, probably because of the thin seed coats.

In transplant fields only one test of chemical treatment has been made. Most of the weed growth was prevented, but the trees were slightly injured.

The use of field peas as a green fertilizer crop on treated soil is possible because after a crop of tree seedlings has been grown and the soil is again plowed not enough soluble zinc is left to interfere with the germination of peas. The zinc residue in the soil tends to benefit the peas by increasing the number of nitrogen nodules on their roots. The effect of loss of zinc from treated ground is also noticeable even where the soil has been disturbed, as in lifting trees for shipment. Weeds have been observed to seed in freely on such areas.

Two forms of danger to the soil are recognized as a result of repeated applications of zinc sulphate. These are the development of soil acidity and the accumulation of zinc in quantities sufficient to injure the trees. Such danger exists in spite of the loss of zinc from the soil by leaching and by absorption in the trees.

The untreated soil at Savenac nursery is naturally acid, and sulphur in various forms tends to increase acidity. Zinc sulphate is expected to increase acidity because it is a salt of a weak base and a strong acid. So far the areas that have been given the chemical weed treatment have not been noticeably more acid than adjacent untreated areas; but lime has already been used throughout the nursery to check the general tendency toward acid reaction on untreated soil, and in the future it is possible that more lime will be needed not only to neutralize acid but also to inhibit the toxic action of zinc on areas treated with zinc sulphate.

Although tests made by the Forest Products Laboratory at Madison, Wis., failed to reveal any trace of soluble zinc in treated soil two years after the application of zinc sulphate, small quantities of insoluble zinc were found. A second crop of trees on this soil was injured by a repetition of the original zinc-sulphate treatment in full amount but was unharmed by an application of half the original dose. Apparently the deposit of insoluble zinc, representing a part of the original amount added to the soil, had again become soluble and existed in the soil as a menace to the crops.

LITERATURE CITED

(1) Anonymous.
1925. TO SAVE WEEDING. So. African Sugar Jour. 9: 407.
(2) Baker, F. S.
1925. CHARACTER OF THE SOIL IN RELATION TO THE REPRODUCTION OF WESTERN YELOW PINE. Jour. Forestry 23: 630–634.
(3) Baumann, A.
1885. DAS VERHALTEN VON ZINKSALZEN GEGEN PFLANZEN UND IM BODEN. Landw. Vers. Sta. 31: 1–53.
(4) Brenchley, W. E.
1914. INORGANIC PLANT POISONS AND STIMULANTS. 110 p., illus. Cambridge, England.
(5) ———
1918. THE SURVIVAL OF WEED SEEDS. Gard. Chron. (3) 64: 193.
(6) Campbell, E. G.
1924. WEED VALUE. Jour. Amer. Soc. Agron. 16: 91–96, illus.
(7) Conner, S. D.
1921. LIMING IN ITS RELATION TO INJURIOUS INORGANIC COMPOUNDS IN THE SOIL. Jour. Amer. Soc. Agron. 13: 113–124, illus.
(8) Cox, H. R.
1915. WEEDS: HOW TO CONTROL THEM. U. S. Dept. Agr. Farmers' Bul. 660, 29 p., illus.
(9) Dannfelt, M. Juhlin.
1925. ZINKSULFAT SÅSOMBEKÄMPNINGSMEDEL MOT OGRÄS I PLANTSKOLAR [ZINC SULPHATE AS A MEANS OF COMBATING WEEDS IN NURSERIES]. Skogen 12: 297–303, illus.
(10) ———
1927. OGRÄSET I PLANTSKOLORNA. ZINKSULFAT OCH NATRIUMKLORAT SÅSOMBEKÄMPNINGSMEDEL. [WEEDS IN THE NURSERY; ZINC SULPHATE AND SODIUM CHLORATE AS MEANS OF CONTROL.] Skogen 14: 227–230, illus.
(11) Dudley, F. L.
1916. THE RELATION OF SULFUR TO SOIL PRODUCTIVITY. Jour. Amer. Soc. Agron. 8: 154–160.
(12) Egginton, G. E., and Robbins, W. W.
1920. IRRIGATION WATER AS A FACTOR IN THE DISSEMINATION OF WEED SEEDS. Colo. Agr. Expt. Sta. Bul. 253, 25 p., illus.
(13) Fellers, C. R.
1918. THE EFFECT OF INOCCULATION, FERTILIZER TREATMENT AND CERTAIN MINERALS ON THE YIELD, COMPOSITION AND NODULE FORMATION OF SOYBEANS. Soil Sci. 6: 81–130, illus.
(14) Freytag, M.
1868. ÜBER DEN EINFLUSS DES ZINKOXYDS UND SEINER VERBINDUNGEN AUF DIE VEGETATION. Mitt. K. Landw. Akad. Poppelsdorf, 82–99.
(15) Gericke, W. F.
1922. PROTECTIVE POWER AGAINST SALT INJURY OF LARGE ROOT SYSTEMS OF WHEAT SEEDLINGS. Bot. Gaz. 74: 204–209.
(16) Goss, W. L.
1924. THE VITALITY OF BURIED SEEDS. Jour. Agr. Research 29: 349–362, illus.
(17) Hart, E. B., and Tottingham, W. E.
1915. RELATION OF SULPHUR COMPOUNDS TO PLANT NUTRITION. Jour. Agr. Research 5: 233–250, illus.
(18) Hartley, C.
1915. INJURY BY DISINFECTANTS TO SEEDS AND ROOTS IN SANDY SOILS. U. S. Dept. Agr. Bul. 169, 35 p., illus.

