CONTROL OF THE GYMNOSPORANGIUM RUSTS BY MEANS OF SULPHUR SPRAYS

J. D. MacLachlan and Ivan H. Crowell

With plate 204

INTRODUCTION

Crowell (1934, 1935) has already demonstrated the value of a colloidal sulphur as a means of controlling *Gymnosporangium Juniperi-virginianae* Schw. on ornamental apple trees, and *G. clavipes* C. and P. on *Juniperus virginiana* L. and *Amelanchier oblongifolia* (T. and G.) Roem. Both of the writers of this paper, individually and jointly, have been studying and experimenting with sulphur sprays for several years in relation to their effectiveness as a means of controlling Gymnosporangium rusts. The results obtained are presented here, along with recommended spray schedules for the control of *G. Juniperi-virginianae*, *G. globosum* and *G. clavipes* on their respective alternate hosts.

SULPHUR SPRAYS WITH RELATION TO TOXICITY TO GYMNOSPORANGIUM SPORES

A. The toxic effect on the basidiospore

Apparently sulphur, in contact with the basidiospores of the Gymnosporangium rusts, has little toxic effect on these spores prior to their being moistened and permitted to germinate. Moreover, the germinating spores must be in close proximity to the sulphur particles to be materially affected. These phenomena were illustrated by a simple experiment. A small amount of linseed oil was mixed with "Flotation sulphur," made up at six pounds to one hundred gallons of water. The mixture was sprayed on a glass slide and allowed to dry. Fresh basidiospores of *G. Juniperi-virginianae* were obtained from germinating teliospores and permitted to fall on the prepared slide. After the spores had been in contact with the sulphur for a period of ten hours, the slide was lightly atomized with distilled water and inverted in a moist chamber. Due to the presence of the oil, the water formed in small droplets carrying some of the spores to the exposed surfaces of the droplets while the remainder of the spores remained in contact with the sulphur. Twelve hours after atomizing, no germ tubes were evident on the spores which remained in contact

with the sulphur either within a droplet or at its periphery but more than seventy per cent of the spores on the exposed surfaces of the droplets and free from the sulphur exhibited normal germ tubes. This experiment indicates (1) that the sulphur has little effect on the spores until they begin to germinate and (2) that the sulphur particles must be in close proximity to the germinating spores to have a toxic effect.

B. Size of sulphur particle with relation to toxicity

It is the belief of Wilcoxon and McCallan (1931) that particle size rather than concentration is the chief factor that determines the relative efficiency of sulphur sprays; the toxic value of the sulphur varies inversely with the diameter of the particle. From this it would appear that a colloidal type of sulphur would be the most efficient. On the other hand, sulphur volatilizes when exposed in a thin layer to wind and direct sunlight, the rate of volatilization varying directly with the size of the sulphur particle. These two factors would indicate that an efficient sulphur should contain particles of active ingredients whose sizes varied from colloidal to a size that would not be completely volatilized by the time of the next spray application.

C. Particle size of the ingredients of certain sulphurs

The relative particle sizes of the ingredients of eight sulphur sprays were illustrated by means of photomicrographs. The sulphurs selected were Dry Lime, Flotation, Kolofog, Linco Colloidal, Liquid Lime, Magnetic Wettable, the Nova Scotia formula and Sublimated sulphur. The respective sulphurs were made up according to the schedule given in Table I. No spreader or sticker was added. Samples of the respective sulphurs were taken immediately after their preparation and sprayed by means of atomizers on glass slides and allowed to dry. Microscopic examination revealed in all cases that the spray ingredients were quite uniformly distributed over the surfaces of the prepared slides. Thus it made little difference what portion of a slide was photographed. Photomicrographs were made as silhouettes at a magnification of 545 diameters and are illustrated in Plate 204. (For further details see explanation of plate.) These photomicrographs might well represent the optimum distribution of the particles of the respective sulphurs on the surface of sprayed foliage. Within Plate 204 are shown photographs of basidiospores and aeciospores of *G. globosum,* also at a magnification of 545 diameters. One can visualize from Plate 204 how it might be possible for a basidiospore to germinate and penetrate the surface of a leaf and yet not come in contact with a particle of one of the coarser sulphurs.

