ARSENICAL COMPOUNDS FOR THE CONTROL OF TURF WEEDS

JOHN MONTEITH, JR., and JOHN W. BENGTSON *

The control of weeds always has been and probably always will be an important factor in the maintenance of turf. The weeds which are most troublesome in turf vary in different districts. A list of perennial weeds which are pests over a wide range would include dandelions, broadleaf and buckhorn plantain, sheep sorrel, and white clover (which is not always considered a weed in turf). Such a list of annual weeds would include crabgrass, goosegrass and the chickweeds. Certain plants, such as the English daisy along our Northwest Coast, become the most menacing turf weeds in limited regions whereas in other parts of the country they are almost unknown.

Hand weeding was naturally the first resort for keeping lawns and putting greens free from weeds. Hand weeding is practical on small areas but rising labor costs are limiting its more general use. The increasing demand for weed-free turf over large areas has stimulated interest in more economical weed control than is offered by the hand weeding method. Many weeds such as crabgrass and plantain can be removed successfully by hand but the mat-forming weeds such as clover, with a network of rhizomes or stolons running through the turf, are extremely difficult to remove by hand. In any turf where there is a heavy infestation of weeds, hand weeding not only is expensive but it results usually in serious damage to the turf.

It is natural therefore, that those who have been interested in controlling weeds have been hopefully watching the study of chemicals for this purpose. It has long been known that vari-

* Director and Agronomist, respectively, of the United States Golf Association Green Section.

ous plants respond differently to treatments with certain poisons. Applying this principle it has been possible by means of a relatively inexpensive treatment with chemicals to destroy one group of plants in a mixed vegetation without killing another group.

The earliest work on chemical weed control in this country was done by Professor Bolley in North Dakota in 1896. He showed that certain weeds, especially mustard, could be controlled in grain fields by spraying with sulphate of iron. Later other chemicals were used by many workers.

A voluminous literature records experiences in controlling weeds with sulphate of iron, sodium chlorate, arsenicals, sulphuric acid, kerosene and other oils, as well as numerous other chemicals. Some of the compounds in the fertilizer group such as sulphate of ammonia, ammonium thiocyanate, calcium cyanamid and kainit, have been found useful as weed killers under certain conditions.

Some of these chemicals have been shown to have a specific effect on certain weeds, as is the case with sulphate of iron on mustard, and kerosene on dandelions. In other cases the selective effect appears to depend upon the fact that most of our troublesome weeds are broadleafed and present relatively large surfaces to the action of the chemical, while the grass blades are narrow and not readily wetted. Much of the chemical weed control work with crop weeds has been done with the objective of killing all vegetation in an area without permanently sterilizing the soil.

Various factors, such as the stage of growth of the plants when treated, soil moisture, temperature and others, influence the results with chemical weed killers. Probably for this reason results reported by workers in different countries vary widely.

For example, in South Africa sulphate of iron combined with sulphate of ammonia has been highly recommended for keeping lawns and putting greens weed-free. This method has also been found effective in England and elsewhere, but in many sections of the United States this combination has failed to give satisfaction. Sulphate of ammonia however universally has a good effect in promoting growth of grass and in that way helps the grass choke out the weeds.

The ideal killer for turf weeds is one that will destroy the greatest number of weeds with the lightest dose; that will cause the least amount of harm to the grass when applied at the dose required to kill weeds; that will be cheap, easy to apply and relatively safe to handle.

Chemical weed killers should not be considered as substitutes for good cultural practices for the production of a weed-free turf. They should be regarded as useful aids to supplement the best cultural methods. Good soil, drainage, suitable grasses, proper cutting and fertilizing, control of insects and diseases, and many other means no doubt will remain of utmost importance in keeping turf free from weeds, even when far better herbicides are developed than are available now. Unfortunately other plants thrive under the same cultural practices that are considered best for turf grasses, and they become troublesome weeds which must be controlled by other than cultural methods.

There are also many areas of turf where a maximum growth of grass is distinctly undesirable. In such areas weeds may develop since there is little competition from the grass. On areas where a heavy growth of grass is desirable an ample fertilizer program may result in a mat of grass heavy enough to smother out many weeds. On numerous lawns, fairways and other

turfed areas, it is definitely advantageous to fight weeds by this method. There are, however, large areas of turf, as for instance in parks and in the rough of golf courses, where such a fertilizer program not only is too expensive but also is definitely undesirable for the reason that it would add greatly to mowing costs. Weeds are often undesirable in such areas; furthermore, they may produce seed which may be spread to other areas where weeds are even more objectionable. In such cases as in many others chemical weed killers may serve a useful purpose.

Review of Previous Green Section Results

Experiments on the chemical control of weeds have been conducted by the Green Section for many years. Much of the work to date was summarized in the December, 1933, number of the Bulletin of the United States Golf Association Green Section. This summary included the following observations:

> Most of the common turf weeds may be selectively controlled by proper cultural treatments and, where these fail, by the judicious use of certain chemical compounds.
>
> Of the chemicals tested, the best results, in the order named, have been obtained with the following: sodium chlorate, arsenic pentoxide as representative of the arsenicals, ammonium thiocyanate, sulphate of iron, and sulphate of ammonia.
>
> With sodium chlorate, crabgrass has been best controlled by three successive applications at the 2-pound rate. Satisfactory control with lighter first and second applications has been indicated.
>
> Under the treatment as suggested for crabgrass, practically all other common turf weeds, such as plantains, field or sheep sorrel, chickweeds, milk purslane, ground ivy, heal-all, and speedwell, disappear within a single season. Dandelion and goosegrass are discouraged. Wild garlic is little affected.
>
> Potassium chlorate, calcium chlorate, and magnesium chlorate may be substituted for sodium chlorate.
>
> The dry method of applying chlorates has been found to be entirely

satisfactory, and the fire hazard, which is always present when chlorates are used in solution, is virtually eliminated with the dry method.

Compounds of arsenic, notably arsenic pentoxide, have been used most successfully on fairway, lawn, and putting green turf to selectively control clover, pennywort, ground ivy, *Galium* sp., knotweed, chickweeds, and heal-all.

Ammonium thiocyanate has yielded results inferior to those obtained by the use of chlorates. In these tests its use tended to encourage certain types of weeds, principally *Poa annua* and dandelion.

Sulphate of iron and sulphate of ammonia, alone or in combination, gave no indications of satisfactory crabgrass control but showed some promise on other weeds.

Calcium cyanamid did not give favorable results when applied as a dust at the rate of 780 pounds to the acre.

The perchlorates of ammonium and potassium proved unsatisfactory as weedkillers.

The turf was discolored by all the chemicals used, and the duration and intensity of the discoloration varied with the rate and time of application as well as with the attendant conditions of moisture and temperature.

Results with chemicals are affected to an undetermined extent by a number of factors, and for this reason more extensive investigations of the problem are deemed necessary.

