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SULFURIC ACID FOR CONTROL OF WEEDS

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Control of wild radish in grain with sulfuric acid.

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SULFURIC ACID FOR CONTROL OF WEEDS[1,2]

W. E. BALL[3] AND O. C. FRENCH[4]

INTRODUCTION

FOR SEVERAL YEARS it has been known that dilute sufuric acid may be used effectively to control annual weeds. Discovery of the method whereby weeds in cereals could be controlled without injury to the grain was made in 1896 by Bonnet, a Frenchman. He found that some plants with broad and rough leaf surfaces and exposed growing points were readily killed by certain chemical sprays, whereas other plants such as cereals, with narrow and smooth leaves and well-protected growing points, were only temporarily injured. Two years later this same worker, coöperating with Brandin and Ducos, employed dilute sulfuric acid successfully as a herbicide but concluded that its practical use was impossible.

In 1911, Rabaté,[5] in France, initiated work on the use of dilute sulfuric acid for weed control. For winter cereals he recommended 10 per cent sulfuric acid by volume (specific gravity 1.100–1.110) used at the rate of 1,000 to 1,200 liters per hectare (107–128 gallons per acre); and for spring cereals 4 to 4.5 per cent by volume (sp.gr. 1.040–1.045) applied at the same rate per hectare. Morettini,[6] in Italy in 1913–15, working with wheat, found dilute sulfuric acid to be most effective among the several chemicals he tested. He obtained six more bushels of grain in sprayed than in unsprayed areas by using the concentrations of acid and the volumes per hectare recommended by Rabaté.

[1] Received for publication August 12, 1935.

[2] This project was inaugurated and supported by the Crop Protection Institute, through funds contributed by the Freeport Sulphur Co., New York City. The California State Department of Agriculture has assisted in the promotion and direction of the project.

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[5] Rabaté, E. Destruction des ravenelles par l'acide sulfurique. Jour. Agr. Prat. (n.s. 21) 75(1):407–9. 1911.

[6] Morettini, A. L'impiego dell' acido solforico per combattere le erbe infeste nel frumento. Staz. Sper. Agr. Ital. 48:693–716. 1915.

Korsmo,[7] beginning in 1914 in Norway, has carried on the most comprehensive study of weed control in grain that has been made. His findings, however, have not yet been widely disseminated, since until recently they were published only in Norwegian. By using dilute sulfuric acid varying in strength from 3.5 to 5 per cent by weight, and by using 100 liters per decare (107 gallons per acre), he obtained an increased yield of grain amounting to 20.5 per cent for spring wheat, 25.8 per cent for barley, and 29.1 per cent for oats. The original weed growth was reduced by 81.8 per cent in all spring cereals by this treatment. Sulfuric acid generally gave better results than other methods used. These methods include weed harrowing before and after germination of cereals, harrowing and spraying, spraying with green vitriol and with nitric acid, dusting with calcium cyanamide and charlock powder, and hand weeding.

Åslander,[8] who has done much research in weed control both in Sweden and the United States, has assembled considerable data regarding the effect of sulfuric acid upon a large number of weed species treated. These data show that many common annual weeds are killed by dilute sulfuric acid. Besides doing careful work in determining the action of the acid on plant tissue, he has studied the influence of humidity, soil moisture, temperature, and rain on the acid treatment. He has found the effectiveness of sulfuric acid to be less influenced by weather conditions than that of iron sulfate, which until recently was the most popular chemical for this type of weed control.

Brown and Streets,[9] in Arizona, recommend dilute sulfuric acid spray for controlling a number of weeds. Under their conditions of high temperature and low humidity they were able to use it very effectively. Best results were obtained by applying the solution at a pressure of 250 pounds per square inch.

The National Sulphuric Acid Association of England[10] has recently found that a "late blight" of potatoes may be successfully checked from descending to the tubers by dilute sulfuric acid applied to the plants at the proper time. This treatment kills the foliage, thus controlling the blight and enabling the farmer to harvest potatoes without waiting for the tops to die normally.

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[7] Korsmo, Emil. Undersøkelser 1916–1923. Øver ugressets skadevirkninger og dets bekjempelse I Akerbruket. p. 378–94. Johansen and Nielsens Boktrykkeri, Oslo. 1932.

[8] Åslander, Alfred. Sulphuric acid as a weed spray. Jour. Agr. Research **24**(11): 1065–91. 1927.

[9] Brown, J. G., and R. B. Streets. Sulphuric acid spray: A practical means for the control of weeds. Arizona Agr. Exp. Sta. Bul. **128**:299–316. 1928.

[10] National Sulphuric Acid Association, England. Agr. Dept. Rept. **1933–34**: 1–12. 1934.

COMMERCIAL USE OF SULFURIC ACID AS A HERBICIDE

The commercial developments in the use of dilute sulfuric acid for weed control in numerous foreign countries indicate its value and popularity. Although data giving the amount applied annually as a herbicide in the Scandinavian countries are not available, much is used there, particularly in Norway. In France the popularity of sulfuric acid has been increasing. In 1931, 27,000 tons of concentrated acid were used for weed control, almost wholly in cereals; in 1933 about 500,000 acres of cereals were treated. In England the National Sulphuric Acid Association started its investigation of this herbicide in 1931. In that year only a few acres of grain were sprayed; in 1932 between 200 and 300 acres; the following year about 5,570; and in 1934 over 20,000.

The possibilities of sulfuric acid as a herbicide are now being investigated in South Africa, Argentina, Russia, Spain, Jamaica, India, Australia, New Zealand, and Canada. The last-named country has for some time been investigating through its National Research Council.

INFLUENCE OF WEEDS ON YIELD OF CEREAL CROPS

In order to fully appreciate the problem which infestations of mustard (*Brassica* spp.[11]) and wild radish (*Raphanus sativus*) present to growers of small grains in California, one needs only to visit the inland valleys during March and April when the weeds are in blossom. In 1935 California grew approximately 1,000,000 acres of barley, 400,000 acres of wheat, and 75,000 acres of oats. By conservative estimates, about 50 per cent of this total acreage is more or less infested with either mustard or wild radish.

Although accurate data on the amount of harm caused by these weed pests are not available, heavy losses are obvious. Among the many reasons why these weeds should be eradicated from grain fields are the following.

Competition for Moisture.—In many parts of California where grain is grown the annual rainfall is barely sufficient to produce a good grain crop even in the absence of weeds. Certainly in these areas, mustard plants, which require much water, are a serious menace.

Competition for Soil Nutrients.—In all cases where grain is infested with weeds there is a continual battle between the weeds and grain for plant food. Despite California's rich soils, mustard and wild radish have been known to starve the grain, thus reducing yield as well as quality.

Competition for Sunlight.—Figure 1 illustrates clearly the shading

[11] The three most common mustards in California are *Brassica arvensis, B. campestris,* and *B. nigra,* in the order given.

of grain by mustard. Grain grown under such conditions is so weak and slender that lodging often takes place.

Increased Harvest Costs.—Not only are the actual costs of threshing the grain increased; but sometimes in severe infestation, fields are never harvested. The cost of cleaning the weed seed from grain, particularly the seed pod of wild radish, greatly decreases the net income to the grower.