TABLE I

THE SULPHUR SPRAYS, TOGETHER WITH THEIR CONCENTRATIONS, USED IN THE INVESTIGATIONS PRESENTED IN THIS PAPER

Sulphurs:	
Dry Lime Flotation Kolofog Linco Colloidal Magnetic Wettable Sublimated	6 lbs. to 100 gallons of water.
Liquid Lime	1 gallon to 50 gallons of water.
Nova Scotia formula	Aluminum sulphate .....4.2 lbs. Liquid Lime Sulphur .....1.4 lbs. Calcium arsenate .....1.2 lbs. Water .....48 gallons

Stickers and spreaders:

(1) "S. S. S." Sticker and Spreader, produced by the Mechling Chemical Co., Canton, New Jersey. This product contains no lime, is not designated to wet sulphur and can be used with any spray except oil. It was used in the proportion of 3 lbs. to 100 gallons of spray.

(2) Fish oil in the proportion of 1 pint to 50 gallons of spray together with dried milk in the proportion of ½ lb. to 50 gallons of spray.

D. Duration of toxicity of sulphur on sprayed foliage

An attempt was made to determine how long different types of sulphur sprays would protect the foliage from infection by the basidiospores. The sprays selected were Magnetic Wettable, Kolofog, Flotation and Linco Colloidal. The tree selected for experimentation was *Crataegus Jonesae* Sarg., a hawthorn that is very susceptible to *G. globosum*. Separate large branches of the hawthorn were sprayed with the respective sulphurs made up according to the schedule given in Table I. No spreader or sticker was added. Samples of the sprayed branches were inoculated with germinating teliospores of *G. globosum* (1) immediately after the sprays were dry, (2) three days later, (3) five days later, and (4) twelve days later. The experiment was carried out in duplicate, each inoculation on a separate twig. Parallel series of check inoculations were made on unsprayed branches of the same tree. Table II presents data on the results obtained and the following conclusions can be made. (1) The host tree was highly susceptible during the period of experimentation as indicated by the check inoculations. (2) The Flotation and Linco Colloidal sulphurs gave perfect protection for at least five days time but gave practically no protection twelve days

after spray application. A somewhat similar series of experiments (Crowell, 1934) also indicates that Linco Colloidal will not protect the foliage of ornamental apples from infection by *G. Juniperi-virginianae* for a period of more than nine to ten days.

TABLE II

DURATION OF TOXICITY OF FOUR SULPHUR SPRAYS TO BASIDIOSPORES OF *G. GLOBOSUM* WHEN APPLIED TO HAWTHORN FOLIAGE

Spray	Degree of infection from successive inoculations obtained			
	Immediately after spraying	3 days later	5 days later	12 days later
Magnetic Wettable	2	1	2	2
Kolofog	1	3	2	2
Flotation	0	0	0	2
Linco Colloidal	0	0	0	3
Check (unsprayed)	3	3	3	3

Experiment begun May 19, 1933.
The degrees of infection obtained by the inoculations were graded as 0, 1, 2 and 3 where 0 — no infection obtained
1 — 1–5 lesions per leaf
2 — 5–20 lesions per leaf
3 — more than 20 lesions per leaf.

III. FIELD TESTS USING FOUR DIFFERENT SULPHURS TO CONTROL *G. JUNIPERI-VIRGINIANAE*

In view of the foregoing investigations, four sulphurs, namely, Flotation, Linco Colloidal, Liquid Lime and the Nova Scotia formula were selected for field tests. These sulphurs were used as a means to control *G. Juniperi-virginianae* on susceptible apple trees and on red cedars.

A. Control of G. Juniperi-virginianae on apples

A number of Wealthy apple trees were marked in a commercial orchard at Wayland, Massachusetts, in August, 1934. These marked trees exhibited severe infection by *G. Juniperi-virginianae* and were used for both spray tests and check purposes the following spring. Spraying was begun on May 2, 1935. The four sulphurs were made up according to schedule with the "S. S. S." sticker and spreader added. (See Table I.) Two trees were used for each spray test; the remaining ones served for check purposes. The spray was applied by means of a hand-pump sprayer. The dates of spray application, as well as conditions of the foliage and the weather conditions at the time of spraying, may be found in Table III.