Immediately after the results of this work were reported in 1933 it became necessary to curtail greatly the experiments with chemicals on turf. Some testing with sodium chlorate and the arsenicals, however, was continued. Although sodium chlorate continued to give favorable results, the various arsenicals appeared to have certain advantages which seemed to justify making a more thorough study of them.

Other promising chemicals also have been tested by the Green Section during the past several years of work at Arlington. The present report is concerned, however, almost entirely with the work on the various compounds of arsenic.

Several arsenical compounds are available commercially. These differ but slightly in name but greatly in their herbicidal properties. To the layman this variety of compounds may be somewhat confusing.

If one is not familiar with the terms it is an easy matter to purchase arsenious acid instead of arsenic acid or to obtain a sample of arsenic trioxide instead of arsenic pentoxide. Such substitutions would give unsatisfactory results and might naturally lead to the erroneous conclusion that arsenicals are not effective in controlling weeds.

Compounds of Arsenic

Arsenic occurs in two forms of compounds, the trivalent and the pentavalent. When arsenic in the trivalent form is combined with other elements it makes such compounds as arsenic trioxide, As_2O_3, (the common white arsenic sometimes referred to simply as arsenic), arsenious acid, and the various arsenites, of which sodium arsenite is the most common. Combined in the pentavalent form with other elements it occurs as arsenic pentoxide, As_2O_5, arsenic acid (which is formed when arsenic pentoxide is dissolved in water), and the various arsenates such as sodium arsenate, lead arsenate and calcium arsenate. A combination of copper arsenite and copper arsenate is in common use under the name of Paris green.

Soluble compounds of the trivalent form are reputed to be more toxic to plant life than those of the pentavalent form. In repeated trials at the light rates commonly used under field conditions, these soluble compounds, whether trivalent or pentavalent, applied at rates containing the same amounts of arsenic, showed little significant difference in toxicity. However, when heavy rates were used the trivalent form proved decidedly more toxic than the pentavalent.

Experiments have shown that the quickly soluble arsenicals are the most toxic to plant foliage and give the most rapid control of weeds. The comparatively insoluble compounds such as calcium arsenate, lead arsenate and arsenic trioxide, act slowly as weed killers and therefore seem to have less general value for weed control than the soluble forms.

Sodium arsenite, sodium arsenate, ammonium arsenate and arsenic pentoxide, being quickly soluble and very toxic to plant foliage, have all been tested rather extensively. Sodium arsenate and ammonium arsenate are more expensive than the other two compounds when based on the amount of arsenic they contain.

Two grades of sodium arsenite, a relatively crude and a more purified form, are available on the market in addition to the chemically pure material. Both are commonly used in large quantities. The crude product usually costs a little less than the purified form. Where the chemical is to be applied as a spray the purified grade may be preferable as it contains less insoluble material which might interfere with the spray equipment.

It should be remembered that all of these arsenic compounds are poisonous and that they should be handled with care. This danger need not check their careful use for they are no more dangerous to handle than the mercury compounds and other poisonous materials that have been in daily use on turf for many years.

Experimental Conditions

Some experimental work with different arsenical compounds has been conducted at the Arlington Turf Garden for a great many years but most of the work reported here was done over a five-year period (1934-1938). The amount of detailed information that has accumulated from the hundreds of experiments conducted during this period is so great that it must necessarily

be omitted. Only the general information covering the experiments is included in this report.

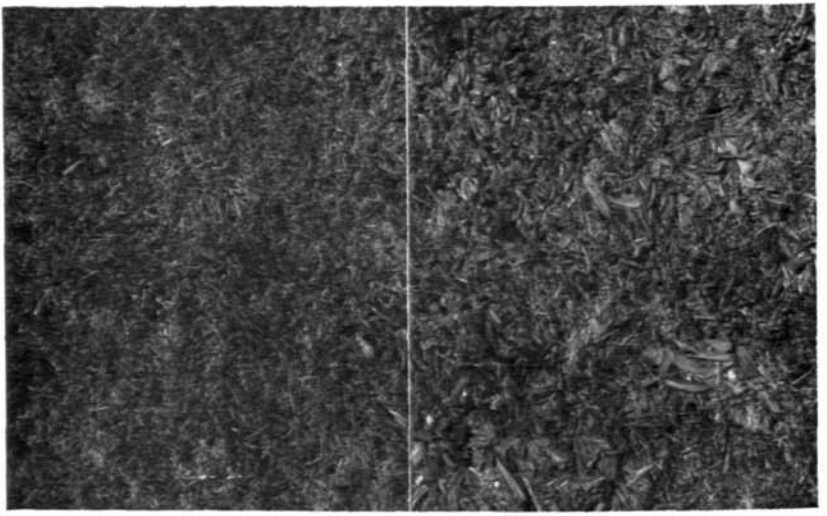
Most of the work has been carried on at the Arlington Experimental Farm. Conditions in the Washington district are especially favorable for crabgrass and some other weeds but are less so for bluegrass. Whenever a treatment showed considerable promise it was tested extensively on golf courses and other turfed areas in different sections of the country. Thus the treatments have been subjected to a wide variety of soil and climatic conditions.

While these treatments have been tested on different kinds of grasses the results reported, unless otherwise indicated, refer to Kentucky bluegrass turf. Most of the experiments at Arlington were conducted on a large neglected lawn. The crabgrass and chickweed tests were laid out on a nearly level, relatively fertile area, which is badly infested with these weeds every year. The experiments on other weeds were conducted on a well-drained, relatively infertile area. In all cases the turf was composed of Kentucky bluegrass and redtop, with patches of bent and *Poa trivialis*. This turf was badly infested with plantains, dandelion, chickweed, crabgrass, clover and many miscellaneous weeds.

Depending on the character of the tests and the distribution of the vegetation, the plot sizes in the experiments at Arlington ranged from 16 to 1,000 square feet. In the extensive experiments conducted in other places the areas treated varied from 16 square feet to entire fairways and football fields.

Method of Evaluating Results

Estimates of the percentage composition of the turf and actual plant counts were used in obtaining the data on percentage control. Plant counts were made more extensively at first but later only occasionally, as this method did not prove to be



Control of buckhorn plantain with a combination of equal parts of sodium chlorate and sodium arsenite applied in sand in September. Left, treated plot; right, untreated check plot. Picture taken the following May.

so applicable particularly in the cases of crabgrass, clover and chickweed. In many instances the remaining dandelions were so stunted from the treatments that they did not bloom and were very inconspicuous. In such a form they are not seriously objectionable in turf. Many small dandelion plants which do not bloom may make up a smaller proportion of the total composition of an area than a few large ones. This is especially true in a dense turf.

Judged by the estimate method a plot showing only 30 per cent dandelion control may have fewer dandelion plants than one showing 60 per cent control. By the actual count method the apparent results may be reversed. However, even though the number of plants may be greater, the figure showing 60 per cent control obtained by the estimate method gives the truest picture of the appearance and quality of the turf, and from this

point of view the control is better. Such differences in apparent results occurred in relatively few instances and only where a dense turf was present.