WEEDS IN WASTE PLACES

Weeds allowed to mature along fence lines, roadsides, ditchbanks, and other waste places often form the principal source of an initial weed infestation and a continuous source of reinfestation. Aside from this detriment, many of these weeds harbor insect pests, which in certain seasons invade field crops. These weeds not only act as a source of food when more succulent crops are not available, but also form a shelter during winter months and furnish a breeding place for many insects. A few weeds which are known to be hosts to certain insects and susceptible to treatment with sulfuric acid are listed as follows:

Weeds	*Insects*
Wild lettuce (*Lactuca* spp.)	Bean thrips, aphid (several species).
Russian thistle (*Salsola kali*)	Sugar-beet leafhopper, western beet-leaf beetle.
Shepherd's purse (*Capsella bursa-pastoris*) and Lamb's-quarters (*Chenopodium album*)	Sugar-beet leafhopper, clover aphid, bean aphid, cotton or melon aphid, cabbage aphid.
Dock (*Rumex* spp.)	Citrus thrips, grape leafhopper, apple leafhopper, sugar-beet wireworm.
Wild mustard (*Brassica* spp.)	Sugar-beet leafhopper, grape leafhopper, onion thrips, sugar-beet wireworm, potato flea beetle, western flea beetle, hop flea beetle.

PRELIMINARY EXPERIMENTS IN FIELD SPRAYING

In the first year's work (1934) a spray unit mounted on a truck was used. The pump was of the reciprocating type, made of bronze, the supply tank being specially constructed of lead-lined steel. All pipes, connections, nozzles, and the like, coming in contact with the dilute acid were of brass. The pump could maintain 75 pounds' pressure per square inch on a 6-foot boom equipped with six nozzles.

Plots of grain, of $\frac{1}{20}$-acre area, arranged at random, were sprayed in fields infested with mustard and wild radish. Five replications were made of each treatment. These treatments consisted of three concentrations of acid,[12] namely 5, 7.5, and 10 per cent by weight, and three volumes, 80, 120, and 160 gallons per acre.

[12] The concentrated acid used throughout these experiments was commercial 66° Baumé.

Mustard and wild radish plants were counted during the blossoming period in both the treated and untreated areas to determine the percentage killed by the spray. Square-yard quadrats were used, ten counts being made in each of the treatments. The results of experiments conducted on the El Dorado Ranch, near Knights Landing, are shown in table 1. For yield determinations ten samples of a square yard each were harvested from each treatment.

Fig. 1.—Effect of dilute sulfuric acid spray on barley heavily infested with mustard. Note the shading of the grain by the mustard in the unsprayed area (left).

EXPERIMENTS ON THE CONTROL OF WEEDS IN GRAIN FIELDS

An effort was made in 1935 to develop a spray equipment satisfactory not only for experimental purposes but also large enough for commercial application in large fields. This equipment, which will be fully described later in this bulletin, was used for all applications made during 1935.

A series of spraying demonstrations were conducted under the supervision of the Agricultural Extension Service of the University of California to give the grain growers of California the benefit of the experience gained in 1934. These applications proved further the effectiveness of sulfuric acid and the practicability of the equipment used under the varying conditions of California agriculture. Operations were conducted in nine of the leading grain counties of the state.

The "randomized block" arrangement in the 1935 field experiments

conforms with the method suggested by Fisher and Wishart.[13] One-tenth-acre plots were used, replicated six times. To determine the percentage of weeds destroyed and the yields, a 3-foot quadrat was em-

TABLE 1

PERCENTAGE OF MUSTARD PLANTS KILLED AND CALCULATED YIELD PER ACRE OBTAINED BY TREATING MUSTARD-INFESTED BARLEY WITH DILUTE SULFURIC ACID; 1934

Treatment No.	Concentration of sulfuric acid, by weight	Approximate volume per acre	Mustard killed	Calculated yield per acre
	per cent	*gallons*	*per cent*	*100 pounds*
1	5.0	80	85.50	25.43
2	5.0	120	88.06	24.49
3	5.0	160	86.91	31.17
4	7.5	80	85.51	27.47
5	7.5	120	95.07	30.03
6	7.5	160	96.79	33.36
7	10.0	80	95.92	31.91
8	10.0	120	95.41	31.72
9	10.0	160	93.96	31.78
10	(Untreated)			15.78
11	(Untreated)			20.73
12	(Untreated)			22.76

TABLE 2

PERCENTAGE OF MUSTARD PLANTS KILLED AND CALCULATED YIELD PER ACRE OBTAINED BY TREATING MUSTARD-INFESTED BARLEY WITH DILUTE SULFURIC ACID; 1935

Treatment No.	Concentration of sulfuric acid, by weight	Approximate volume per acre	Mustard killed	Calculated yield per acre
	per cent	*gallons*	*per cent*	*100 pounds*
1	8	130	85.38	30.81
2	10	95	90.86	35.54
3	10	130	93.08	34.82
4	10	170	96.87	33.34
5	12	95	95.43	32.73
6	(Untreated)			22.82

ployed. In the counting of mustard plants, only three counts were made in each treatment, whereas for yield determinations five samples were taken from each plot. Table 2 shows the results obtained from the Cecil ranch, near Davis. This grain, which was heavily infested with mustard (*Brassica arvensis*), was sprayed March 27. The grain was from 2 to 3

[13] Fisher, R. A., and J. Wishart. The arrangement of field experiments and the statistical reduction of the results. 24 p. Imperial Bureau of Soil Science, London, 1930.

inches high, while the mustard was mostly in the four to six-leaf stage of development. There was some germination of mustard seed in this field after the spraying took place. Figures 2 and 3 show samples of this grain at harvest.

Fig. 2.—Samples of barley taken from adjoining plots. The bundle at the right is free from mustard.

The results given in table 3 were obtained from a barley field also heavily infested with mustard (*Brassica arvensis* and *B. campestris*), on River Farms property near Knights Landing. Figure 4 shows samples of results of two treatments on this ranch. The spraying took place on April 4 when the grain was 6 to 8 inches high and the mustard 4 to 6 inches. This experiment presented an excellent example of grain-lodging caused by mustard. Figure 5 is from a photograph of this field at harvest.

FACTORS INFLUENCING THE EFFECTIVENESS OF SULFURIC ACID AS A WEED SPRAY

Time of Application.—Much has been written regarding the proper time for spraying mustard-infested grain fields in order to control weeds effectively. Under California conditions, the most satisfactory results have been obtained when the earliest growth of mustard is 6 or 7 inches high. Figure 6 shows the range of size at which mustard may be effectively killed with dilute acid. Mustard has been sprayed in the early blossoming stage without significant injury to the grain. Spraying at this stage, however, is not generally recommended because long periods of dry weather following late applications are apt to injure the grain

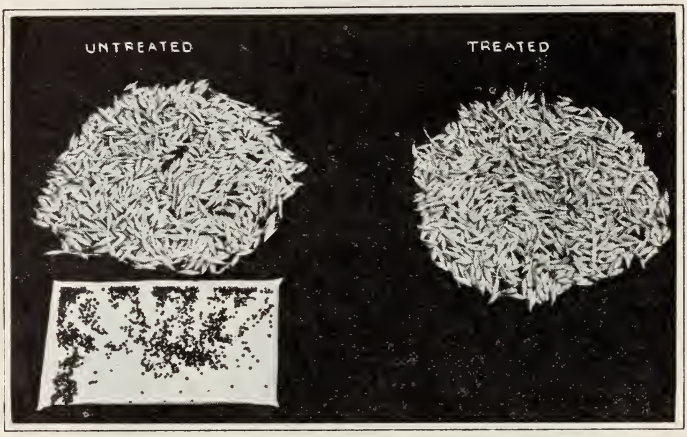

Fig. 3.—Uniform samples of barley, showing the amount of mustard seed in the grain from an untreated field.