TABLE III

SPRAY SCHEDULE ON APPLES WITH REFERENCE TO CONDITION OF FOLIAGE AND WEATHER AT THE TIME OF SPRAYING

Date	Foliar condition	Weather
May 2	Leaves ¼–½ in. long. Flower buds just beginning to show pink tips.	Cool, cloudy.
May 8	Late prepink stage. Leaves expanding.	Cool, cloudy.
May 16	Blossoms opening. Leaves well expanded. A slight frost injury evident.	Clear, warm.
May 23	Petals dropping.	Cool, cloudy. No rain since last spraying.
June 3	Many large secondary leaves.	Warm, cloudy.
June 14	No evidence of any infection.	Warm, clear.

Note: On May 23, lead arsenate (2 lbs. per 100 gallons) was added to the respective sprays to protect the foliage from insect injury. In early June, the owner of the property sprayed the trees with lead arsenate and dry lime sulphur but, as evidenced by the check trees, this spraying did not affect the results of the experiment.

Records on the results of the experiment were collected on August 9, 1935. The degree of control was based on the reduction in the number of foliar lesions on sample branches removed at random from various portions of the sprayed and checked trees. In Table IV may be found data on the results obtained.

As may be seen from Table IV, better than ninety per cent control of the rust was obtained. It may be noted that the experiment with the Nova Scotia formula in which one spray was omitted (See explanation under Table IV) apparently gave the best results of all. This indicates that the differences recorded for the sulphurs, with the possible exception of Flotation, are of no significance as to their relative value. If of any significance they indicate differences in thoroughness of spraying. It must be remembered that the spraying was done with a hand-pump sprayer.

B. Control of G. Juniperi-virginianae on red cedars

In Massachusetts, the aeciospores of *G. Juniperi-virginianae* are dispersed from about the middle of July until the leaves drop in the autumn. This factor necessitates protection to the red cedar for a much longer period than is necessary for the apple. A spray program was carried out in 1934 which involved various time intervals for spray application and

extended from the time of the initial discharge of the aeciospores until December.

A large nursery at Framingham, Massachusetts, afforded an excellent opportunity for experimentation. A plantation of approximately five hundred large red cedars, arranged in five rows, runs parallel to, and about one hundred yards from, a row of *Malus ioensis plena* Rehd. Both hosts had exhibited very heavy infection by *G. Juniperi-virginianae* for at least two years prior to the initiation of the spray program.

The sprays were made up according to the schedule given in Table I. As a sticker and spreader, the fish oil and dried milk were added. For experimentation, trees were selected which exhibited an abundance of old galls of *G. Juniperi-virginianae*. Parallel spray programs were carried out for each of the four sulphurs. Eight trees, for each sulphur, were sprayed just prior to the initial discharge of the aeciospores, namely, July 25, 1934. Subsequent spray applications were made to respective pairs of these trees at time intervals of one, two, three and four weeks. Spraying was discontinued on one tree of each pair on October 31 by which time practically all the aeciospores had been dispersed. The last spray was applied on December 5. The remainder of the plantation served for check purposes.

TABLE IV

DATA ON FUNGICIDAL CONTROL OF *G. JUNIPERI-VIRGINIANAE* ON THE WEALTHY APPLE

Sulphur spray	Total leaves examined	Number of infected leaves	Total number of lesions	Number of lesions per leaf of total foliage examined	Reduction of rust on total foliage examined
Check (unsprayed)	723	223 (30.8%)	2214	3.06	——
Flotation	1109	152 (13.7%)	409	0.37	88%
Linco	998	79 (7.9%)	226	0.23	93%
Liquid Lime	760	33 (4.3%)	99	0.13	96%
Nova Scotia	569	43 (7.6%)	104	0.18	94%
Nova Scotia (less 1 spray)	511	22 (4.3%)	39	0.08	97%

Note: The data for the two trees sprayed with the Nova Scotia formula have been kept separate. Through error one tree was not sprayed on May 16. However, no rains had occurred, sufficient for basidiospore dispersal, between May 16 and the following spray application. Consequently, the omission of this spray should make no difference in the results obtained.

