THE EFFECT OF SURFACE FILMS AND DUSTS ON THE RATE OF TRANSPIRATION

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The fungicides commonly employed are either in the form of solutions (e. g., ammoniacal copper carbonate), suspensions (lime wash and Bordeaux mixture), and powders (sulphur). The use of spray mixtures or other fungicides has become world wide, and many problems of physiological interest have arisen respecting the effects of these substances on the plants which they are designed to protect. Bordeaux mixture has been under continuous observation for a period of about twenty years, and has proved interesting in both its toxic and other relations. The striking influence of this fungicide upon sound plants has awakened widespread interest, and numerous experiments have been made to determine the nature of the effects. Bordeaux mixture consists essentially of suspension films of copper hydroxid and certain other complex (mostly hydrated), largely insoluble, copper compounds; and when properly sprayed upon plant surfaces from the best nozzles, the particles are of extreme fineness, and there is realized an almost perfect surface film. In spite of the greatest care in preparation and application, it is injurious to certain plants, such as the peach and the plum, and may not be used satisfactorily in such cases for disease control. In recent years it has been shown that the extent of the injury to the apple and other plants may be considerable, and Bordeaux mixture is in such cases being supplanted. In this discussion, however, we may omit any detailed consideration of the toxic effects of this mixture, a phase of the subject which has received much consideration in this country from Bain (2), Crandall (6), Clark

(4), Swingle (21), and others. Moreover, with the exception of incidental references, we wish to deal at this time only with its physiological action in prolonging the vitality of leaves and plants.

During the first years of the use of this spray mixture it was natural that any increased vitality of the sprayed plants would be attributed merely to the action of the fungicide in restraining fungous or insect pests. Indeed, we find no authentic suggestion of any other effect than that mentioned for eight or ten years after the discovery of this fungicide. Since 1892 there have been frequent observations indicating beyond any reasonable doubt that in the absence of all disease-producing organisms there is often prolonged vitality of the sprayed plants as contrasted with the unsprayed. The increased longevity is particularly noticeable in plants like the potato, in which, under normal conditions, the foliage frequently dies in advance of the first killing frost. Nevertheless, lengthened life in leaves of deciduous trees, notably of the apple, has likewise been reported. It is not always possible to state definitely to just what extent any apparent increased vitality is to be attributed to the physiological action of the fungicide rather than to the control of pests, and it must be said that the frequency of the phenomenon and the reliability of the observers alone preclude the possibility of constant errors in this matter.

In practical field experimentation the most significant differences in yield and vitality as a result of spraying with Bordeaux mixture have been evident in the case of the potato, and with this crop it is a matter of common observation both in Europe and America. In recent years the consecutive reports on potato spraying by F. C. Stewart (19) and his associates at Geneva, New York, suggest in a decisive way the probable magnitude of the Bordeaux influence when disease is a minor factor. In general, observers are perhaps liberal in their estimates of the gain from fungous suppression.

It will be pertinent to note a few observations and comments from the reports of the work done at Geneva. In 1904 the increase in yield from spraying potatoes five times was 233 bushels per acre. "Spraying prolonged the life of the plants 25 days. Late blight was the only trouble." In his experiments of 1906 Stewart notes an increase in yield of 63 bushels per acre due to spraying five times. He remarks: "Late blight, early blight, flea beetles and tip burn were all factors in this experiment, but none of them caused much damage." More striking were the results the following year when an increase in yield of $73\frac{2}{3}$ bushels per acre was obtained from spraying five times. In this case it is reported: "Late blight and rot were wholly absent and early blight appeared only in traces. There was some tip burn and a light attack of flea beetles. Considering the seemingly small amount of damage done by blight and insects, it is remarkable that spraying should have increased the yield so much." In 1909 the increase in yield in spraying six times was $49\frac{3}{4}$ bushels per acre, and the comment upon this result is as follows: "Early blight, late blight and rot were all absent. Some injury from flea beetles was noticeable throughout the season. After September 1 there was considerable tip burn. As late as September 24 the difference between sprayed and unsprayed rows appeared slight. The sprayed rows held most of their foliage until killed by frost on October 14."

The senior author of this report visited the experimental plats which afforded these data in late September, 1911, prior to the killing frosts of October 27, and the contrast between the sprayed and unsprayed rows was pronounced; at the same time there was very little evidence of any disease on the unsprayed plats. Regarding the condition of the plants Stewart says: "There was no late blight whatever, only a very little early blight, and very little flea beetle injury. The unsprayed rows were affected by no disease of any consequence except tip burn, and even of that there was only a moderate amount. As the plants were still partially alive twenty weeks after planting it is clear that they could not have been very much injured by anything. Yet spraying increased the yield at the rate of 93 bushels per acre. Plainly we have here a striking example of the beneficial influence of Bordeaux in the absence of diseases and insect enemies."