TABLE 3

PERCENTAGE OF MUSTARD PLANTS KILLED AND CALCULATED YIELD PER ACRE OBTAINED BY TREATING MUSTARD-INFESTED BARLEY WITH DILUTE SULFURIC ACID; 1935

Treatment No.	Concentration of sulfuric acid, by weight	Approximate volume per acre	Mustard killed	Calculated yield per acre
	per cent	*gallons*	*per cent*	*100 pounds*
1	8	170	97.82	33.66
2	10	95	96.43	33.80
3	10	130	98.12	34.37
4	10	170	99.37	34.30
5	15	95	97.74	36.64
6	(Untreated)	.....	.....	19.96

Fig. 4.—Bags of barley, showing comparative yield of grain resulting from spraying with dilute sulfuric acid. The weights shown represent samples from 30 quadrats of one square yard each.

Fig. 5.—Effect of sulfuric acid treatment on lodging of grain. In the center the treated grain is shown standing erect, while dark strips on the right and left of the center are unsprayed areas in which the grain and weeds are lodged. Still farther to the right and left are other treated strips.

permanently. Conversely, spraying too early often results in a reinfestation from mustard seeds germinating after the treatment.

Because of the variation in the seasonal conditions in different parts of California, the period during which cereals can be sprayed with the acid extends from early January, in the southern counties, to late April in the northern counties—a total period of four months. The date will vary from year to year, according to the season.

Recovery of Grain Plants.—The time required for the grain to recover completely from the spray depends primarily upon two factors. Of these

Fig. 6.—Mustard plants in the best stages of development for treatment with sulfuric acid. The corresponding sizes of grain plants are illustrated at the right.

the first is the stage of development of the grain at the time of application. Young grain, from 4 to 6 inches high, will completely recover in 7 to 10 days; while grain from 10 to 12 inches high when sprayed often requires from 3 to 4 weeks for complete recovery. The second factor is the weather following the application; with plenty of moisture in the soil and with favorable growing conditions, recovery is greatly facilitated.

Stand of Grain.—A heavy stand of grain offers considerable competition to the young mustard plants, causing them to grow slender, with but few basal leaves. Under these conditions most mustard plants in grain are very readily destroyed with a concentration of acid as low as 7.5 per cent by weight. These same weeds growing in a thin stand of grain have a tendency to "stool" and develop a very short, sturdy stalk, so that a 15 per cent solution of acid by weight is often necessary for their complete destruction.

Temperature and Humidity.—The action of dilute sulfuric acid on plant tissue is more rapid on warm, dry days than on cool days. Åslan-

der[14] has made a rather comprehensive study of temperature and humidity. Using a 2 per cent solution of acid, he was able to kill plants in one hour at 30 degrees Centigrade, whereas at 6 degrees this same concentration of acid required five hours for similar results. He found also that mustard plants were killed under all conditions of humidity but that best results were obtained in dry air.

Rain, Dew, and Fog.—Rain falling shortly after the application will reduce the effectiveness of the acid. If two hours have elapsed, however, after the spraying, the rainfall will have no serious effect. In the event of threatening rain, it has been found advisable to increase the concentration of the acid and reduce the volume of solution per acre. Rain falling about an hour after application of acid on one of the experimental plots, in 1935, rendered the 10 per cent trial nearly worthless, while a 15 per cent application was very effective. The greater the concentration of the solution, the more rapid the kill of the mustard plant.

Fog and heavy dew have much the same influence as rain. When mustard plants are thoroughly wet from either fog or heavy dew, it is advisable to apply a stronger concentration, allowing the dilution to take place on the plants. Where, for example, under normally dry conditions a 10 per cent solution applied at the rate of 130 gallons per acre would be used, a 15 per cent solution applied at the rate of 95 gallons per acre under wet conditions gives similar results.

Degree of Weed Infestation in Relation to Yield of Grain.—Several investigators maintain that sulfuric acid has a fertilizing effect on the cereal. Frequent large differences in yield between the sprayed and unsprayed grain would lead one to believe such to be the case. The limited data available indicate, however, that the differences in yield are directly related to the degree of weed infestation. In other words, if a field heavily infested with mustard or wild radish is sprayed, a reasonably large increase in yield may be expected; on the other hand, little difference can be expected from spraying light infestations. The question naturally arises as to the degree of infestation that will justify sulfuric acid treatment. This question can best be answered if the purpose in the mind of the grower is known. If the control of weeds from the standpoint of future infestations is considered, lightly infested fields may well be sprayed. If, however, the thought is of the economic gain on one year's crop only, then of course the acid will be applied only to the more heavily infested fields. Where pulling by hand is impossible because of heavy infestations, or when its cost approaches that of an application of acid, then spraying should be practiced.

[14] Åslander, Alfred. Sulphuric acid as a weed spray. Jour. Agr. Research 24(11): 1065–91. 1927.

EFFECT OF SULFURIC ACID ON THE SOIL

Experience in France shows that it is sometimes advisable to precede the sulfuric acid treatment with a light application of lime, whereas reports from England state that the acid application has been found to produce little change in the soil acidity. Martin[15] makes the following statement: "Results show that the change in acidity of the soil is so small, if indeed it exists at all, that no increase in lime is required beyond the amount that would normally be applied in the ordinary course of good husbandry." In California, where most soils are neutral or slightly alkaline, the effect, if any, would probably be beneficial.

EFFECT OF SULFURIC ACID ON THE CEREAL PLANT

The effect of sulfuric acid on the control of grain diseases has not been included in this study. Rabaté,[16] however, has found it to be effective in controlling crown-rot of grain, a disease which causes lodging. Because of the lack of competition with weeds, together with the set-back received at the time of application, sprayed grain seldom lodges. Figure 5 shows the condition of the sprayed and unsprayed grain at harvest time on the River Farms experiment. Sprayed grain is generally from a week to ten days later in reaching maturity than the untreated.

ERADICATION OF MUSTARD AND WILD RADISH FROM GRAIN FIELDS BY THE ACID TREATMENT

Dilute sulfuric acid applied as a weed spray has no effect upon the weed seeds that are ungerminated in the soil. One year's application, therefore, will not free a field of mustard and wild radish. According to experiments on buried seeds, mustard seed may germinate after having been buried in the soil as long as 40 years. Experience in France, where this method of weed control has been in progress for nearly 25 years, shows that from 6 to 7 years of repeated sprayings are necessary to free a field of these weeds. Since each year's treatment reduces the seed population considerably, the infestation will probably be reduced, after a few years, so that hand-pulling may be more economical than spraying.