Records of the control obtained by this series of spray programs were collected in May 1936, following a rainy period when the galls had gelatinized and could be counted easily. Counts were made of the number of galls on each of the sprayed trees and on four unsprayed trees selected at random. In Table V may be found data on the results obtained. A comparison of the number of galls on sprayed and on unsprayed trees revealed better than ninety per cent control. This degree of control is evident throughout the entire series of spray programs. Any differences in the degree of control obtained cannot be attributed to either the particular sulphur used or the time interval of spray application. Moreover, the spray schedule which extended from the time of the initial discharge of aeciospores until the last of October gave as good control as the schedule which continued until the first of December. Such variations as do occur in the degree of control obtained may be attributed to differences in thoroughness of spraying. As in the spray experiments on the apple trees, the sulphurs were applied by means of a hand-pump sprayer.

RECORDS OF THE CONTROL OBTAINED IN COMMERCIAL AND ORNAMENTAL PLANTINGS BY MEANS OF A COLLOIDAL SULPHUR

During the past five years extensive spray programs have been conducted, using a colloidal sulphur, for the control of the Gymnosporangium rusts on their respective alternate hosts. The spraying was done on commercial and ornamental plantings in the vicinity of Boston, Massachusetts. In all cases Linco Colloidal sulphur was used in the proportion of 6 lbs. to 100 gallons of water. The "S. S. S." sticker and spreader (See Table I) was added in the proportion of 2 lbs. to 100 gallons of spray. Most of the spraying was done with a power sprayer.

In certain instances trees were left unsprayed and served as checks to indicate the degree of control obtained. Some of these instances are now recorded to illustrate the effectiveness of using a sulphur fungicide to control the Gymnosporangium rusts.

A. Control of G. Juniperi-virginianae on apples

The Apple Scab Schedule as recommended by the Massachusetts State Agricultural Experiment Station was followed while spraying a number of orchards. McIntosh, Wealthy and Ben Davis apples predominated in these orchards. During the latter part of the season, counts were made of the number of foliar lesions on approximately five hundred leaves taken as random samples from various sprayed branches in each

TABLE V

DATA ON FUNGICIDAL CONTROL OF *G. JUNIPERI-VIRGINIANAE* ON THE RED CEDAR

SULPHUR SPRAY	TIME INTERVALS OF SPRAY APPLICATION													
	One week				Two weeks				Three weeks				Four weeks			
	Series A*		Series B		Series A		Series B		Series A		Series B		Series A		Series B	
	No. galls	Control %	No. galls	Control %	No. galls	Control %	No. galls	Control %	No. galls	Control %	No. galls	Control %	No. galls	Control %	No. galls	Control %
Flotation	0	100	3	98	4	98	0	100	1	99	2	99	11	94	9	95
Linco	3	98	–**	—	9	95	1	99	6	97	7	96	4	98	4	98
Liquid Lime	1	99	1	99	1	99	1	99	2	99	0	100	5	97	–	—
Nova Scotia	0	100	0	100	2	99	1	99	0	100	2	99	2	99	5	97

The number of galls on four unsprayed trees was 90; 139; 240; 300, respectively.

By control is meant the percentage reduction in the number of galls on the sprayed trees as compared with the number on the unsprayed trees.

*The A series of trees were sprayed from July 25 to October 31; the B series from July 25 to December 1, 1934.
**In two cases the trees were removed and data could not be obtained.

of the orchards. Similar samples from adjacent and unsprayed McIntosh trees were also taken and served for check purposes. The results of the counts were indicative of better than ninety-five per cent reduction in the number of foliar lesions. The effect of the control obtained was clearly visible in the much healthier foliage and the production of a better quality and a larger quantity of fruits on the sprayed trees.

B. Control of G. Juniperi-virginianae on red cedars

Several groups of red cedars in various localities have been sprayed during the past five years. Prior to this spray program the trees had exhibited severe infection by the rust. For the first two years the spray was applied at monthly intervals during July, August and September. The schedules for the next three years was changed to three sprays at three week intervals beginning early in July. Due to the long time interval for the development of the rust, the results of this spray program are available for the first three years only. An average of one to four galls of the rust per tree was all that could be found and these infections were easily removed by hand picking. Neighboring unsprayed trees continued to exhibit large numbers of the galls.