Examining the comments of these and of other investigators regarding increased vitality as a result of spraying with Bordeaux, we find that where the condition of the plant is well defined at the close of the season, or at the time of the first killing frost, the sprayed plants are almost invariably more vigorous. Often, in the practical absence of any disease, sprayed plants may remain healthy until killed by frost, while unsprayed plants may have died from a few days to a few weeks in advance of frost.

Following a recital of notable increases of yield in Connecticut as a result of spraying potatoes with Bordeaux, Clinton (5) expresses the conviction that an explanation must be found in the conservation of water. His statement follows:

"The question naturally comes up, why did the sprayed potatoes give this increased yield over the unsprayed if there was no particular injury caused by the late blight fungus? Some little benefit was no doubt derived from the prevention of the early blight, but this must have been scarcely appreciable because this fungus was not at all conspicuous these years. Again, some very small benefit may have been due to lessening insect attack, since potatoes sprayed with both Bordeaux and Paris green keep off the insects somewhat better than where sprayed only with Paris green. This is especially true as regards the potato flea beetle. But here again the gain was of a very minor kind. Ordinarily botanists have explained this increase as due to some stimulative effect the Bordeaux mixture has on the chlorophyll of the potato leaves in increasing starch production. Personally, the writer believes that the results are largely due to *conservation of moisture in the leaves in dry seasons by clogging up the stomata and water pores with the sediment of the spray.* The reasons for this belief are (1) that the potato leaves, through their numerous stomata and terminal water pores, lose water very easily, and are especially susceptible to what is known as tip burn in dry seasons; (2) that the unsprayed vines uniformly suffered earlier and more severely from tip burn than the sprayed, which were green for about two weeks after the unsprayed were dead; (3) that in 1910, which was a season like the preceding years, except with a little injury from blight at the very end of the season, spraying with 'Sulphocide' and commercial lime-sulphur, sprays with comparatively little sediment, did not prolong the life of the vines or give increased yield, while spraying with Bordeaux mixture did."

Although this theoretical explanation did not come to our attention until the experimental work reported in this paper was complete, it was, in modified form, the only possible opinion which we felt inclined to advocate, as a clue to the increased longevity caused by Bordeaux, until the contrary evidence yielded by our experiments.

Review of Literature

The experimental work undertaken in the past to determine the nature of the Bordeaux influence (apart from direct injury) has touched mainly upon (1) questions of increased photosynthesis due either to "stimulation" of chloroplastid or chlorophyll development, or to a direct influence upon light quality; (2) changes in the respiratory rate, or surmised effects upon metabolism; and (3) a modification of the normal rate of transpiration. A few observations from the extensive literature with particular reference to its bearing on transpiration may be cited.

Rumm (16) finds that in sprayed grapes the chlorophyll content of the leaves increases and the fruit ripens earlier with a higher sugar percentage. He attributed these phenomena to the higher "assimilatory activity," and in turn relates this to the following observation on transpiration:—that abscised, sprayed twigs remain fresh longer than those unsprayed, from which it is deduced that there is a falling off in transpiration as a result of spraying. Through independent observations made during the same year, Müller-Thurgau (15) and Bayer (3) subscribe to the view that lessened transpiration follows spraying. Moreover, this confirmation of Rumm is obtained by the former through an experiment which also proclaims that the reduction in transpiration as a result of spraying may be as much as forty per cent. Nevertheless, the report referred to is extremely brief and does not indicate clearly the condition of the plants during the period of observation, a matter most important in the final interpretation of the data afforded.

Frank and Krüger (9, 10) reported some rather extensive quantitative experiments as a result of which they conclude, contrary to Rumm, that transpiration is accelerated by spraying. They state that sprayed leaves are in general more robust, thicker and stiffer. They also report an increased yield in pot experiments from spraying. All these indications, as well as those of Leydheker (13) and others (1, 12) denote differences of yield which are so slight as to be of no fundamental importance in the present consideration. Nevertheless, the transpiration data of Frank and Krüger, as already observed, were obtained by satisfactory methods, and these are of greater interest when taken in conjunction with those of Zucker (22) who confirms their results entirely.