(19) HARTLEY, C., and PIERCE, R. G.
1917. THE CONTROL OF DAMPING-OFF OF CONIFEROUS SEEDLINGS. U. S. Dept. Agr. Bul. 453, 32 p., illus.

(20) HASELHOFF, E.
1892. UEBER DIE SCHÄDIGENDE WIRKUNG VON KUPFERSULFAT UND KUPFERNITRATHALTIGEM WASSER AUF BODEN UND PFLANZEN. Landw. Jahrb. 21: [263]–276.

(21) JAVILLIER, M.
1907. SUR L'INFLUENCE FAVORABLE DE PETITES DOSES DE ZINC SUR LA VÉGÉTATION DU STERIGMATOCYSTIS NIGRA V. TGH. Compt. Rend. Acad. Sci. [Paris] 145: 1212–1215.

(22) ———
1908. LE ZINC CHEZ LES PLANTES. RECHERCHES SUR SA PRÉSENCE ET SON RÔLE. Ann. Inst. Pasteur 22: 720–727.

(23) ———
1908. SUR LA FIXATION DU ZINC PAR LE STERIGMATOCYSTIS NIGRA V. TGH. Compt. Rend. Acad. Sci. [Paris] 146: 365–367. (Presented by E. Roux.)

(24) KITCHIN, P. C.
1920. PRELIMINARY REPORT ON CHEMICAL WEED CONTROL IN CONIFEROUS NURSERIES. Jour. Forestry 18: 157–159.

(25) KÖNIG, J.
1879. UNTERSUCHUNGEN ÜBER BESCHÄDIGUNGEN VON BODEN UND PFLANZEN DURCH INDUSTRIELLE ABFLUSSWASSER UND GASE. Biedermann's Zentbl. Jahrg. 8: 564–567.

(26) MCHARGUE, J. S.
1925. THE OCCURRENCE OF COPPER, MANGANESE, ZINC, NICKEL, AND COBALT IN SOILS, PLANTS, AND ANIMALS, AND THEIR POSSIBLE FUNCTION AS VITAL FACTORS. Jour. Agr. Research 30: 193–196.

(27) MAZÉ, P.
1914. INFLUENCES RESPECTIVES DES ÉLÉMENTS DE LA SOLUTION MINÉRALE SUR LE DEVELOPPMENT DU MAIS. Ann. Inst. Pasteur 28: 21–68, illus.

(28) MEEK, C. S., and LIPMAN, C. B.
1922. THE RELATION OF THE REACTION AND OF SALT CONTENT OF THE MEDIUM ON NITRIFYING BACTERIA. Jour. Gen. Physiol. 5: 195–204, illus.

(29) MILLER, H. G.
1919. RELATION OF SULPHATES TO PLANT GROWTH AND COMPOSITION. Jour. Agri. Research 17: 87–102, illus.

(30) NOBBE, F., BAESSLER, P., and WILL, H.
1884. UNTERSUCHUNGEN ÜBER DIE GIFTWIRKUNG DES ARSEN, BLEI, UND ZINK IM PFLANZLICHEN ORGANISMUS. Landw. Vers. Sta. 30: [381]–423.