C. Control of G. clavipes on pomaceous hosts

Gymnosporangium clavipes is primarily a fruit parasite on its pomaceous hosts. The period of susceptibility of the fruits is confined to the early stage of their development. Ornamental plantings of *Amelanchier* and *Crataegus* were sprayed for the control of this rust. Three applications gave the best and the most consistent results. The first application was made when the blossom buds were opening. The second and third applications were made at weekly intervals. On species of *Amelanchier*, as high as ninety-eight per cent of the fruits remained free from infection while ninety-five per cent of the fruits on unsprayed nearby plants were infected by the rust. On species of *Crataegus*, a comparison with neighboring unsprayed trees showed a reduction of approximately eighty per cent in the number of infected fruit.

D. Control of G. clavipes on red cedars and on common junipers (Juniperus communis)

The number of spray applications to red cedars and common junipers was determined by the length of time over which aeciospores are discharged from diseased fruits of the respective alternate hosts. The period of discharge of aeciospores from diseased Amelanchier species normally begins in late May and continues until early July when the fruits drop. On the other hand, diseased fruit of species of *Crataegus*

will remain on the tree until late fall. Moreover, aeciospores have been found on diseased hawthorn fruit throughout the season.

A number of plantings of red cedars and common junipers were sprayed over a period of five years to control *G. clavipes*. These plants had all shown heavy infections by the rust. In one instance the owner had contemplated their complete removal. In localities where diseased Amelanchier species were the source of inoculum, the initial spray application was made the latter part of May. Spraying was continued at three week intervals on the common juniper, and at three to four week intervals on the red cedar, until early in July. New infections were reduced to one to four lesions per sprayed tree and at the end of the five year spray program practically all of the old perennial infections had died. In localities where diseased Crataegus fruits were the source of inoculum, spray applications were made at three week intervals from the time of the initial discharge of the aeciospores, namely, the latter part of May, until the hawthorn fruits had dropped in the fall. A comparison of the number of lesions formed on branches of the sprayed and of neighboring unsprayed trees indicated better than seventy-five per cent control.

RECOMMENDATIONS FOR FUNGICIDAL CONTROL OF THE GYMNOSPORANGIUM RUSTS

A. Selection of fungicide

The results of the investigations presented in this paper indicate that at least certain of the sulphur fungicides may be used effectively to control the Gymnosporangium rusts on any of their respective alternate hosts. The finer sulphurs proved to be the more efficient. Linco Colloidal, Liquid Lime, the Nova Scotia formula and possibly Flotation (See Table I) gave satisfactory control for the particular rusts against which they were tested. The addition of a sticker and spreader is recommended.

B. Determinant factors in the formulation of the spray schedules

The time of year for spray application

The date of initial spraying, as well as the length of time over which spray applications must be made are determined by two factors, (1) the period of time during which the respective hosts are susceptible and (2) the period of time over which the spores are dispersed from diseased alternate hosts. For a large proportion of the pomaceous hosts the period of susceptibility of the foliage is restricted to approximately two

months after the leaves develop (Crowell, 1934) (MacLachlan, 1935a). Certain species of *Malus,* however, have been found to be susceptible to *G. Juniperi-virginianae* throughout the growing season (Crowell, 1934). The fruits of *Amelanchier* and *Crataegus* are resistant to *G. clavipes* one month after the blossoms open (Crowell, 1935). It is possible that Juniperus hosts are susceptible to these rusts throughout the period of dispersal of the aeciospores.

The basidiospores of these rusts are the source of infection on the respective pomaceous hosts. These spores are dispersed during or following rainy periods in the spring and are capable of causing infection immediately. Under normal conditions their initial release takes place during the latter part of April which is shortly before the leaves or fruit have appeared on the pomaceous hosts. Depending upon the number of rains, most of the teliospores will have germinated by the middle of June. In some instances ungerminated teliospores of *G. Juniperi-virginianae* have been found on the galls in July. It is doubtful, however, that such spores give rise to a sufficient degree of infection to be worthy of consideration; the foliage and fruit of most of the pomaceous hosts are resistant to infection by this late period.