Records on the degree of control were taken several times following the treatment.

On acount of the variable composition of the turf it has been necessary to use frequent checks. Estimates of composition on the untreated areas which served as checks were made at the same time as the estimates on the treated areas. Unless the turf contained a relatively high percentage of a particular weed estimates were not used in recording control figures. Plant counts or merely observations were made but such observations were not used in figuring the percentage of control.

The grass injury as mentioned in the data refers to the actual discoloration of the turf grasses shortly after the treatment. Since the grass recovers rapidly, such discoloration usually represents only a temporary condition, depending somewhat on the degree of injury. When a small percentage of grass was present the browned appearance of all vegetation on the treated area may have been much worse than shown in the data.

In any weedy turf the soil is likely to be badly infested with weed seeds. When the crop of weeds growing in an area is killed the weeds are quickly replaced by new seedlings. For many types of weeds, therefore, repeated treatments are required. Obviously this reinfestation greatly complicates the matter of obtaining data on the degree of control secured. While a treatment may show control several weeks after its application, a few months later an entirely new crop of weeds may be growing in the area.

One treatment a year may kill the current growth of chickweed and crabgrass and prevent it from going to seed but several

years may be necessary to exhaust the supply of weed seed in the soil and completely clean up an area. A dense vigorous turf helps greatly in preventing this reinfestation by crowding out many new seedlings as they start growth.

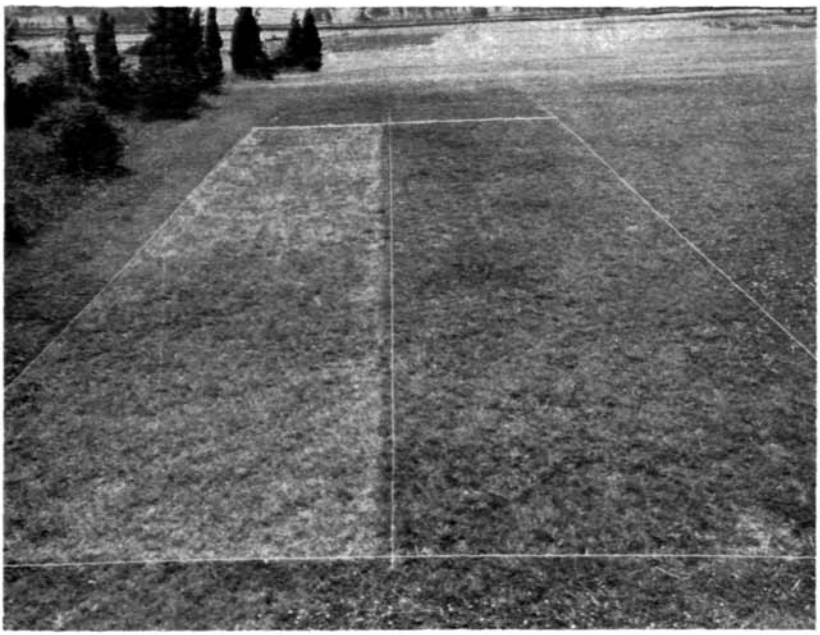
The chemicals used in controlling weeds may be applied dry or in solution depending on the type of chemical, the size and type of area to be treated, and various other factors.

Methods of Application

The dry method, in nearly all cases, consists of mixing the chemical with a carrier such as sand, soil, or fertilizer. A uniform mixture is best obtained by dissolving the required amount of chemical in a small quantity of water and mixing with the carrier. The dry chemical, however, can be mixed directly with the carrier provided care is taken to see that a uniform mixture is secured. The carrier containing the chemical is broadcast over the area to be treated. A sufficient amount of carrier must be used to insure uniform distribution. A convenient amount when spread by hand is from 8 to 16 quarts to 1,000 square feet.

The dry method offers many advantages. The chemical is deposited on the vegetation close to the ground and does not wet the foliage. Therefore some of the danger from poisoning is eliminated. There is always some danger in keeping supplies of poisonous chemicals on hand. When these are mixed with sand this danger is practically eliminated. The dry method is also safer to use around shrubbery and flowers. The treatments may be made by hand, so no expensive equipment is necessary. When an application of fertilizer is to be made the arsenic may be mixed with it and the two treatments applied in one operation, thereby reducing labor costs.

The chief disadvantages of the dry method are the greater cost of the larger quantity of chemical required, the cost of the



Greater injury to grass from spray treatments of arsenic acid than from dry treatments. Left, arsenic acid applied in spray at ½-pound rate; right, arsenic acid applied in sand at rate of 1½ pounds to 1,000 square feet.

material used as a carrier, and the extra time required to treat large areas.

In the wet method a solution of the chemical is applied either as a spray or by means of an ordinary garden sprinkling can. Different dilutions were tested and best control was obtained by dissolving the required amount of chemical in the least possible amount of water provided there was sufficient solution to thoroughly cover the foliage. On the small plots a compressed air hand sprayer which delivers a continuous fine spray has been used. Throughout these tests the rate of application has been 5 gallons of spray to 1,000 square feet. With the hand sprayer this rate of application could have been reduced

but it was used because it is comparable to that obtained with power sprayers.

Earlier work indicated that the dry method, while requiring a heavier rate of application than with a spray, gave about the same degree of control of most weeds but with less injury to the turf grasses. Continued experiments have substantiated this earlier work. However, where power sprayers with boom attachment are available the spray method is more economical and quicker. This is especially true where large areas are to be treated. Chickweed and crabgrass are usually more effectively controlled by the use of a spray.

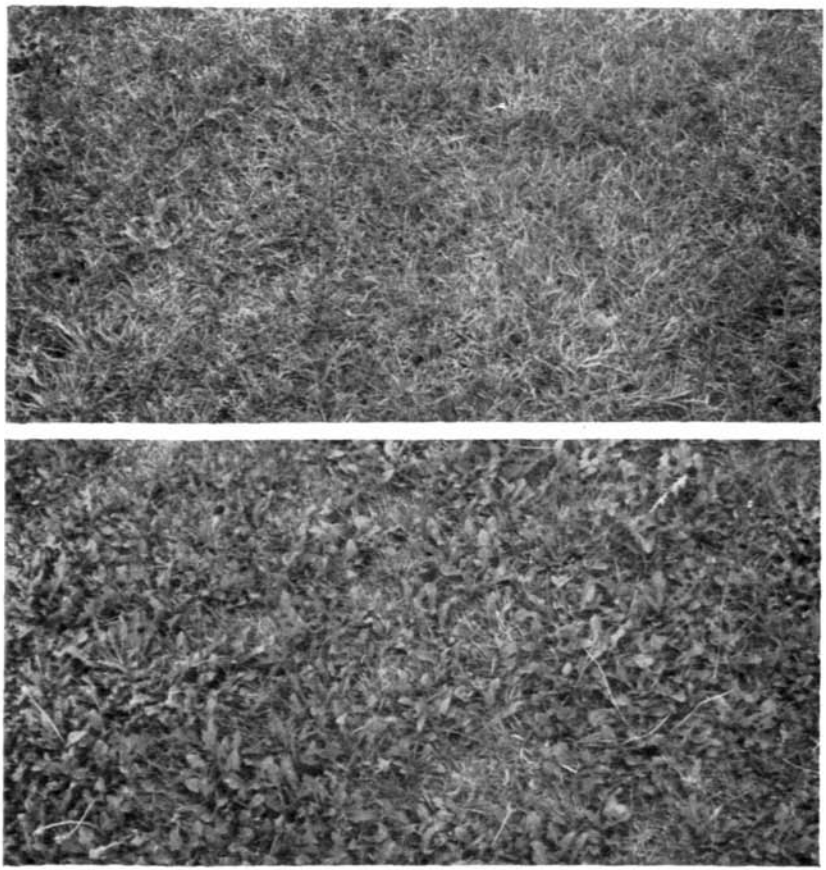
Another advantage of the spray is that in solution the chemical is more uniformly distributed than when mixed with a dry carrier. The spray also is usually more evenly distributed than the dry mixture.