Schander (18) in an extensive paper reports a comparatively small amount of experimental work on transpiration, but in the cases given his results indicate a retardation of water loss after spraying. His experiments with cobalt paper were inconsistent, and twigs of *Taxus baccata* and potted bean plants were then employed, yielding the positive results noted. However, his work embraced very few plants, and the transpiration differences observed are inconsiderable. He suggests that lessened transpiration of sprayed plants is to be expected, since the Bordeaux mixture must exert a shading influence as a result of the exclusion from the leaf of certain injurious rays. He attempts to verify this assumption of partial shading by a study of leaf temperatures, but the experiments in this direction give no positive evidence for his theory. No adequate mention is made of the conditions surrounding these experiments, nor of the precautions observed.

Ewert's (8) experiments tend to substantiate the views of Rumm and Schander; but, unfortunately, the results are not satisfactory for accurate quantitative purposes, since evaporation from the pots was merely checked and not prevented,batting being employed to cover the soil surfaces. His experiments are of particular interest, however, with respect to his graph for comparative respiration in sprayed and unsprayed plants. In the sprayed plants, respiration was found to be distinctly lower than in the unsprayed. It will be noted, however, that this diminished respiration is scarcely in keeping with the observation of Rumm and others regarding the higher assimilatory activity in sprayed plants.

It is unnecessary in this report to review the considerable literature which has accumulated bearing on the question of increased starch formation as a result of the application of Bordeaux mixture, especially as it is proposed to discuss this phase of the subject in a later paper.

METHODS

As indicated in the title, the experimental work here reported is concerned merely with the transpiration of sprayed and unsprayed leaves or plants. Other effects of sprays and dusts may be communicated in subsequent reports. In general, the methods involved are modifications of customary practices.

The methods used were of two types, the experiments being carried out either by means of (1) leaves in burette potometers connected with side arm flasks, or (2) potted tomato plants.

Potometer Experiments.—After much preliminary experimentation with a view to determining suitable leaves or twigs for potometer work, leaves of the castor bean were selected. Some of the preliminary experiments with other leaves are of interest, however, and will be referred to subsequently. Castor bean (*Ricinus communis*) leaves offer some special advantages, especially (1) large surfaces, (2) resistance towards Bordeaux mixture, and (3) prolonged vitality after abscision.

The burettes were connected with the side arm flasks, as indicated in plate 1, and the flasks completely filled with water. The petioles of the leaves were cemented into the mouths of the flasks by means of "plastolina." If a ring of this plastic substance is placed around the mouth of the flask when the glass is dry and a ball of the same material, larger than the mouth of the flask, is carefully attached around the petiole, then the petiole and plastolina may be plunged into the mouth of the flask and the two masses unite in a manner such as to give a perfectly air-proof, water-tight connection. It has been found desirable, for purposes of safety, to put on a second layer of the plastolina as soon as it is evident that the first permits no leakage. Even with these precautions, considerable diurnal changes in temperature may cause leakage, and it is particularly important that each experiment should be carefully examined prior to making all readings. The water columns in the burettes were so gauged as to eliminate the possibility of forcing water into the leaves. The burettes were employed solely in order to get accurate readings of the water loss from hour to hour without shifting or disturbing the plants by weighing; also rapidly to get data, should it seem necessary, under changing conditions. All of these considerations proved very important, as it was found that a slight shifting of the position of the leaf affected materially the transpiration magnitudes.

For each leaf used it was necessary to get its rate of transpiration in terms of some standard in order that the ratios might be established between certain leaves prior to the addition of the spray to some of them and the ratio between the same leaves after the application. At one time it seemed possible that the revolving table method of standardizing porous cups might be applicable, but on further consideration it was believed that the use of this method in the laboratory, and the subsequent disposition of the plants in the open, would lead to errors of considerable magnitude. For our purpose it was not considered desirable to conduct the whole experiment on the revolving table, but this method will be employed in connection with our further studies. It was found very important to standardize the leaf in a given position and then permit it to remain in that position, as far as possible, throughout the experiment. This method was necessary largely because of the fact that it seemed wise to conduct the experiment in the open, during a considerable interval, at least. Further reference to the arrangement of the plants will be made in the discussion of the experimental work.

Experiments with potted plants.—For the experiments with potted plants tomatoes were used. The pots were dipped in paraffin wax and the same sealing mixture was coated over the surface of the soil. In all the experiments reported there was no leakage in any case from improper sealing. Water was added daily, or twice a day, to supply the loss by transpiration, the addition of water being made by means of a thistle tube fixed in each pot. The bell of the thistle tube was covered with paraffined paper during the entire interval. It was also found necessary to insert in each pot a small bent tube in order to provide for the changes in air pressure.