The aeciospores of these rusts are the source of infection on the Juniperus hosts. These spores are dispersed during the summer and, unlike the basidiospores, their dispersal is not dependent upon periods of rainfall. The time of their dispersal varies with the different rusts and in some cases with the pomaceous hosts attacked. The aeciospores of *G. clavipes* are dispersed from diseased Amelanchier fruit from late May until the middle of July at which time the infected fruit drop and decay. Crataegus fruits, infected by *G. clavipes,* do not drop until autumn and a certain number of aeciospores may be found on these diseased fruits throughout the season. The initial release of the aeciospores of *G. Juniperi-virginianae* takes place early in July; those of *G. globosum* two or three weeks later. Aeciospores of both of the latter rusts may be found on the diseased organs of their respective pomaceous hosts throughout the summer.

The greater proportion of the aeciospores of all the rusts are dispersed within the first few weeks after their formation. A high percentage of the aeciospores of *G. clavipes* will germinate at the time of their release from the aecia. It is possible, then, that the greatest amount of infection of the Juniperus hosts by this rust takes place in June. A very low percentage of the aeciospores of *G. Juniperi-virginianae* and *G. globosum* will germinate at the time of their release from the aecia (Crowell, 1934) (MacLachlan, 1936). If, however, the aeciospores of *G. globosum* are

kept for about six weeks at a temperature of 0°C., better than eighty per cent germination may be obtained. It is possible, then, that a large proportion of the Juniperus hosts are infected by *G. Juniperi-virginianae* and *G. globosum* at two rather distinct periods: (1) immediately after the aeciospores are released when low percentages of the spores germinate but spores are in great abundance and (2) later in the season by the aeciospores which required a dormant period prior to their germination but remained on the Juniperus foliage during this time interval.

The time interval between spray applications

The time interval between spray applications to the broad-leaved hosts is necessarily short. Fine sulphur volatilizes when exposed to wind and sunlight on broad-leaved foliage. Moreover, the leaves of such plants are most susceptible to the Gymnosporangium rusts during their period of rapid expansion (MacLachlan, 1935a). This period usually coincides with the time of active dispersal of the basidiospores. Consistent control of the Gymnosporangium rusts on their respective pomaceous hosts will not be obtained if the time interval between spray applications exceeds seven to ten days. A number of instances could be cited where control was not obtained although the correct number of spray applications was made. In each case an analysis of the spray schedule showed that a time interval of more than ten days had occurred in one or more instances between consecutive spray applications. Since the basidiospores of these rusts are dispersed during rainy periods, the time intervals between spray applications should be governed somewhat by the weather. The time interval between the formation of the basidiospores and infection of the pomaceous host is usually a matter of hours. Under cool moist conditions, the basidiospores may live for several days but they are subject to desiccation and are readily killed by high temperatures (MacLachlan, 1935b). The optimum time for spray application to the pomaceous host is immediately before a rainy period.

Longer intervals between spray applications may be employed with safety when spraying the Juniperus hosts. The germ tubes of the aeciospores can penetrate the leaves of the red cedar on the upper and stomatal surfaces only. The imbricated arrangement of the leaves is such that the sulphur is retained for relatively long periods of time within the axil formed by the upper surface of the leaf and the stem to which the leaf is attached. Examination of sprayed red cedars revealed that particles of the spray ingredient were still present, in the axils formed by the leaves, six months after the last spray application. Satisfactory control of the Gymnosporangium rusts may be obtained when the spray is applied at time intervals of three to four weeks.

C. Spray schedules for the control of three Gymnosporangium rusts

The spray schedules have been based on the conditions as they exist in Massachusetts with respect to host and fungus.

1. Control of *G. Juniperi-virginianae* and *G. globosum.*

On pomaceous hosts. Six applications at seven to ten day intervals. The first application should be made prior to the first rain after the young leaves emerge from the buds. The apple scab schedule will give satisfactory control under the condition that no time interval between spray applications exceeds seven to ten days. If there are not sufficient rains during May to gelatinize the telia on infected red cedars and thereby cause most of the teliospores to germinate, it may be necessary to add one extra application to the spray schedule.