STUDY OF WETTING AGENTS OR "SPREADERS"

Believing that the usefulness of sulfuric acid as a general herbicide for the control of weeds along fence lines, ditchbanks, roadsides, and similar waste places, could be increased by the addition of a material that would cause the solution to wet the foliage more thoroughly, experimenters

[15] Martin, L. D. Spraying weeds in cereal crops with sulphuric acid. Jour. Min. Agr. [Gt. Brit.] 40:1129–35. March, 1934.

[16] Rabaté, E. The use of sulphuric acid against weeds and certain crop parasites. Internatl. Rev. Sci. and Pract. Agr. [Rome] (n.s.) 4:535–45. 1926.

have tested many so-called "spreaders." A method developed by O'Kane, Westgate, Glover, and Lowry,[17] modified somewhat to meet our conditions and equipment, has been utilized in these tests. This method consists primarily of measuring the "angle of contact" that a drop of liquid makes with a solid. A small angle indicates that the droplet is flattened, hence covers greater surface. For a given liquid and a given solid, the

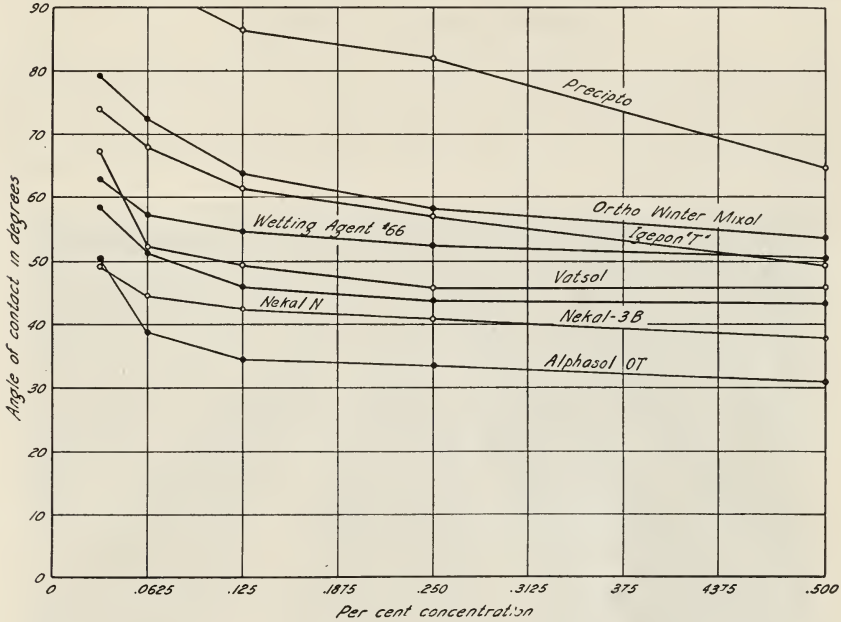

Fig. 7.—The relative contact performance of several wetting agents or "spreaders" in 10 per cent sulfuric acid on waxed glass.

angle is constant, provided the droplets are small and the rate of evaporation is not great. When droplets of 10 per cent acid containing different concentrations of wetting agents had been placed on waxed bottles, the image of the droplet was projected, and the angle of contact measured. The waxed surfaces were formed on bottles by dipping them into a supersaturated solution of beeswax in carbon tetrachloride. These surfaces were uniform and, in addition, fairly resistant to spreading liquids, thus permitting the study of higher concentrations of spreaders. The results of these tests are shown graphically in figure 7. Dilute sulfuric acid without the addition of a spreader forms an angle of contact with waxed bottles greater than 90 degrees.

Certain field tests with a wetting agent have shown that the effective-

[17] O'Kane, W. C., W. A. Westgate, L. C. Glover, and P. R. Lowry. Surface tension, surface activity, and wetting ability as factors in the performance of contact insecticides. New Hampshire Agr. Exp. Sta. Tech. Bul. 39:1–44. 1930.

ness was much greater than when the acid alone was used. Plants with waxy leaf surfaces are often not injured by the acid spray, whereas the addition of a spreader often kills them. Grasses, however, though badly scorched, are not always completely killed by this spray. Water-grass (*Echinochloa crus-galli*) has been sufficiently dried up by the spray to allow burning, thus leaving the ground bare.

WEED CONTROL IN ONIONS

Since onions react to dilute sulfuric acid in a manner similar to cereals, the control of annual weeds by spraying the growing crop with this material has been tried. The onion crop treated was heavily infested with knotgrass (*Polygonum aviculare*), a weed rather easily killed by the acid.

Fig. 8.—Onions 24 hours after a spraying with 10 per cent sulfuric acid. Unsprayed rows infested with knotgrass (*Polygonum aviculare*) are shown in the foreground.

In early trials with a knapsack sprayer, 10 per cent acid by weight was found to be very successful; and, though the onions were badly scorched for several days after treatment, they recovered completely within two weeks (fig. 8). Application of the spray with power equipment on this same field later in the season did not give a complete control of the weeds, and the injury to the onions appeared greater. It would seem advisable, then, as in spraying cereals, to apply the acid when both onions and weeds are young.

In some cases in these experiments a spreader was used, but without

marked differences in results. The injury to the onions was only slightly greater when the spreader was used and the knotgrass was killed by the spray both with and without the addition of the wetting agent.

EQUIPMENT FOR APPLYING SULFURIC ACID

Effect of Sulfuric Acid on Metals and Other Materials.—In the United States the use of dilute sulfuric acid as a herbicide has been retarded largely by lack of sprayers that will resist corrosion. Some materials, such as brass, bronze of low zinc content, rubber, and steel withstand the effects of the acid very well under certain conditions. The concentrated acid can be handled, for example, in steel drums and iron or Everdur[18] pipe, but will rapidly attack rubber hose. The dilute acid can be handled in either Everdur pipe or rubber spray hose but will quickly corrode steel and wrought iron. Nickel will resist the effect of either dilute or concentrated acid but is too expensive to use except for such parts as nozzle disks. Though present knowledge of acid-resistant materials is very extensive, manufacturers in this country have not been willing to guarantee a pump made of any material to apply dilute sulfuric acid satisfactorily under field conditions. The common acid-resistant materials are limited to such uses as piping, nozzles, and stationary parts of an acid-handling system.

Avoiding Open Handling of Sulfuric Acid.—The use of acid is not dangerous if a few facts are kept in mind: it is safe, for example, to pour concentrated acid into water; but if water is poured into concentrated acid, heat is generated very rapidly, and the sputtering and splattering that occurs might cause serious burns to the person doing the mixing. Handling this chemical in the open always involves the danger of acid burns, which are rather obstinate in healing. The acid, also, whether in dilute or concentrated form is very destructive to the shoes and other clothing worn by the operator.

Concentrated sulfuric acid is heavy; commercial 66° Baumé acid has a specific gravity of 1.84, a gallon weighing 15.3 pounds. Commercial acid is generally shipped in 50 and 100-gallon drums, the total weight when full being approximately 1,700 pounds for a 100-gallon, and 900 pounds for a 50-gallon drum. Obviously, handling the acid drums is difficult unless some mechanical device is provided to hoist or roll drums into place.