The pots were weighed at the beginning and at the close of the experiment, but the condition of the plant and the amount of water entering readily from the thistle tube were found adequate to indicate the daily water requirements. To the total provisional transpiration quantities obtained from a summation of the quantities daily added, the differences in weight between the beginning and the close of the experiment were added or subtracted as required. From five to ten plants were employed with each kind of spray or dust used, and the plants of each lot were so distributed in the greenhouse that an equal number—so far as possible—from every group was subject to exactly the same influences. Moreover, positions in the greenhouse were shifted several times during the observation intervals of from ten days to two weeks. As a result of a large amount of experimental work in the greenhouse it has become apparent that the points just referred to are important. Plants situated nearer the edges of the benches, or those which receive drafts from opening doors or from convection currents, show considerable differences in transpiration rates, and this should be obviated.

The leaves in the potometer work and the potted plants were sprayed or dusted liberally, and in the case of the sprays, in particular, care was taken to cover completely with a fine spray of the material both surfaces of the leaves. The dust applications were made in the late afternoon when the leaf surfaces were less dry, and after dusting the upper surfaces of the leaves the plants were inverted and the lower surfaces equally well treated. The dusts were prepared by grinding to an impalpable powder in a mortar.

The Bordeaux mixture employed was made by the 4-6-50 formula, the weights of ingredients for making small quantities being approximately as follows:

$CuSO_4$	9.6 grams
CaO	14.4 grams
Water	1000 cc.

The weak Bordeaux was one-half the strength of the above. The $Ca(OH)_2$ was prepared by slaking gradually 60 grams of

CaO in 1 liter of water; and the mixture designated $Al(OH)_3$ was prepared by mixing two solutions each of 900 cc., the one containing 26 grams of $AlCl_3$ and the other 30 grams of CaO (slaked as for the Bordeaux mixture). The clay suspension consisted of 90 grams of fine air-dried clay in 1 liter of water. The lime-sulphur employed was the usual 1–25 strength.

EXPERIMENTAL DATA AND DISCUSSION

It will be observed from the brief review of earlier work that the evidence regarding the effect of Bordeaux mixture on the transpiration rate is inconsistent. A majority of the observers adopt the view that the effect of this surface film is to reduce the transpiration. On a priori grounds this view would seem to be logical, since it would indicate a water conservation to which, in dry seasons at least, the plant might respond with increased vitality and yield. Nevertheless, it was believed that the experimental evidence at hand was of insufficient scope to establish this view of it. Contrary to expectations, all of our more important experimental evidence and observations are antagonistic to the a priori assumption as applied to the effects of Bordeaux mixture.

Potometer experiments.—In attempting to secure leaves satisfactory for the work, some incidental observations were made which are of interest. The work was begun during the winter, so that greenhouse-grown plants alone were available. Furthermore, in this work with potometers, Bordeaux mixture alone has been used by us. Testing leaves of squash (*Cucurbita sp.*), *Pelargonium zonata*, and *Phytolacca*, also shoots of potato and *Irescene*, as to their behavior under the conditions required, it was found that of comparable leaves, sprayed and unsprayed, invariably the sprayed leaves were the first to wilt. This might be attributed either to an injurious action of the spray or to a greater water consumption. That the last mentioned is the more probable explanation finds confirmation through a special observation on the potato. Owing apparently to some stoppage of the vascular system, abscised potato shoots are unsuitable for potometer work, wilting in a comparatively short time even when cut under water; and sprayed potato shoots wilt more quickly than unsprayed, thus pointing to a more rapid water elimination after spraying. Potted potato plants from which the shoots were cut withstood the fungicide satisfactorily.

Leaves of the large elephant's ear (*Caladium sp.*) proved unsatisfactory on account of the excessive "bloom," which interfered with the proper application of the spray. Canna leaves were similarly unfavorable, and leaves of the calla lily wilt soon after abscision.

It has been stated above that the leaves of the castor bean proved most satisfactory in the potometer work. The experiments with these leaves were carried out in the open, except as otherwise noted, during the early fall. The plants were arranged for standardization and for subsequent observation at distances of about ten feet apart on an exposed lawn uniformly sodded. No readings were made until the leaves had become adjusted to the conditions. Observations were made at frequent intervals when the water loss was rapid, in order to maintain the water column at a fairly uniform level, so that many of the data given in the tables which follow represent summations of several successive readings. Three series of potometer experiments were made, each series embracing six leaves, but in one series, accidents to some of the leaves, and the necessity of substituting new ones after the experiment began, resulted in such a shortening of the standardization intervals that it was thought necessary to discard the results, although they were in the same direction as the others obtained.

The data are presented in full in the tables and all available data are used in computing the relations given. The relations may be more conveniently expressed if we first divide the leaves into classes, designated by letters, as follows:

$A-$, three leaves (i. e., the transpiration quantities of these) in the standardization interval before spraying.