A disadvantage of the spray method is that the expensive equipment necessary for large-scale operations may not be available. On the home lawn around shrubbery and flowers misty spray may drift onto the foliage even in calm weather and this may result in defoliation of these plants.

COMPARISON OF EFFECTIVENESS OF ONE APPLICATION OF SODIUM ARSENITE ON DIFFERENT WEEDS AT VARIOUS RATES. TREATMENTS MADE IN MARCH. OBSERVATIONS ON CONTROL MADE IN APRIL AND JUNE.

Method of Application	Rate in pounds	Per cent control of various weeds			Per cent burn to grass
		Plantain	Chickweed	Clover	
Spray	1/4	30	100	60	10
Spray	1/2	80	100	94	40
Spray	1	100	100	96	80
Dry (Sand)	3/8	14	100	67	15
Dry "	3/4	25	100	84	20
Dry "	1	50	100	99	30

The relative effectiveness of the spray and dry method is illustrated in the table above. Note that satisfactory control



Dandelion control with arsenicals in the Chicago District. Above, area on fairway sprayed with arsenic acid; below, typical weed-infested area on the same fairway.

can be secured with either method. The rate of application in the dry method, however, must be increased two or three times. One application at rates giving satisfactory control of the perennial weeds causes too great an injury to the grass. Repeated lighter treatments, however, give satisfactory control.

In the sprinkle method the chemical is dissolved in water and applied with a watering can. Much larger quantities of

water are used than by the spray method. Twenty-five to 30 gallons to 1,000 square feet are necessary to insure uniform distribution. The sprinkle method may be used where spray equipment is not available. It, however, requires larger quantities of the chemical to effect the same degree of control.

Comparison of Arsenicals

Both sodium arsenite and arsenic pentoxide are widely used as herbicides and have been employed in numerous tests at Arlington Farm. Arsenic pentoxide when dissolved in water forms orthoarsenic acid, in which form it functions as an herbicide. A crude form of arsenic acid (70 per cent) which, on the same arsenic content basis, is apparently equally effective, is sold commercially in this country at a much lower price than arsenic pentoxide. This crude arsenic acid has been used extensively in experimental work at Arlington Farm.

Comparison of Effectiveness of Sodium Arsenite and Arsenic Acid

Sand Treatments in October

Weed	Per cent control: Sodium arsenite 1 pound	Per cent control: Arsenic acid 2 pounds	Per cent burn to grass: Sodium arsenite 1 pound	Per cent burn to grass: Arsenic acid 2 pounds
Plantain	99	92	50	35
Dandelion	95	91	80	41
Chickweed	98	96	87	53
Clover	99	97	54	37

Spray Treatments in October

Weed	Per cent control: Sodium arsenite ½ pound	Per cent control: Arsenic acid 1 pound	Per cent burn to grass: Sodium arsenite ½ pound	Per cent burn to grass: Arsenic acid 1 pound
Plantain	91	95	60	50
Dandelion	24	28	60	54
Clover	98	97	60	50

Figured on the arsenic content basis, crude arsenic acid and sodium arsenite are about equal in price. These two compounds

have been compared in a large number of tests at Arlington. One pound of sodium arsenite, whether applied dry or in solution, is roughly equal to two pounds of crude arsenic acid in its toxicity to weeds. The arsenic acid, however, is less toxic to the grass, particularly at the heavier rates. The figures in the table on page 24 are an average of several experiments. They are typical of the results obtained in numerous tests from one application of these chemicals.

Rate of Application

The most desirable rate of application of any chemical for controlling weeds in turf is one which is heavy enough to kill the greatest possible number of weeds while at the same time causing the least possible injury to turf grasses. All plant tissues have certain fundamental likenesses, and any chemical which will destroy one plant is almost certain, if used in sufficient quantities, to cause some injury to all plants. No herbicide yet discovered is selective enough in its action to destroy one group of plants and cause no injury to another. The application recommended must necessarily be a compromise, since any rate that will effectively destroy weeds will cause some temporary injury to the grass.

The amount of chemical to apply depends upon the method and time of application, the type of weeds and grass in the turf, the soil and climatic conditions, and many other factors. No standard rate of application therefore can be recommended for all conditions. In some cases the fact that turf is badly discolored for two or three weeks may not be objectionable, and a heavy rate of application may be used in order to clean up the weeds in one operation. In other cases only slight and

temporary discoloration of turf is permissible and only the lighter rates of application may be used.

Since a definite recommendation covering rates of application to suit all conditions cannot be made, those contemplating the use of these chemicals should become acquainted with the factors affecting the results and should make small-scale tests before applying the chemical to large areas.

Generally speaking, the spray treatments of arsenicals at any given rate have proved to be more efficient in weed control than dry treatments of the same chemical made at the same rate. On the other hand, they are more injurious to turf grasses. To obtain equivalent control by the dry method, it is necessary to use two or three times the quantity of arsenical used in spray treatments.

The results of numerous treatments on weedy Kentucky bluegrass turf in the Washington district have shown that sodium arsenite or arsenic acid as a spray applied in early fall at 4 ounces to 1,000 square feet generally will give satisfactory weed control with the least amount of injury to the grass. Under different conditions of soil and climate, this amount has had to be decreased or increased. Also, if the turf consists largely of bent and fescue, application at this rate may be too heavy. By the dry method, sodium arsenite has given the best results when applied at the rate of ½ to 1 pound to 1,000 square feet.

The effectiveness of different rates of application is illustrated in the table on page 22. Note that one application of sodium arsenite at 4 ounces as a spray readily has killed chickweed but has given in this instance only 30 per cent control of plantain.

An application of sodium arsenite as a spray at ½ to 1 pound has given satisfactory control of plantain. The grass injury, however, has been increased to such a degree that some injury to the stand is likely to result. For this reason perennial weeds such as plantain and dandelions are best controlled by several repeated treatments at a rate causing only a light temporary injury to the grass. These figures are typical of numerous experiments where this chemical has been applied at various rates on different weeds.