For the reasons just mentioned, it is desirable to handle acid as little as possible; furthermore, considerable time is consumed in transferring acid from drums to sprayer tanks. If concentrated acid is mixed with water in open tanks, either the amount of acid has to be measured or the

[18] Everdur is a copper-silicon-manganese alloy.

dilute mixture must be tested by the specific-gravity method to determine the concentration. This is a time-consuming and rather disagreeable task. Valves, faucets, or gear pumps, when used to draw concentrated acid from drums, soon corrode so that their operation becomes

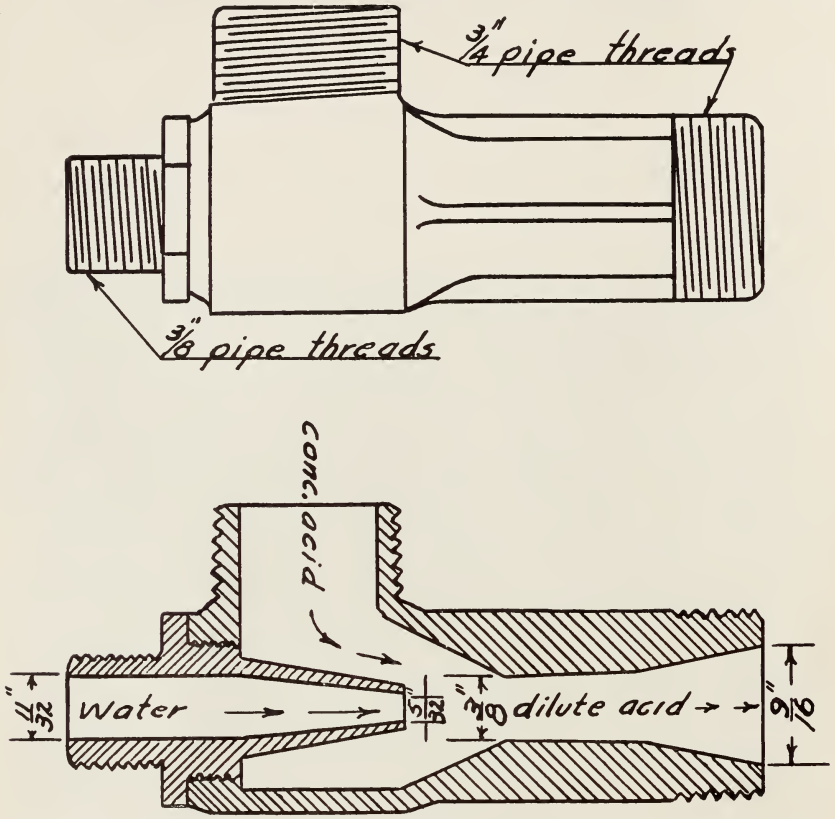

Fig. 9.—Penberthy No. 62, ⅜-inch steam ejector used on experimental sprayer for mixing concentrated acid and water.

difficult. Considering the problems presented by concentrated acid, it is desirable to eliminate all handling except in closed drums. Such a method has been developed.

Development of Ejector Mixing Method.[19]—The object in developing a sprayer for sulfuric acid was to eliminate the necessity of handling concentrated acid and also of pumping the dilute acid. Possibly some acid-resistant materials could be obtained for constructing a pump to handle dilute sulfuric acid, but the pump would probably be too expensive for agricultural use. It seemed desirable, furthermore, to use ordi-

[19] French, O. C., and W. E. Ball. A study of suitable equipment for applying sulphuric acid for weed control. Agr. Engin. 15:411–13. 1934.

nary orchard sprayers that are now available by adding a field-spray boom, by providing an arrangement for carrying concentrated acid, and by installing an acid-injecting device in the water-discharge line from the pump. The use of an injecting device would then allow the pump to handle only water.

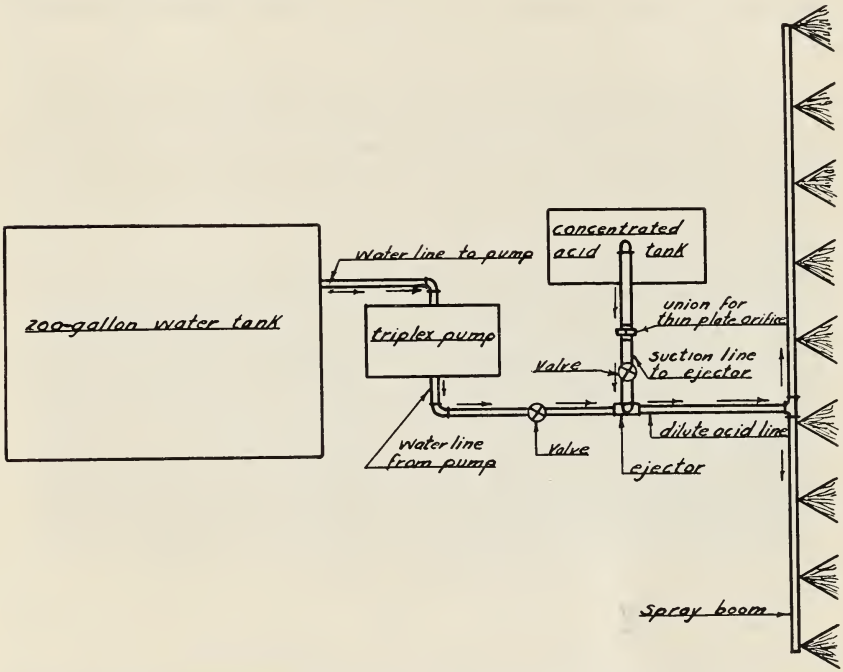

Fig. 10.—Schematic plan of experimental setup used in the development of the ejector acid-mixing method.

The injecting device originally suggested was a specially designed brass Venturi tube. After some preliminary trials comparing a Penberthy bronze ejector (fig. 9) with the Venturi tube, the latter was abandoned because one of suitable size was not commercially available, whereas the ejectors can be purchased from plumbing dealers for a nominal sum.

In the experiments with the ejector on a portable orchard sprayer, a set-up was used as illustrated in figure 10. The sprayer had a triplex pump with a capacity of about 16 gallons per minute. A boom 16 feet long fitted with Hummer nozzles[20] containing No. 4 disks was connected to the discharge line from the pump. In the discharge pipe, at a point 3 feet from the boom, a No. 62 Penberthy ⅜-inch ejector was installed. A ¾-inch pipe, placed in a container for the concentrated acid, was con-

[20] Known also as Chipman nozzles.

nected to the low-pressure side of the ejector. A union was placed in this ¾-inch pipe to hold nickel disks with round-hole orifices to control the amount of acid drawn into the ejector. With this arrangement the pump and piping system handled only water up to the ejector. A sufficient number of nozzles were placed on the boom to create the necessary pressure differential between the pump and the boom to develop less