$A+$, the same three leaves as in $A-$, but for any interval after spraying.

B, three control leaves (unsprayed throughout) during the standardization interval.

B', the control leaves as in B, after standardization.

The ratio $\frac{A-}{B}=Q$ is to be compared with the ratio $\frac{A+}{B'}=Q'$.

If Q' is greater than Q, then the spraying facilitates transpiration; if less, then the converse is true. If no accidents occurred during the experiments, $\frac{A-}{B}$ would, of course, be a constant quantity, each term referring properly to the summed transpiration quantities for three leaves during the standardization interval. Accidents are unavoidable, however, during the subsequent observations, and whenever these occur it is necessary to compute a new value of Q' for any particular "run" in which the accident occurs. The only consideration then is to have the same leaves (i. e., their summed transpiration quantities) in the ratios before and after standardization. If, for example, it is necessary to use a ratio, Q', of Nos. 1 and 3 to Nos. 2, 4, and 6 after spraying, then the new value of Q (in the standardization interval) for comparison must also be computed with Nos. 1 and 3 against Nos. 2, 4, and 6.

TABLE I

EFFECT OF FILMS OF BORDEAUX MIXTURE ON TRANSPIRATION OF STANDARDIZED CASTOR BEAN LEAVES; DATA FOR DAY PERIODS

No. of leaf	1	2	3	4	5	6	Ratio
Transp. 12:30–2:30 P. M., 1st day before spraying	$A-$ 10.8	B 17.3	$A-$ 28.5	B 45.9	B 33.8	$A-$ 33.6	$\frac{A-}{B}=\frac{72.9}{97.0}$
Transp. 3:12–5:00 P. M., 1st day after spraying	$A+$ 7.6	B' 20.4	$A+$ 23.2	B' 26.2	B' 26.1	$A+$ 39.5	$\frac{A+}{B'}=\frac{70.3}{72.7}$
Relation, sprayed to unsprayed, 1st day	Rate changed from $\frac{72.9}{97.0}$ (=.75) to $\frac{70.3}{72.7}$ (=.97)						
Transp. 8:12–9:48 A.M., 2nd day after spraying	$A+$ 10.2	B' 37.7	$A+$ 63.1	B' 32.3	B' 29.7	$A+$ 67.1	$\frac{A+}{B'}=\frac{140.4}{99.7}$
Relation, sprayed to unsprayed, 2nd day, *a*.	Rate changed from $\frac{72.9}{97.0}$ (=.75) to $\frac{140.4}{99.7}$ (=1.41)						
Transp. 11:16–11:53 A. M., 2nd day after spraying	$A+$ 4.9	B' 5.9	$A+$ 31.5	B' 13.8	B' 7.5	$A+$ 25.3	$\frac{A+}{B'}=\frac{61.7}{27.2}$
Relation, sprayed to unsprayed, 2nd day, *b*.	Rate changed from $\frac{72.9}{97.0}$ (=.75) to $\frac{61.7}{27.2}$ (=2.3)						