(31) OLSON, G. A., and ST. JOHN, J. L.
1921. AN INVESTIGATION OF SULFUR AS A PLANT FOOD. Wash. Agr. Expt. Sta. Bul. 165, 69 p., illus.

(32) PITZ, W.
1916. EFFECT OF ELEMENTAL SULPHUR AND OF CALCIUM SULPHATE ON CERTAIN OF THE HIGHER AND LOWER FORMS OF PLANT LIFE. Jour. Agri. Research 5: 771–780, illus.

(33) RABATÉ, E.
1924. EMPLOI DE L'ACIDE SULFURIQUE POUR LA DESTRUCTION DES HERBES ET POUR LA LUTTE CONTRE DIVERS PARASITES. Rev. Path. Veg. et Ent. Agr. 11: [288]–298, illus.

(34) REIMER, F. C. and TARTAR, H. V.
1919. SULFUR AS A FERTILIZER FOR ALFALFA IN SOUTHERN OREGON. Oreg. Agr. Expt. Sta. Bul. 163, 40 p., illus.

(35) RUSK, H. M.
1920. THE EFFECT OF ZINC SULPHATE ON PROTOPLASMIC STREAMING. Bul. Torrey Bot. Club 47: 425–431, illus.

(36) SOMMER, A. L.
1927. THE SEARCH FOR ELEMENTS ESSENTIAL IN ONLY SMALL AMOUNTS FOR PLANT GROWTH. Science (n. s.) 66: 482–484.

(37) SOMMER, A. L., and LIPMAN, C. B.
1926. EVIDENCE ON THE INDISPENSABLE NATURE OF ZINC AND BORON FOR HIGHER GREEN PLANTS. Plant Physiol. 1: 231–249, illus.

(38) SORAUER, P.
[1914–1922]. MANUAL OF PLANT DISEASES I. NON-PARASITIC DISEASES. Translated by F. Dorrance. Ed. 3, v. 1, 908 p., illus. Berlin.

(39) STORP, F.
1883. UEBER DEN EINFLUSS VON KOCHSALZ-UND ZINKSULFATHALTIGEM WASSER AUF BODEN UND PFLANZEN. Landw. Jahrb. 12: 795–844.

(40) TRUE, R. H., and GIES, W. J.
1903. ON THE PHYSIOLOGICAL ACTION OF SOME OF THE HEAVY METALS IN MIXED SOLUTIONS. Bul. Torrey Bot. Club 30: 390–402.

(41) WHERRY, E. T.
1922. SOIL ACIDITY PREFERENCES OF SOME EASTERN CONIFERS. Jour. Forestry 20: 488–496.

(42) WILSON, J. K.
1917. PHYSIOLOGICAL STUDIES OF BACILLUS RADICICOLA OF SOYBEAN (SOJA MAX PIPER) AND OF FACTORS INFLUENCING NODULE PRODUCTION. N. Y. Cornell Agr. Expt. Sta. Bul. 386, p. 367–413, illus.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

November 18, 1929

Secretary of Agriculture	ARTHUR M. HYDE.
Assistant Secretary	R. W. DUNLAP.
Director of Scientific Work	A. F. WOODS.
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Director of Personnel and Business Administration.	W. W. STOCKBERGER.
Director of Information	M. S. EISENHOWER.
Solicitor	R. W. WILLIAMS.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Dairy Industry	O. E. REED, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	R. Y. STUART, *Chief.*
Bureau of Chemistry and Soils	H. G. KNIGHT, *Chief.*
Bureau of Entomology	C. L. MARLATT, *Chief.*
Bureau of Biological Survey	PAUL G. REDINGTON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Agricultural Economics	NILS A. OLSEN, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Plant Quarantine and Control Administration	C. L. MARLATT, *Chief.*
Grain Futures Administration	J. W. T. DUVEL, *Chief.*
Food, Drug, and Insecticide Administration	WALTER G. CAMPBELL, *Director of Regulatory Work, in Charge.*
Office of Experiment Stations	———, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*

This bulletin is a contribution from

Forest Service	R. Y. STUART, *Chief.*
Branch of Research	EARLE H. CLAPP, *Assistant Forester, in Charge.*
Office of Forest Experiment Stations	E. N. MUNNS, *Silviculturist, in Charge.*
Northern Rocky Mountain Forest Experiment Station.	R. H. WEIDMAN, *Director.*

U S GOVERNMENT PRINTING OFFICE: 1929

END