Heavy rates of application have given 100 per cent control and thus have appeared superior to the lighter rates. They are not advocated for general use, however, as they cause too severe injury to turf, and leave it discolored over too long a period. These heavy rates have been used in the experimental work in order to obtain information on the correct rates of application.

One light treatment with arsenicals readily has destroyed the current crop of such weeds as chickweed and crabgrass. However, new seedlings usually reinfest the area. Either heavier applications or repeated treatments have been necessary for the control of perennial weeds such as plantains and dandelions. Experiments have shown that two or three repeated light treatments have successfully controlled perennial weeds with little injury to turf grasses. Any new seedlings that appeared also have been destroyed by the repeated treatments. Effective control of plantains and dandelions has been secured by three sprayings at the rate of 4 ounces of sodium arsenite to 1,000 square feet, or by three treatments of the dry material at the rate of ½ pound to 1,000 square feet, repeated at intervals of two to four weeks. These treatments also have destroyed the seedlings, and a high degree of control has been maintained for two years. Over a period of several years, satisfactory

control has been obtained with single fall treatments made in successive seasons.

Where rain or other factors apparently have decreased the effectiveness of a particular treatment, an additional treatment made within a few days has given good results. By this method the turf has been browned for only a normal period, while two treatments at longer intervals would have prolonged the period of browned turf. Tests have shown that when an application is repeated within a few days it is better to cut in half the rate for the second treatment. This does not hold true for a second treatment at an interval of two weeks or longer.

Where poor weedy turf is present and where a prolonged period of browned grass is not objectionable, it may be advisable to make a heavy treatment for a complete clean-up of all weeds present. Rates of application that will give complete control and not destroy the turf grasses will vary with local conditions. Kentucky bluegrass, although seriously injured, has recovered from three applications of arsenic acid applied as a sprinkle at the rate of 8 pounds to 1,000 square feet and followed by watering. The turf on these plots has been exceptionally vigorous and remarkably free from all weeds over a three-year period following the last treatment. Under different conditions, the more sensitive turf grasses or even Kentucky bluegrass might not recover from this heavy rate. These results show the large quantities of arsenic acid which Kentucky bluegrass has been able to tolerate.

Effect on Different Types of Weeds

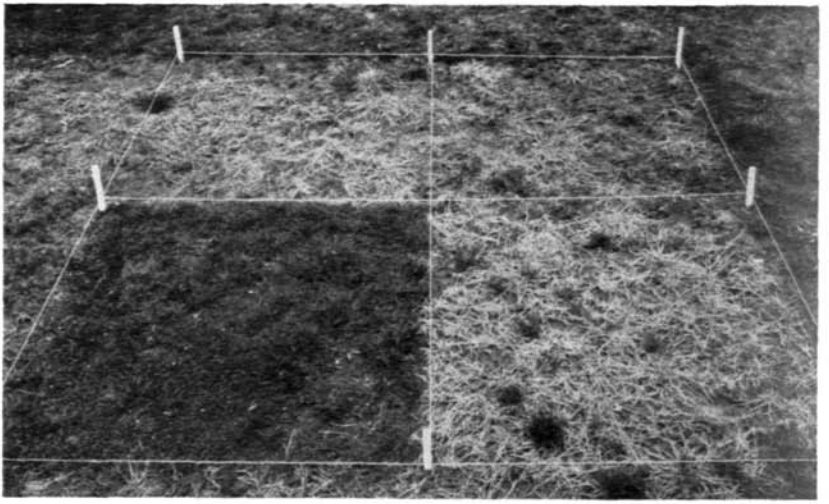
It is generally recognized that certain types of weeds are easier to control by mowing, hand weeding or good cultural practices than others. Some weeds can also be controlled more

easily than others by the use of chemicals. This variation in the susceptibility of the different weeds to herbicides may be due to differences in size, shape and structure of the leaves, to kind and distribution of roots, and to growth and seeding habits.

Annual weeds and the low-growing, mat-forming type of weeds such as the chickweeds are generally more susceptible to arsenicals than deep-rooted perennials, such as dandelions. A single application of arsenicals at the suggested rates is often sufficient to control any particular infestation of mat weeds. The deep-rooted perennials, however, are more difficult to eradicate. This is probably due largely to the fact that they store sufficient reserve food in their long roots to enable them to send up new shoots even though their tops may have been killed to the crowns.

On account of differences in growth and seeding habits of the various types of weeds, some weeds are best controlled by early spring treatments, whereas others are more easily controlled by treatments in the fall. For instance, chickweed, which is a troublesome pest in turf in many districts, makes its principal growth in the late fall or early spring. It is easily controlled by spraying in the winter or early spring.

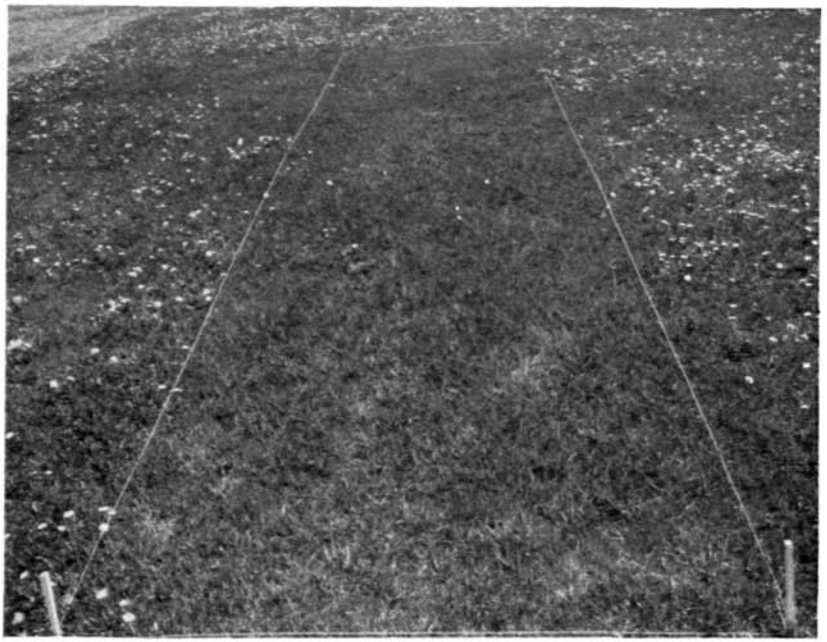
On the other hand, crabgrass, the most troublesome of all weeds in turf in the Washington district, does not become conspicuous until early summer and makes its best growth during midsummer. Under favorable conditions, this weed by early fall has nearly smothered out any bluegrass which may have been present in the turf. Early fall treatments may kill the existing crabgrass and prevent the weed from setting seed, but they are not made early enough to prevent it from choking out the turf grasses.



Invasion of crabgrass following severe turf injury resulting from heavy applications of arsenicals in July. The bleached remains of the crabgrass the following spring show how completely this weed covered the treated areas in late summer. The check plot, lower left, is covered with clover and other weeds which had continued to compete successfully with crabgrass.