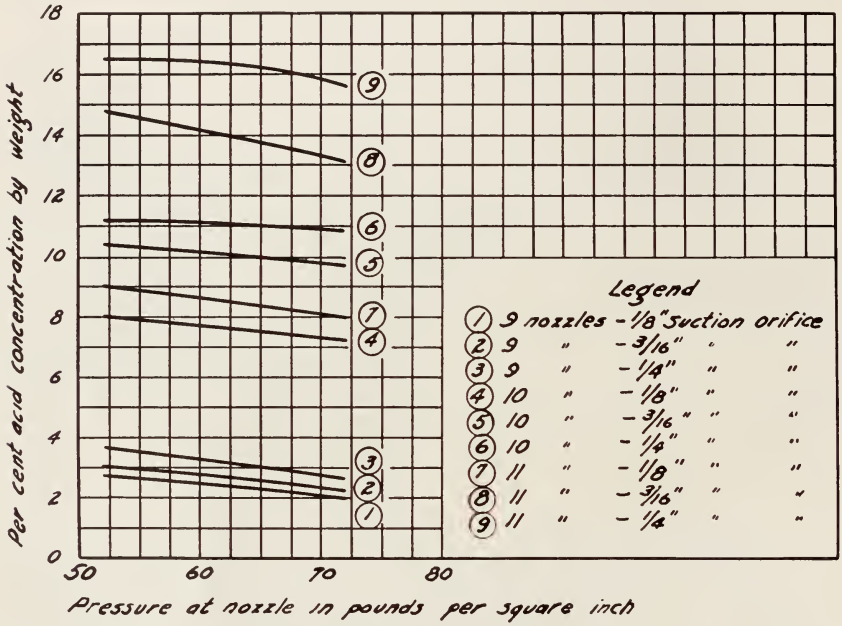

Fig. 11.—The range of concentration of sulfuric acid obtained with a Penberthy ejector by varying the pressure and the number of nozzles on the spray boom.

than atmospheric pressure at the suction side of the ejector. The acid concentration of the dilute solution discharged from the boom was determined by catching samples from the nozzles and obtaining the specific gravity of the solution by means of a hydrometer. When checked by weighing the intake of acid, this method proved to be sufficiently accurate for ordinary field spraying. By means of samples taken at different nozzles on the boom, the uniformity of mixture was confirmed.

The concentration of the solution was determined for varying rates of discharge for three sizes of orifices in the ejector suction line—namely, ¼, 3/16, and ⅛ inch diameter. For each orifice tested, nine rates of discharge were obtained by using pressures at the boom nozzles of 52, 62, and 72 pounds per square inch for 9, 10, and 11 nozzles equipped with No. 4 disks.

The results of these tests to determine the range of concentration re-

sulting from change in pressure and number of nozzles are shown in figure 11. For a No. 62 ejector, according to these data, acid concentrations from as low as 2.0 per cent by weight to as high as 16.5 per cent could be obtained by changing the size of the suction orifice and the quantity of spray-boom discharge. Ordinarily the acid concentration could be varied through a great enough range by simply changing the suction orifice. The concentrated acid mixed almost instantaneously

Fig. 12.—Field-sprayer unit for spraying sulfuric acid. Note the alternate tilting of nozzles.

with the water in the throat of the ejector. Since the viscosity of concentrated acid varies greatly with temperature, this factor was at first expected to complicate the problem. Concentrated acid varying in temperature from 46° to 104° F was run through the ejector; the concentrations determined at the nozzles showed a variation of less than 1 per cent which, for this work is insignificant. Likewise, it seemed that a difference might result in acid concentration as the level in the concentrated-acid container was lowered. Tests, however, showed that under ordinary conditions pressure at the ejector was sufficiently reduced so that a difference of 2 or 3 feet in suction lift resulted in a negligible variation in acid concentration.

Equipment Used in 1935.—In order that the ejector mixing method developed in the preliminary experiments might be used under actual field conditions, there was assembled for use in 1935 a spray unit capable of applying the acid in a commercial manner.

A portable orchard sprayer (with a power take-off), capable of delivering 20 gallons per minute, was selected as the basic machine. This unit was equipped with a standard 400-gallon metal tank and mounted

on dual 6.00 × 20 inch pneumatic tires. On the rear of this sprayer a frame was built that held a 50-gallon drum of concentrated sulfuric acid and also supported an 18-foot folding boom (fig. 12).

The boom was made of Everdur pipe, in three sections. The center section was of ¾-inch pipe, 6 feet long. The two outer sections, each 6 feet long, were of ½-inch pipe, being connected to the center section with short lengths of rubber spray hose so that they could be folded in to the

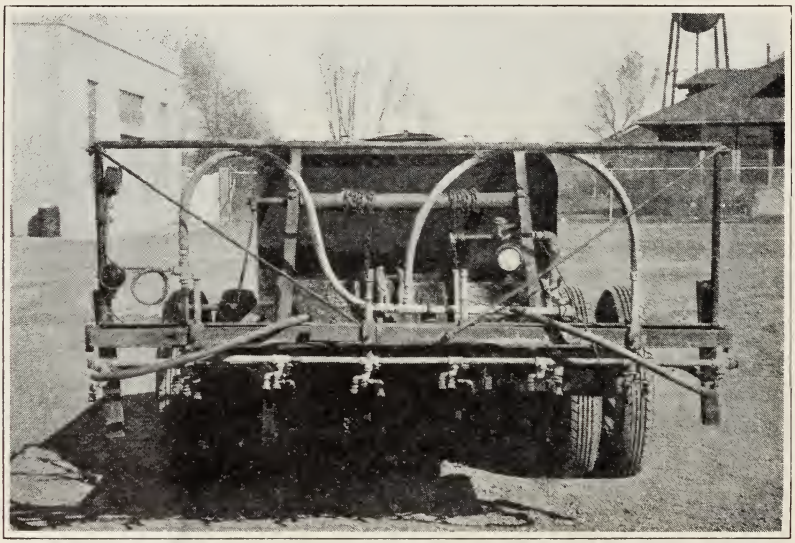

Fig. 13.—Rear view of sprayer, showing boom folded for transportation.

center. When folded, the boom (fig. 13) had an over-all length of approximately 7 feet, facilitating transportation and the moving of the rig through narrow gates. Twenty Hummer nozzles with special nickel disks that discharged fan-shaped spray of approximately 65° included angle were placed equidistant on the boom to obtain an approximate width of 19 feet of spray. With the boom 2 feet above the foliage, this arrangement of nozzles gave a double coverage. The nozzles were connected to the boom by means of two street-ell pipe fittings in order that the spray could be directed either slightly ahead or to the rear of the boom (fig. 12). By tilting alternate nozzles, a more thorough coverage is possible. To insure uniform pressure throughout the boom, provision was made for the dilute acid mixture to enter at two places in the center section of the boom by means of rubber hoses. A gauge was connected to the boom to register pressure of the dilute acid. A No. 62 Penberthy ejector was attached to the water discharge line from the spray pump at the rear of the water tank (fig. 14*a*). Immediately ahead of the ejector

on the water line, a quick-opening gate valve and also a pressure gauge were installed (fig. 14, *b* and *e*). A ¾-inch pipe was connected to the suction side of the ejector and then placed through the plug of the concentrated-acid drum (fig. 15). The plug was drilled slightly larger than the outside diameter of the ¾-inch pipe. In this pipe line another quick-opening gate valve and a union were installed (fig. 15, *a* and *b*). The