TABLE II

EFFECT OF BORDEAUX MIXTURE ON TRANSPIRATION OF STANDARDIZED CASTOR BEAN LEAVES; DATA FOR DAY AND NIGHT PERIODS

No. of leaf.	1	2	3	4	5	6	Ratio
Transp. 4:04–5:25 P. M., 1st day before spr.	*A*– 7.5	*B* 7.6	*A*– 10.9	*B* 11.7	*A*– 7.6	*B* 9.4	
Transp. 8:21–11:17 A. M., 2nd day before spr.	*A*– 20.2	*B* 30.7	*A*– 32.4	*B* 40.9	*A*– 23.3	*B* 17.9	
Total transp. before spr.	*A*– 27.7	*B* 38.3	*A*– 43.3	*B* 52.6	*A*– 29.9	*B* 27.3	$\frac{A-}{B}=\frac{101.9}{118.2}$
Transp. 12:30–4:50 P. M., 1st day after spr.	*A*+ 36.7	*B′* 42.6	*A*+ 62.9	*B′* 50.2	*A*+ 41.0	*B′* 30.2	$\frac{A+}{B'}=\frac{140.6}{123}$
Relation, sprayed to unsprayed, 1st day	Rates changed from $\frac{101.9}{125.2}$ (=.86) to $\frac{140.6}{123}$ (=1.14)						
Transp. 8:56 A. M., to 4:44 P. M., 2nd day aft. spr.	*A*+ 20.7	*B′* —	*A*+ 28.9	*B′* 18.2	*A*+ 17.0	*B′* 12.1	$\frac{A+}{B'}=\frac{66.6}{30.3}$
Relation, sprayed to unsprayed, 2nd day	Rates changed from $\frac{101.9}{79.9}$ (=1.28) to $\frac{66.6}{30.3}$ (=2.2)						
Transp. 10:27 A. M., to 3:40 P. M., 3rd day aft. spr.	*A*+ 8.4	*B′* —	*A*+ 11.2	*B′* 4.4	*A*+ 7.8	*B′* 3.5	$\frac{A+}{B'}=\frac{27.4}{7.9}$
Relation, sprayed to unsprayed, 3rd day	Rates changed from $\frac{101.9}{79.9}$ (=1.28) to $\frac{27.4}{7.9}$ (=3.46)						
Transp. 9:58 A. M., to 4:42 P.M., 4th day aft. spr.	*A*+ —	*B′* —	*A*+ 22.1	*B′* 14.1	*A*+ 15.3	*B′* 7.9	$\frac{A+}{B'}=\frac{37.4}{22.0}$
* Relation, sprayed to unsprayed, 4th day	Rates changed from $\frac{74.2}{79.9}$ (=.93) to $\frac{37.4}{22.0}$ (=1.7)						
Total transp. after spraying	— —	— —	*A*+ 125.1	*B′* 86.9	*A*+ 81.1	*B′* 53.7	$\frac{A+}{B'}=\frac{206.2}{140.6}$
Relation, sprayed to unsprayed, totals	Rates of totals changed from $\frac{74.2}{79.9}$ (=.93) to $\frac{206.2}{140.6}$ (=1.47)						
Transp. 5:30 P. M., to 8:21 A. M., 1st night bef. spr.	*A*– 6.9	*B* 6.3	*A*– 9.0	*B* 11.2	*A*– 6.4	*B* —	$\frac{A-}{B}=\frac{22.3}{17.5}$
Transp. 4:50 P. M., to 8:40 A. M., 1st night aft. spr.	*A*+ 6.9	*B′* 7.8	*A*+ 2.7	*B′* 7.5	*A*+ 6.2	*B′* 3.5	$\frac{A+}{B'}=\frac{15.8}{15.3}$
Relation, sprayed to unsprayed (night)	Rate changed from $\frac{22.3}{17.5}$ (=1.27) to $\frac{15.8}{15.3}$ (=1.03)						
Transp. 3:45 P. M., to 9:30 A. M., 2nd night aft. spr.	*A*+ 20.0	*B′* —	*A*+ 15.1	*B′* 4.9	*A*+ 5.8	*B′* 4.2	$\frac{A+}{B'}=\frac{40.9}{4.9}$
Relation, sprayed to unsprayed (night)	Rate changed from $\frac{22.3}{11.2}$ (=2.0) to $\frac{40.9}{4.9}$ (=8.34)						

* For this "run" the plants were transferred to a room in the building.

Summarizing the data for the rates in table II, day intervals, we find that $Q:Q'$, in the successive periods, as .86:1.14, as 1.28:2.2, as 1.28:3.46, and as .93:1.7. If we make the ratio before spraying equal in each case, to 1.0, then the value for the periods after spraying in the successive day intervals are respectively 1.33, 1.72, and 1.83. These differences in rate are so marked and consistent as to outweigh all considerations of individual differences, as disclosed by a detailed study of the figures in table II. It will also be noted that the less extensive data from table I are confirmatory; thus $Q:Q'$, in the successive intervals, as .75:.97, as .75:1.41, and as .75:2.3. On the basis of 1.0 for the ratio before spraying, we have for the periods after spraying, respectively, 1.29, 1.88, and 3.07. From the records of the potometer experiments it is obvious that only one conclusion may be drawn, namely, that the rate of transpiration is materially increased after spraying.

Some points relative to environmental conditions, however, require special mention, and certain suggestive results must be left for further experimental study. Attention has been drawn to the fact that, in general, the potometer experiments were conducted in the open, during early October. During the last days of the work, cooler weather and danger from rain made it desirable to transfer the potometers to a room in the building, and the data for the third and fourth days after spraying, table II, were secured under these new conditions. In this room the shades were drawn and every precaution taken to secure uniformity. It will be noted that while the order of results is in the same direction as for the lawn exposure, the ratio is even higher than the average. No "shading action" of the Bordeaux, as postulated by Schander (18), could be considered a factor of importance in this case.

The results in the laboratory suggest, further, that the ratio of sprayed to unsprayed will vary considerably with the conditions. Before removing the potometers to the laboratory, the night temperatures were so low that two night "runs" (including the interval from about 6 P. M. to 8 A. M.) were necessarily excluded on account of leakage. Other night "runs," as shown in the tables, indicate the probability that under certain conditions unfavorable for evaporation, the surface film may actually effect a diminution in the rate of transpiration, although the transpiration data do not suffice to warrant more, at present, than an impression. In fact, the night "runs" should be considered apart from those of the day, for the latter are much more satisfactory.