Crabgrass seedlings in the two-and three-leaf stage are easily killed in late May or early June. However, even light treatments made at this time of the year have a temporary browning effect on the turf. This slight retarding effect on the growth of the turf grasses gives a distinct advantage to the succeeding crops of crabgrass which reoccur in many turfed areas until mid-August. For treatments of crabgrass at this season, sodium chlorate has given better results than the arsenicals.

The best crabgrass control with arsenicals has resulted from late summer or early fall applications after the crabgrass seed is no longer germinating. Such treatments followed by a reseeding and fertilizing program have produced good stands of Kentucky bluegrass. The grass seed germinated rapidly and developed in the spots left bare by the killing of the crabgrass.

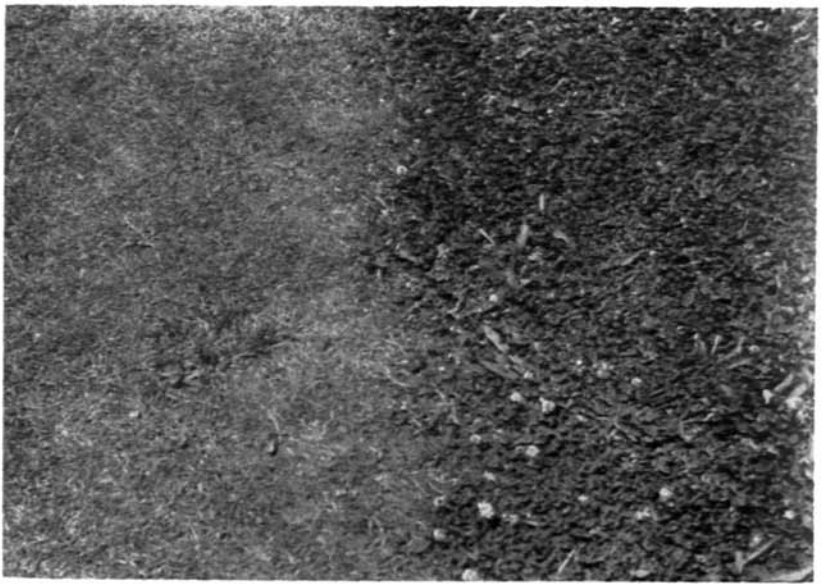


Dandelion control with arsenicals. The marked area includes four different plots treated with arsenic pentoxide or arsenic acid in succeeding falls. It is surrounded by untreated areas showing dandelions in bloom.

Removing the competition of the crabgrass has enabled the seedlings of the permanent grasses to become well established during the fall. Such a stand of grass helps to choke out the crabgrass seedlings when they begin to appear the following May or June.

Plantains and dandelions are difficult to eradicate on account of their deep roots. The plantains are greatly reduced by a single treatment of sodium arsenite or arsenic acid, particularly when such a treatment is made in early fall. Two or three treatments are usually necessary to give complete control.

Although dandelions are more difficult to kill than plantains, they have been satisfactorily controlled with arsenicals by a



Eradication of clover from bent turf with arsenic acid. Left, repeated light treatments in fall; right, untreated plot.

series of three or more treatments. Any remaining plants have been so stunted in growth that they did not produce seed and generally were not objectionable. Even when dandelions have been eradicated from an area, new plants may appear from seed which has blown in. It has been noted, however, in tests at the Arlington Turf Garden, at Chicago, and elsewhere, that in small plots or narrow strips from which dandelions have been removed by arsenicals, the reinfestation of dandelions was remarkably slow. Some of the treated areas have remained relatively free from dandelions for three or four years in spite of the heavy production of seed along the borders of the plots and in adjoining areas.

Clover, which is considered a weed in many turfs, is killed readily in the seedling stage by light sprays. Both clover seed-

lings and established patches of clover in turf have been more successfully eradicated by successive treatments in the fall than in other seasons.

The relative susceptibility of various weeds to arsenicals is illustrated in the table on page 22. Note that while chickweed has been killed readily with one spray application of sodium arsenite at the rate of ¼ pound to 1,000 square feet, plantain in these tests has been controlled only 30 per cent. Tests have also shown that other weeds show varying degrees of susceptibility.

A light treatment which causes little injury to the grass may give only a low degree of control of many weeds. For this reason repeated treatments may have to be made when light rates are used.

Effect on Different Grasses

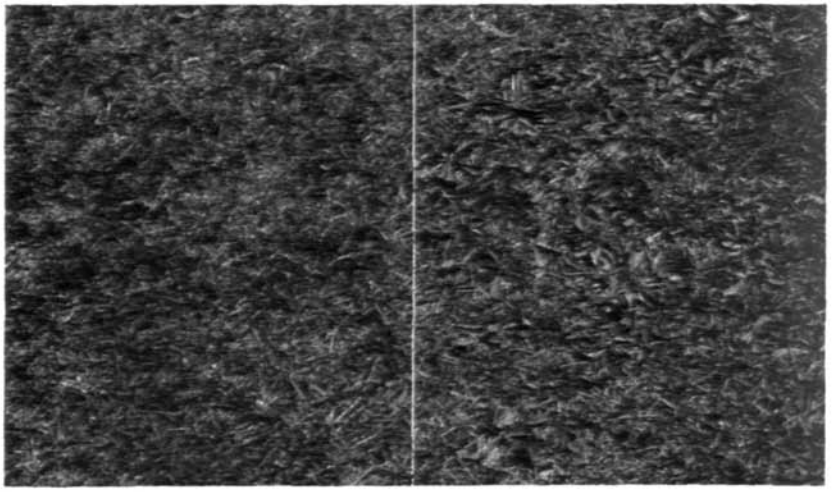
Grasses differ in their sensitiveness to arsenical treatments. Kentucky bluegrass and Bermuda grass seem to be the most resistant, being temporarily browned but recovering quickly from the treatment. *Poa annua,* the fescues, the bents, and *Poa trivialis* are increasingly sensitive in the order named. When the more sensitive grasses represent a large percentage of the turf, the rates of any particular treatment should be reduced.

Effect of Height of Cut on Injury to Kentucky Bluegrass by Spray Treatments of Arsenic Acid at ½ Pound Rate

Height in Inches	Percentage injury
3/16	40
1¼	30
2½	15

The amount of injury to turf grass resulting from applications of arsenicals varies with the height of mowing at the time

of application. The more closely the grass is clipped, the more sensitive it is to treatment. When grass is cut at the height used on putting greens, the injury has been shown to be greater than when it is cut at heights used on fairways or in the rough.



Plantain control with arsenic acid applied in sand in spring and again in September. Left, treated plot; right, untreated check plot. Picture was taken the following May.