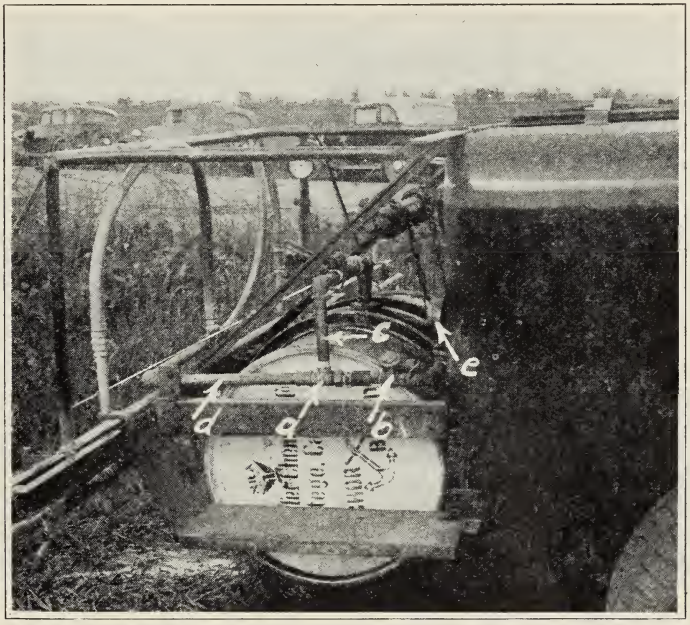

Fig. 14.—Side view of piping system: *a*, ejector; *b*, water cut-off valve; *c*, pipe carrying concentrated sulfuric acid to the ejector; *d*, pipe carrying dilute solution of acid to the boom; *e*, pressure gauge on the water line.

union allowed the piping to be disconnected so that acid drums could be readily removed. This union contained a thin nickel disk with an orifice in it to control the amount of acid drawn into the ejector. The cut-off valve on this line was necessary to keep water from being forced back into the acid tank through the ejector when the valve on the water line was closed. Everdur pipe was used from the valve on the acid-suction line to the boom. The pipe in the acid drum and to the valve was ordinary black iron.

In order to lift the 50-gallon drum of concentrated acid up into place, a small winch was built on the frame just behind the water tank. When the two chains on the winch were placed under the acid drum, the drum could easily be raised into the frame and fastened with strap-iron hangers (fig. 15*c*).

A small tractor of track-layer type with a power take-off was used to pull and to supply power for the sprayer. A track-layer tractor seemed desirable because of the soft fields ordinarily encountered during the spray season.

Tests of the 1935 Sprayer.—According to preliminary experiments, probably only three different concentrations of dilute acid are required

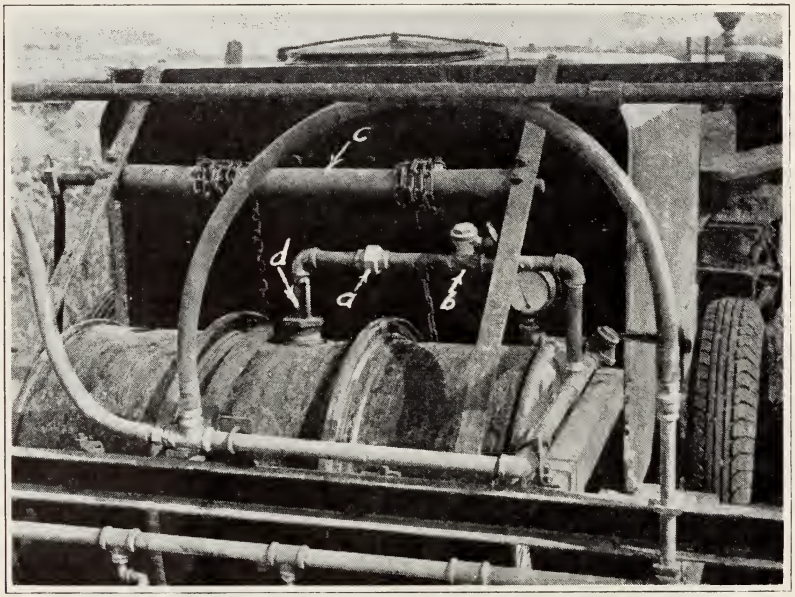

Fig. 15.—View showing piping system: *a*, union to hold acid-control disk; *b*, concentrated acid cut-off valve; *c*, winch for raising acid drum into place; *d*, ejector suction pipe through bung of concentrated acid drum. The bung is provided with a ¼-inch air vent.

for most spray work—namely 8, 10, and 15 per cent by weight. Of these, 10 per cent is most commonly used. The equipment was designed to give these concentrations. Nozzles were used that delivered approximately 0.65 gallon per minute each, at 70 pounds per square inch pressure, this pressure having already been determined as optimum. With 20 nozzles on the boom the total discharge was 13 gallons per minute at 70 pounds' pressure. Nickel disks with round-hole orifices drilled with Nos. 35, 30, and 15 drills for 8, 10, and 15 per cent acid concentrations, respectively, were used in the union in the concentrated-acid line.

For operation of the sprayer the pump was started and the pressure regulator adjusted so that the pressure in the boom was about 70 pounds when acid was going through the ejector. When the acid valve was closed the pressure in the boom would drop about 10 pounds; this was a visible means of determining whether or not acid was being drawn

into the ejector. To get 70 pounds' pressure in the boom it was necessary to have about 225 pounds' pressure at the pump or just ahead of the ejector.

The concentration of the diluted acid was determined by the specific-gravity method. This consisted of catching a sample of the spray solution from one of the nozzles, in a hydrometer jar, and reading the specific gravity direct with a hydrometer. By means of a conversion table (table 4) the specific-gravity reading was converted into percentage of acid

TABLE 4

AMOUNT OF CONCENTRATED SULFURIC ACID BY WEIGHT AND VOLUME REQUIRED PER HUNDRED GALLONS OF WATER FOR VARIOUS CONCENTRATIONS AND THE CORRESPONDING SPECIFIC GRAVITY*

Per cent concentration	Concentrated acid		Specific gravity at—			
	Gallons	Pounds	20° C	25° C	30° C	40° C
5	2.88	44.0	1.0317	1.0300	1.0281	1.0240
6	3.46	53.0	1.0385	1.0367	1.0347	1.0305
7	4.08	62.5	1.0453	1.0434	1.0414	1.0371
8	4.74	72.5	1.0522	1.0505	1.0481	1.0437
9	5.39	82.5	1.0591	1.0571	1.0549	1.0503
10	6.05	92.5	1.0661	1.0640	1.0617	1.0570
11	6.70	102.5	1.0731	1.0710	1.0686	1.0637
12	7.34	112.5	1.0802	1.0780	1.0756	1.0705
13	8.00	122.5	1.0874	1.0851	1.0826	1.0774
14	8.65	132.5	1.0947	1.0922	1.0897	1.0844
15	9.30	142.5	1.1020	1.0994	1.0968	1.0914

* National Research Council of the United States of America. International critical tables of numerical data, physics, chemistry and technology **3**:56. McGraw-Hill Book Co., Inc. New York City. 1928.

concentration. For this work a relatively inexpensive hydrometer graduated from 1.000 to 1.200 in 0.005 subdivisions was satisfactory. A glass hydrometer jar 1½ inches in diameter and 12 inches high proved convenient for protecting the hydrometer stem from the wind.

As experiments have proved, the volume of dilute acid solution required per acre is approximately 125 to 135 gallons when a 10 per cent concentration is used; 90 to 100 gallons for 15 per cent; and 150 to 170 gallons for an 8 per cent solution.