Experiments with potted plants.—The experiments with potted tomato plants were divided into two series which were consecutive in time, and different only with respect to the substances applied to the leaves. As far as has been ascertained, this is the first time that tomato plants have been used in such work, but in our experience they are more satisfactory than potatoes. In the first series (table III) 30 plants were used, in lots of 10 each, for the applications of (1) strong Bordeaux mixture, (2) weak Bordeaux, and (3) controls. In the second series (table IV, V) 80 plants were used in 8 lots, and the substances employed as sprays or dusts are noted in the tables. In the second series it is to be noted that there are 3 substances of the nature of films ($Ca(OH)_2$, $Al(OH)_3$, and lime-sulphur), 1 true suspension (clay), and 3 powders (charcoal, $CaCO_3$, and powdered $Al(OH)_3$).

The methods of procedure involved in these experiments have already been outlined. It is necessary to add, however, that the plants used were about 12 inches high and as uniform in size as could be obtained. It was not possible satisfactorily to standardize plants for an experiment extending over several weeks: and it was necessary to rely in part upon numbers, and in part upon a rigidly accurate method of selecting the individual in each lot to eliminate any errors. The method of selection consisted in getting together 8 plants so similar in size and vigor that no choice could be made between them, then distributing these at random to the 8 lots, this being continued until each lot embraced 10 plants.

In each case the experiments extend over 2 periods. At the close of the first period the plants were shifted in position and a second application of the spray mixture or dust was given. With the conclusion of the experiment the green weights of all plants were taken, thus enabling us to determine, in addition to the total transpiration quantities, the amount of transpiration per gram of green substance.

TABLE III

THE EFFECTS OF BORDEAUX MIXTURE ON THE RATE OF TRANSPIRATION; DATA IN GRAMS FOR 30 POTTED TOMATO PLANTS

	1st period Oct. 18 to Nov. 4		
Covering	Strong Bord.	Weak Bord.	Check
Plants nos.	1–10	11–20	21–30
Transpiration quantities	702	681	390
	684	651	555
	665	540	375
	630	585	525
	625	857	395
	710	440	465
	640	585	415
	445	648	365
	645	645	490
	560	....	545
Total	6306	5622	4520
Ave. per plant	630.6	625	452.0
	Second period Nov. 5–15		
Covering	Strong Bord.	Weak Bord.	Check
Plants nos.	1–10	11–20	21–30
Transpiration quantities	571	628	356
	559	549	554
	575	442	368
	574	603	518
	515	720	385
	740	453	420
	514	499	437
	570	534	417
	495	702	439
	546	....	564
Total	5659	5130	4458
Ave. per plant	565.9	570	445.8

TABLE III (*Continued*)

THE EFFECTS OF BORDEAUX MIXTURE ON THE RATE OF TRANSPIRATION; DATA IN GRAMS FOR 30 POTTED TOMATO PLANTS

Green wts. of plants used.

Plants nos.	1–10	11–20	21–30
Green weights in grams	55	80	49
	58	58	63
	51	41	46
	39	51	56
	50	60	39
	67	45	53
	46	40	48
	46	53	40
	39	74	48
	49	..	55
Total	500	502	497
Ave. per plant	50.0	55.8	49.7

TABLE IV

THE EFFECT OF VARIOUS SPRAYS AND DUSTS ON THE RATE OF TRANSPIRATION; DATA IN GRAMS FOR 80 POTTED TOMATO PLANTS. 1ST PERIOD, OCT. 25 TO NOV. 8

Covering	$Ca(OH)_2$	$Al(OH)_3$	Clay	$Al(OH)_3$ pwd.	Char-coal	$CaCO_3$	Lime-sulfur 1–25	Check
Plants nos.	30–39	40–49	50–59	60–69	70–79	80–89	100–109	90–99
Transpiration quantities	431	394	345	416	378	436	508	352
	437	370	333	370	460	353	414	323
	435	386	430	393	374	315	474	461
	411	383	383	383	460	510	354	443
	358	329	347	645	273	375	526	490
	372	377	520	449	467	346	421	309
	314	398	437	365	320	471	352	330
	416	410	560	531	359	361	346	323
	375	517	362	408	386	456	285	343
	485	460	452	412	331	364	402	317
Totals	4034	4024	4169	4372	3808	3987	4082	3691
Ave. per plant	403.4	402.4	416.9	437.2	380.8	398.7	408.2	369.1

TABLE V

THE EFFECTS OF VARIOUS SPRAYS AND DUSTS ON THE RATE OF TRANSPIRATION; DATA IN GRAMS FOR 80 POTTED TOMATO PLANTS. 2ND PERIOD, OCT. 25 TO NOV. 8.