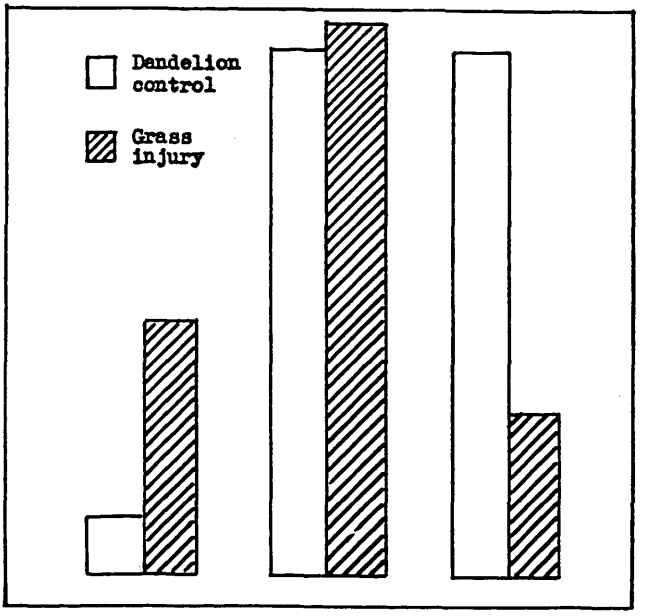
This is demonstrated in the table on page 33 showing temporary injury caused by the application of arsenic acid at ½ pound in spray treatments made in October.

Time of Application

Early spring and fall are the best seasons for the growth of Kentucky bluegrass. During the hot summer this grass makes little growth and consequently is at a distinct disadvantage in competing with crabgrass and many other weeds. Unless turf grasses enter the summer with the advantage of vigorous growth and maximum cover of the ground, crabgrass and other weeds are likely to take over the area. Experimental work on the control of weeds in farm crops has indicated that most weeds

are easiest to kill at the time when they have the least amount of reserve food stored in their roots.

This is usually sometime in late spring. In many districts it is not practical to take advantage of this weakened condition of certain weeds as the late spring treatments retard the turf



Percentages of dandelion control and grass injury with sodium arsenite at 1-pound rate at various times during growing season. Left, early spring; center, summer; right, early fall. Note that the early fall treatments give best control with least injury to the grass.

grasses, leave open areas where the weeds were killed, and make conditions favorable for the invasion of crabgrass, clover and other weeds. Treatments made in early fall leave the grass relatively free to cover the ground during the rest of the fall and spring so that crabgrass and other weeds have less chance to invade the area.

Tests have shown that high temperatures increase the effectiveness of arsenical treatments on weeds but also greatly increase the injury to the grass. This holds true whether the high temperature is confined to a several-day period in the fall or occurs in any of the summer months. Treatments during the summer months therefore should be made during cool, cloudy weather.

Generally speaking, the results with arsenicals are most satisfactory when applications are made in early fall, because at that time of the year the best weed control is effected with the least injury to the grass. The figure on page 35 has been made up from various experiments on dandelion control. Similar figures have been constructed for other weeds such as plantain, crabgrass, clover, etc. Although they differ in detail, in general they demonstrate the same relationship and justify our conclusion that early fall is the best time for application of arsenicals for control of most weeds.

EFFECT OF MOISTURE ON FOLIAGE AT TIME OF APPLICATION OF SODIUM ARSENITE AT 1 POUND RATE IN MARCH

	Foliage wet	Foliage dry
Plantain (percentage control)	70	50
Grass (percentage burn)	60	30

Experiments have shown that the amount of moisture on the foliage either before or after treatment, and the amount of moisture in the soil, influence the degree of control secured as well as the severity of injury to the grass.

When the foliage is wet at the time of application of arsenicals, there is generally a significant increase both in the control of weeds and in the burn produced on the grass. Take, for instance, the control of plantain with early spring dry treat-

ments with arsenicals. Although the plantain has been controlled 40 per cent better with the sodium arsenite applied to wet foliage than to dry, the grass has suffered 100 per cent greater burn.

If the material is to be applied when the vegetation is wet, allowance should be made for the greater injury to both the weeds and the grass in deciding on the rates to be used.

It has been recognized that showers coming shortly after application of the arsenicals reduce their effectiveness. Experiments have been set up therefore to determine the significance of this effect.

The arsenicals were applied in sand to bluegrass turf at several rates. Some of the plots were watered with 232 gallons of water to 1,000 square feet. Others received only 83 gallons to 1,000 square feet, and still others were not watered at all. The results on burn to the grass caused by the treatments with sodium arsenite are given in the table below.

EFFECT OF WATERING AFTER DRY (SAND) TREATMENT WITH SODIUM ARSENITE IN MAY

Rate of treatment in pounds	Percentage of burn to grass		
	Heavy watering (232 gallons to 1,000 square feet)	Light watering (83 gallons to 1,000 square feet)	No watering
1	8	15	60
2	20	50	80
4	80	85	95

From this table it can be seen readily that the burn to the grass resulting from these treatments has been progressively reduced with the addition of increasing amounts of water to the soil following treatment. This has been particularly striking at the lowest rate used in this test (1 pound to 1,000 square feet).

On the other hand, it should be remembered that this watering has a corresponding effect on weed control. Therefore, watering after the treatment decidedly reduces the effectiveness of the arsenicals as herbicides. Similar results may be expected from rainfall following an application of arsenicals, so treatments should be made when fair weather is predicted.

The higher rates would not be used in practice, but have been included for experimental purposes only.

As a rule, a high degree of soil moisture has decreased the effectiveness of a treatment when applied as a spray. If the soil is dry, the recovery of the grasses may be delayed.

Effect of Shade

Except for the tees, the shaded areas on golf courses are usually confined to the rough or to out-of-the-way places where the quality of the turf is not conspicuous. On the other hand, in parks and on home lawns, the shaded areas are the most frequented sections. Fortunately, crabgrass is usually not a pest in shade, but chickweed and other weeds may be abundant. Although proper fertilizer practices will do much to encourage an increase in the turf grasses and a decrease in the weed population, chemical treatments have been shown to hasten weed control and turf improvement in such areas.

In the experiments with chemicals, the same methods have been used in shady areas as in the exposed areas. The grass in the shady areas has been more severely burned than that in the open, the average burn having been estimated at 73 per cent in the shade and 23 per cent in the open. These results indicate that it may be necessary to use lighter rates for treating turf growing in the shade. Particularly is this true where the turf consists of the fescues and *Poa trivialis,* since these are among the grasses most sensitive to arsenical injury.

Arsenical compounds are fixed in the first few inches of soil so that, unless excessive rates are used, no damage should result to trees, which are normally deep rooted. Care should be taken, however, to avoid touching shrubbery or flowers with the spray.

Clearing Areas of Weeds for Reseeding

For satisfactory turf improvement in places where the weed infestation has become so severe as to seriously reduce the stand of turf grass, it is advisable to accompany the chemical treatment with an application of quickly available fertilizer and a reseeding program.