On Juniperus hosts. Four applications at three to four week intervals. The first application should be made prior to the initial discharge of the aeciospores, namely, about the middle of July for *G. Juniperi-virginianae* and about the first of August for *G. globosum.*

2. Control of *G. clavipes*

On pomaceous hosts. Three applications at seven to ten day intervals. The first application should be made when the blossom buds are opening. The schedule should be arranged to avoid spraying during pollination.

On Juniperus hosts. The first application should be made during the latter part of May and continued at three to four week intervals. If diseased *Amelanchier* species are the source of the aeciospores the final spray may be made early in July. If diseased *Crataegus* species are the source of the aeciospores, spraying should be continued until September.

SUMMARY

A sulphur fungicide, in contact with viable basidiospores of a Gymnosporangium rust, has little effect on these spores prior to their germination. Moreover the sulphur particles must be in close proximity to the germinating basidiospores to have a toxic effect.

An efficient sulphur for the control of the Gymnosporangium rusts should contain particles of active ingredients whose sizes vary from colloidal to a size that would not be completely volatilized by the time of the next spray application.

From an experiment presented in this paper and from previous investi-

gations it has been concluded that the most efficient of the sulphurs tested would not protect the foliage of the pomaceous hosts for a time interval of more than seven to ten days between spray applications.

Field tests for the control of *G. Juniperi-virginianae* on the Wealthy apple and on the red cedar were made. Four different sulphur fungicides were used. Better than ninety per cent control of this rust was obtained on both of the alternate hosts.

Extensive spray programs, using a colloidal sulphur, have been conducted with successful results in commercial and ornamental plantings for the control of three Gymnosporangium rusts.

Spray schedules for the control of *G. Juniperi-virginianae, G. globosum,* and *G. clavipes* on their respective alternate hosts are presented.

ACKNOWLEDGMENTS

To Professor J. H. Faull, for his guidance and many helpful suggestions, sincere appreciation is expressed.

The writers also wish to thank Dr. E. F. Guba for assistance in making photomicrographs of the sulphur fungicides; Mr. C. Gilgut for assistance in conducting field tests and in the compilation of data; and members of the planting community on whose properties field tests were made.

LITERATURE CITED

CROWELL, I. H. (1934). The hosts, life history and control of the cedar-apple rust fungus Gymnosporangium Juniperi-virginianae Schw. (Jour. Arnold Arb. **15**: 163–232.)

——— (1935). The hosts, life history and control of Gymnosporangium clavipes C. and P. (Jour. Arnold Arb. **16**: 367–410.)

MACLACHLAN, J. D. (1935a). The hosts of Gymnosporangium globosum Farl. and their relative susceptibility. (Jour. Arnold Arb. **16**: 98–142.)

——— (1935b). The dispersal of viable basidiospores of the Gymnosporangium rusts. (Jour. Arnold Arb. **16**: 411–422.)