Covering	$Ca(OH)_2$	$Al(OH)_3$	Clay	$Al(OH)_3$ pwd.	Char-coal	$CaCO_3$	Lime-sulfur 1–25	Check
Plants nos.	30–39	40–49	50–59	60–69	70–79	80–89	100–109	90–99
Transpiration quantities	494	812	624	665	573	560	846	590
	463	587	582	601	610	543	641	569
	592	653	693	609	530	553	667	564
	539	587	615	654	744	700	622	701
	604	654	594	754	556	512	680	764
	457	614	579	606	617	552	616	546
	544	665	694	476	569	706	604	496
	647	605	753	704	664	585	478	558
	597	806	579	641	596	620	601	514
	582	810	590	711	562	617	428	601
Totals	5509	6793	6303	6421	6021	5948	6183	5903
Ave.	550.9	679.3	630.3	642.1	602.1	594.8	618.3	590.3
*Transp. per gm.	11.8	12.2	12.3	11.4	13.1	12.0	12.8	12.1

Green wts. of plants 30–109 at close of 2nd period.

Green weights in grams	39	71	46	58	49	50	56	58
	39	43	47	52	43	47	51	47
	49	58	51	45	48	43	42	38
	42	53	49	79	35	53	53	57
	60	56	54	77	35	53	67	53
	43	56	58	47	59	51	40	56
	41	53	52	47	46	57	52	35
	50	55	50	54	48	47	36	46
	60	58	48	47	52	43	49	46
	43	54	59	55	43	51	39	51
Totals	466	557	514	561	458	495	485	487
Ave. per plant	46.6	55.7	51.4	56.1	45.8	49.5	48.5	48.7

* Computed on the basis of green weights at the close of second period.

An examination of the data in the several tables involved in the pot experiments serve to indicate that while there is a certain amount of individual variation in the transpiration quantities of the various plants in any group, general conclusions seem to be warranted. The individual variations in transpiration in the Bordeaux series are in closer accord with the variations in green weight of the plants used than are those in the other series. Taking all factors into consideration, a film of Bordeaux mixture is found to facilitate transpiration. Other films and dusts employed do not seem to affect the rate of transpiration to the same extent.

In a consideration of the results in detail it is to be noted that the Bordeaux series (table III) is not strictly comparable with the other (tables IV, V), since they were not conducted simultaneously. If the transpiration in grams per gram of green weight for the control (Bordeaux series) is represented by 100, then the rate for weak Bordeaux on this basis is 113.2, and the rate for strong Bordeaux is 125.43. The differences are in the same direction, but not so great as those obtained with the potometer experiments. The use of both weak and strong Bordeaux mixture materially strengthens the conclusions to be deduced.

The series which gives the results with other sprays and dusts is not so easily interpreted. The transpiration quantities vary slightly on either side of the control, and no covering gives a negative difference (contrasted with the control) greater than six per cent (this is the case of $Al(OH)_3$), or a positive difference greater than about eight per cent (charcoal).

These slight average differences may be no more than would be explained by the possible experimental error; but it is of interest to perceive that, with the exception of clay, those surface applications which give lower values than the control are those which might diminish the absorption of heat in direct sunshine. The results might then be the resultant of two factors, (1) the direct effect of the surface film or dust on the rate of water loss, and (2) the indirect effect exerted through a modification of the temperature of the leaf.

Accepting as a general conclusion an acceleration of transpiration (specifically in the castor bean and in the tomato) as a result of an application of a film of Bordeaux mixture, the following questions arise: (1) What is the physical or chemical basis of the increased evaporation from plant surfaces covered with Bordeaux mixture? (2) Is the increased evaporation in any way related to the increased vitality or longevity of sprayed leaves? Neither of these questions may be answered intelligently at present. With respect to the first, we have arranged experiments to determine the effects of Bordeaux on the passage of water vapor through non-living membranes; but the results are thus far conflicting, due possibly to the fact that we have not yet used membranes which are satisfactory analogues of leaves. Experiments in this direction will be reported later. No relation of transpiration to increased longevity can be foretold, although it seems possible that the highest efficiency equilibrium relation of longevity may involve, in certain plants, a relatively high transpiration rate as either a direct or an indirect factor. No answer to the question will be satisfactory until a further study of other effects ("stimulation," increased "assimilatory activity," etc.) of Bordeaux mixture shall have been made.

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