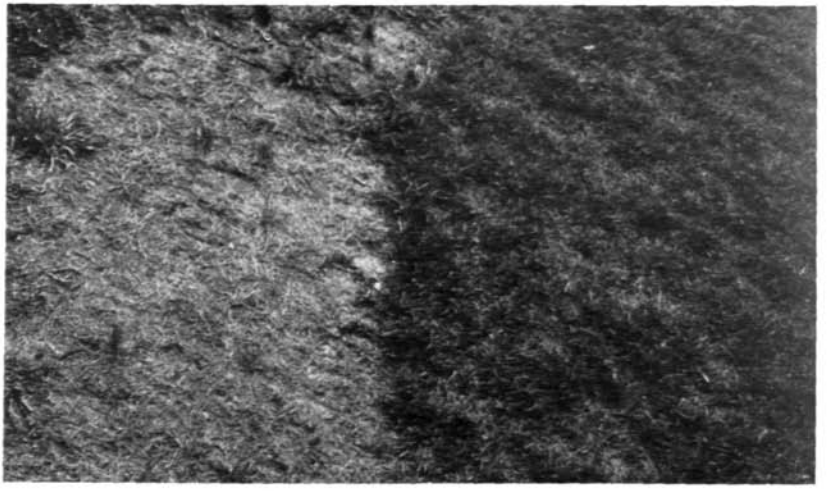
The varsity football field at the United States Naval Academy, Annapolis, presented such a problem in the summer of 1934. Crabgrass had taken almost complete possession of the turf, and it was recognized that this grass would last only a short time during the playing season. The Green Section cooperated in treating this field twice with sodium chlorate. The first application was made at the rate of 120 pounds to the acre on July 31. The second treatment of 80 pounds to the acre was put on eight days later.

A complete fertilizer was applied and seed planted with a disk seeder the middle of August. In spite of the retardation of the seedlings by the sodium chlorate residue in the soil, germination was excellent and a good stand of grass was obtained for the opening game. This treatment provided a good cover for the fall season without disturbing the surface by sodding or by cultivation for a new seed bed. The mat of dead roots and stubble of the crabgrass provided a satisfactory footing for the players while the new grass was becoming established.

Experiments conducted at Arlington simultaneously with the Annapolis treatment showed that as good a kill of crabgrass could be obtained with sodium arsenite and arsenic acid as with

sodium chlorate. Further, the arsenicals did not retard the growth of seedling grass as much as did the sodium chlorate. In other tests, grass seed planted only three and four days after the arsenicals were applied germinated successfully.

On several occasions at Arlington it has been necessary to delay seeding, due to prolonged fall rains starting within two



Crabgrass control with arsenicals. Entire plot was treated with sodium arsenite in early fall. Left, not seeded; right, seeded with Kentucky bluegrass at time of application of arsenicals. Picture was taken the following April.

or three days after the chemical treatments. Some areas, therefore, have been seeded immediately before the application of the arsenical. Germination has proved to be entirely satisfactory, and the seedlings have not been retarded seriously. By spiking in grass seed or putting it in with a disk seeder before applying the chemicals, the weeds are cut and bruised, and this may make them a little more sensitive to chemical injury.

The fact that the seed of the grass which is expected to replace the weeds is in the soil before the weeds are destroyed

is of even greater practical importance, since the period of discolored turf is reduced to a minimum. The rainy periods that may be expected in fall will hasten growth of the new grass rather than serve to delay its planting. This method makes it possible to do all the seeding, fertilizing and burning with chemicals during the same period of good weather and thereby avoid any long interval between the time the weeds are killed and the time when the new crop of grass begins to grow.

Experiments with this type of treatment on crabgrass-infested turf at Arlington have given remarkable results. The addition of fertilizers and reseeding following a September application of arsenical at the rate of 4 ounces to 1,000 square feet has resulted in an increase of the desirable turf grasses from 5 per cent in the fall of 1937 to 75 per cent in the fall of 1938.

For this particular type of treatment, rates of from 4 ounces to 1 pound of sodium arsenite have given satisfactory results. In turf where sufficient permanent grasses are present to justify some caution in preserving them, the lower rates should be used. However, where crabgrass and other weeds have taken over the area completely, the higher rates of application should be used. This increased rate will be more effective on perennial weeds and cause no harmful effects to the grass seedlings.

Several series of tests made at Arlington at weekly intervals during September have shown that the exact time of treatment of crabgrass-infested turf is not an important factor in this method of control. The treatment, however, must be made early enough to enable the seedling grasses to become established before winter sets in.

Additional experiments with this type of treatment are now under way.

Arsenic Residue in Soil

The ideal chemical to use for the control of turf weeds should leave no deleterious substances in the soil and should not have a prolonged toxic effect on the turf grasses. Since the quickly soluble compounds of arsenic are readily fixed by the soil, they appear to be remarkably free from either evil. None of the arsenical treatments have shown any residual toxic effect when used at the recommended rates.

Even a total of 24 pounds of crude arsenic acid to 1,000 square feet applied in three treatments and watered in following each treatment has not killed the bluegrass and has had no prolonged toxic effect on the grass. In fact the opposite has been true, as the treatment appears to have stimulated the Kentucky bluegrass and has resulted in a vigorous weed-free turf. This stimulating effect of arsenic has been observed in many of the experiments at Arlington, and also has been noted by other workers.

Experiments on the effect of heavy applications of the relatively insoluble arsenicals at rates as high as 40 pounds to 1,000 square feet have given variable results. Some of these heavy treatments appear to have had a retarding effect on the growth of Kentucky bluegrass. Other investigators also have observed this retarding effect.

Arsenicals in Combination with Fertilizers

A proper program of fertilization carried on over a period of years may control many turf weeds. When arsenicals are used in combination with a fertilizing program, the time needed to produce a good turf may be decreased and control

secured with less fertilizer and consequently at a lower cost. This combination has the further advantage of reduced mowing expense, since the grass is not stimulated to such rapid growth as when larger quantities of fertilizers alone are used to accomplish weed control.

On poor soils, turf grasses do not withstand the encroachment of the weeds, and under such conditions the use of some fertilizer is necessary if a satisfactory stand of grass is to be retained in the turf. On such soils, weeds, especially chickweed and clover, may be successfully controlled by the use of arsenicals, but unless the grass is encouraged the bare areas left vacant by the dead weeds are readily taken over by other weeds, the seeds of which are either present in the soil or are blown onto the area. When using the dry method, the arsenic may be mixed with the fertilizer and both of them applied at the same time. When using a spray, the fertilizer may be applied just before the chemical treatment.

Further reports on experiments at Arlington with arsenicals in combination with fertilizers will be published in a future issue of TURF CULTURE.

WARNING

Arsenic is a deadly poison. All arsenic compounds are dangerous.

Do not leave the powder or solution where children or animals can get it.

When applying the chemical see that the men do not inhale either dust or spray.

Exposed skin should be covered as far as possible. Poisoning may result from a deposit of arsenic on the skin.

Faces and hands should be washed as soon as the work is finished, especially before smoking, eating or handling any materials which are put into the mouth.

Do not permit grazing animals to eat plants that have been poisoned with arsenic.