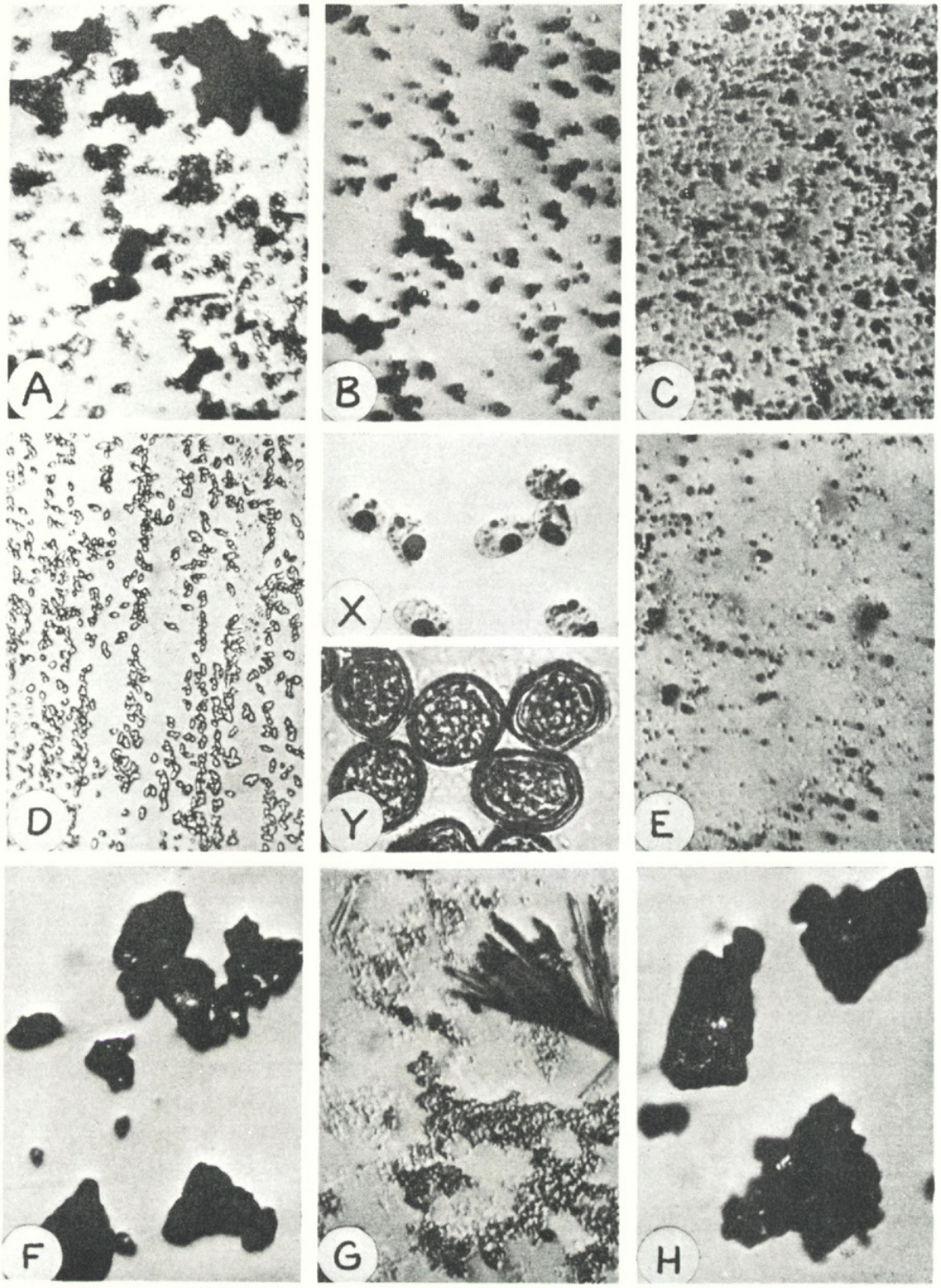
——— (1936). Studies on the biology of Gymnosporangium globosum Farl. (Jour. Arnold Arb. **17**: 1–25.)

WILCOXON, F. and S. E. A. MCCALLAN (1931). The fungicidal action of sulphur. III. Physical factors affecting the efficiency of dusts. (Contrib. Boyce Thompson Inst. **3**: 509–528.)

EXPLANATION OF PLATE 204

Illustration of the relative particle size of the ingredients of certain sulphurs

The sulphurs were made up according to the schedule given in Table I of the text. No spreader or sticker was added. The respective mixtures were sprayed on glass slides by means of atomizers, allowed to dry, then photographed. The illustrations show the ingredients of the sprays at a



GYMNOSPORANGIUM CONTROL BY SULPHUR SPRAYS

FULL-TONE — MERIDEN

magnification of 545 diameters. The respective sulphurs are indicated as A – Dry Lime, B – Flotation, C – Kolofog, D – Liquid Lime, E – Linco Colloidal, F – Magnetic Wettable, G – The Nova Scotia formula, and H – Sublimated. Magnetic Wettable is approximately 70% bentonite clay. Some of the finer particles of the Linco Colloidal are barely visible in the Figure. Clusters of crystals were visible on the slide that was sprayed with the Nova Scotia formula. One half of one crystal is illustrated. These crystals disappeared on spraying the slide with water. In the center of the Plate are shown photographs of the basidiospores (X) and the aeciospores (Y) of *G. globosum*. These spores are also illustrated at a magnification of 545 diameters.

Laboratory of Plant Pathology,
Arnold Arboretum, Harvard University.