To apply any definite volume of material per acre it is necessary to know three factors: first, the quantity discharged per minute from the boom; second, the width of strip that the spray from the boom will cover; and third, the rate of travel through the field. The sprayer used for this study, as stated previously, delivered 13 gallons per minute at optimum pressure and covered a strip 19 feet wide. With a tractor whose field speeds were 2, 2.6, and 3.6 miles per hour, the volume of

spray applied per acre was 170, 130, and 95 gallons for low, intermediate, and high gear respectively.

Grain fields were sprayed with this equipment at the rate of from 4½ acres per hour in low gear to 8 acres per hour in high gear. When water was readily available, from 40 to 50 acres could easily be sprayed in a ten-hour day.

Water pumped directly out of ditches into the sprayer tank was used in many of the tests. As there was an 18 mesh-to-the-inch screen in the water-discharge line, very little trouble with nozzles' clogging was experienced. Proper servicing of this screen is essential because the small nozzles will clog unless good screening of the water is obtained. If the screens supplied with sprayers do not fit tightly against the castings in the screen bowl, gaskets must be placed between the screen cage and the bowl-opening plate.

Conversion of a Portable Orchard Sprayer to an Acid Sprayer.—To use the ejector system of mixing acid and water it is necessary to maintain a rather definite relation between the water pressure ahead of the ejector and the amount of pressure in the boom. A pressure drop of approximatly 150 pounds per square inch through the ejector must occur in order to reduce pressure on the suction side of the ejector sufficiently to cause acid to flow in the suction line. Unless the boom has sufficient capacity to allow this pressure drop to occur, the ejector will not function properly. The most practical size of ejector is the No. 62 Penberthy or one corresponding very closely to its specifications. The dimensions of this ejector are shown in figure 9.

To utilize this ejector it is necessary to have a pump that delivers at least 16 gallons per minute at 200 pounds pressure per square inch. Many triplex portable orchard sprayers have this capacity or more. The sprayer should have at least a 300 and preferably a 400-gallon tank for water. More than 400 gallons' capacity would be desirable except that the additional weight is a disadvantage when the spray rig is being pulled through a grain field, which is apt to be soft during the spray season.

A boom with 20 nozzles, of the flat, fan-shaped spray type, that will cover a strip 19 to 20 feet wide, is about the optimum size. Each nozzle should deliver approximately 0.65 gallon per minute at 70 pounds pressure per square inch. If the nozzles are spaced 12 inches apart on the boom an effective spray giving double coverage will be obtained. The boom should be adjustable for height; 18 inches above the ground is about as low as is ever necessary, and 27 inches is a maximum height for most grain-field work. The boom should be made of Everdur or brass pipe

and fittings; nozzles should be of similar material with nickel or monel-metal disks. All pipe from the ejector to the boom and from the valve on the acid-suction line to the ejector must likewise be acid resistant. Brass pipe should not be used in the concentrated acid drum; black iron pipe is more satisfactory. A gasket-type union placed somewhere between the acid drum and the valve on the acid-suction line is convenient for holding the orifice disk that controls the amount of concentrated acid flowing to the ejector. The size of hole to drill in the acid-control disk will probably vary slightly with each individual sprayer. A simple way to determine the size of hole in the disk necessary to give a desired acid concentration is to start with the size given above under "Tests of the 1935 Sprayer" and then to check the acid concentration with a hydrometer. If this does not quite meet the requirements, change the drill size accordingly, and recheck the specific gravity of the dilute solution coming from the nozzle until the desired concentration is obtained. The specific gravity of various acid concentrations is shown in table 4.

A pressure gauge should be placed on the boom so that it is visible to the operator. An ordinary gauge with a range from 0 to 100 pounds is suitable. The gauge should be mounted on a goose-neck pipe filled with oil so that the acid solution will not damage the gauge. Such an arrangement can be seen in figure 14.

This bulletin does not give exact specifications for building every sprayer of this type, but rather gives general specifications and some details that will be required on any sprayer of sulfuric acid. Many modifications of the equipment described in this bulletin will doubtless be made by those building spray rigs.

Cost of Application of Acid.—Costs for spraying grain fields vary greatly according to the amount of acid necessary, the cost of the acid, and the distance of water from the spraying operations. The cost of acid in 1935 was $1.40 per hundred pounds in 100-gallon lots. The amount required per acre depends largely on the size of mustard; in general, 10 per cent concentration is satisfactory, or 6.05 gallons per acre, making a cost of $1.50 per acre for acid. Water costs vary with the equipment necessary to supply the water to the sprayer and also with the distance that water must be transported.

The cost of materials necessary to convert an orchard sprayer to a field-type sprayer should not be over $100.00, including labor. At present prices, apparently a charge of $1.50 per acre for machinery and labor should be ample, making the total cost of application per acre approximately $3.00.

PRECAUTIONS IN HANDLING SULFURIC ACID

The few precautions required in handling sulfuric acid are simple, but important. *First,* though the action of concentrated acid on steel drums is hardly noticeable, the acid does react slightly with the metal after standing for a few months in the drum, and free hydrogen is liberated. Hydrogen is inflammable; if a flame were exposed near a recently opened drum partly filled with acid, an explosion might result. For this reason it is always best never to have a flame near a drum of acid from which the plug has just been removed. *Second,* drums of concentrated acid should never be left lying exposed to hot sunlight with the plug fitting tightly. The acid will expand, and the pressure might burst the drum. If the drum is partly filled with the acid it is more dangerous than when full because the air becomes compressed within the drum; a fault in the drum would produce an explosion. *Third,* to obtain the longest possible life of equipment it is advisable to flush out the boom with water after each day's spraying. *Fourth,* the operator should wear old clothes; woolens are more resistant to the acid than cotton fabrics. Rubber clothing gives even more effective protection, but is expensive. Leather shoes are readily attacked by the acid, hence rubber boots should be worn. As an additional safeguard, goggles might be worn to protect the eyes from the acid spray. *Fifth,* an operator of an acid sprayer should always have a solution of water and bicarbonate of soda (baking soda) readily available to neutralize any acid that may come in contact with his body.

SUMMARY

For a number of years, sulfuric acid has been used in controlling annual weeds, particularly mustard and wild radish in grain fields. In France, 500,000 acres of cereals were sprayed with sulfuric acid in 1933; while in England, in 1934, over 20,000 acres of grain were sprayed.

Of the 1,475,000 acres of small grain grown in California in 1935, approximately 50 per cent was infested with weeds that may be controlled with sulfuric acid.

The lack of suitable equipment for applying dilute sulfuric acid has retarded the use of that chemical as a herbicide in the United States. After two years of experimental work, however, a successful sprayer has been developed. The use of an ejector mixing device eliminates the necessity not only of having dilute acid in contact with a spray pump but also of mixing the acid in open containers.

According to experimental results, approximately 95 per cent of the mustard and wild radish in grain fields may be controlled with dilute sulfuric acid. Sprayed plots have often produced 50 per cent more grain than unsprayed plots.

The concentration of the acid and the volume of solution per acre may vary with climatic conditions; but in general 10 per cent acid by weight, applied at the rate of 130 gallons per acre, has given best results.

Under the conditions of these experiments the total cost of an application has been approximately $3.00 per acre.

ACKNOWLEDGMENTS

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