CAUSE AND CONTROL OF BORDEAUX INJURY.

SUMMARIZED BY
F. H. HALL
FROM BULLETIN BY
U. P. HEDRICK

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F. H. HALL.

Bordeaux mixture is, without question, the fruit grower's most valuable aid in the struggle against plant diseases. For the apple grower, in particular, it is invaluable; for it has been, and must continue to be until something better is discovered, the specific for scab; and to neglect its use in seasons favorable to this disease will cause great financial loss.

Yet Bordeaux is not a perfect application for use in the apple orchard; since it has been known for many years that, under some conditions, the mixture itself may cause injury. Some horticulturists and investigators refuse to recognize bordeaux injury as such and claim that "spray injury" is due to improper preparation of the mixture. They hold that properly made bordeaux with sufficient lime to neutralize the acidity, is

*This is a brief review of Bulletin No. 287 of this Station, on Bordeaux Injury, by U. P. Hedrick. Any one especially interested in the detailed account of the investigations will be furnished, on application, with a copy of the complete bulletin. The names of those who so request will be placed upon the Station mailing list to receive future bulletins, popular or complete, as desired. Bulletins are issued at irregular intervals as investigations are completed, not monthly.
always safe to use. Evidence has so accumulated, however, especially during the past two seasons, that there can no longer be any doubt that bordeaux made with extreme care and using a great excess of lime may sometimes spot the leaves of the apple and mark or deform the fruit.

Several classes of evidence support the statement that bordeaux is sometimes injurious: (1) Circular letters were sent in the fall of 1905 to 116 of the leading apple growers of New York State; and of the 108 answers received 98 were from men who had used bordeaux in 1905. Nearly all of these report some experience with injury; while 69 of the 98, or about 70 per cent., report severe injury to fruit or foliage or both. Ten of these growers believe that the spraying did more harm in 1905 than the apple scab for which the bordeaux was used. (2) Many American investigators, from Weed in 1889, to Scott, in 1906, have recognized bordeaux injury in one form or another, among those making announcement in print relative to the direct connection between the mixture and the injury being Weed and Green of the Ohio Station, Jones of the Vermont Station, Bain of the Tennessee Station, Beach and Stewart of this Station, Lodeman of Cornell Station and Von Schrenk and Scott of the U. S. Department of Agriculture. (3) Through correspondence, many others have confirmed the belief that bordeaux injury really exists, independent of any "burning" of foliage through deficiency of lime or improper making. Among those in America so writing may be mentioned Walker in Arkansas, Macoun in Canada, Paddock in Colorado, Gulley in Connecticut, Henderson in Idaho, Beach in Iowa, Munson in Maine, Fletcher in Michigan, Faurot in Missouri, Emerson in Nebraska, Sanderson in New Hampshire, Green in Ohio, Sears in Nova Scotia, Butz in Pennsylvania, and Melander in Washington. (4) Other letters from foreign experimenters report similar phenomena in France, Germany and other Continental countries and in Australia, Tasmania and New Zealand. (5) In experiments made by this Station in investigation of the subject, when the bordeaux was made by the Horticultrist in person, following the most approved formula and exercising every care to secure a perfect mixture,
22 per ct. of the fruit on one tree was marked by the spray and practically all the trees under test showed marked spotting of the fruit when the spraying was done under certain weather conditions.

Many peculiarities in the distribution and extent of bordeaux injury are shown by the reports upon it. Often the apple grower who has lost heavily by such injury says, "I have sprayed just as in past seasons when I have had no injury." The damage is severe in some seasons, some localities, or some orchards; scarcely noticeable in other seasons, other localities and other orchards. Even part of the trees in a single orchard may be badly affected, while other trees in the same orchard escape entirely. In some seasons the harm is greatest upon the foliage; in other seasons, on the fruit. Varieties whose leaves are badly spotted may show no sign of injury on the fruit; or the reverse of this may be true. Sometimes the damage is evident within a few days after spraying; again it may not reveal itself for several weeks. Strangest of all, not infrequently very weak bordeaux causes greater injury than a much stronger mixture used under similar conditions; though usually the injury is greater as the mixture is stronger. Most, though not all, of these peculiarities, are due to variations in weather conditions; for it is now certain that unfavorable moisture conditions play by far the largest part in bringing out the poisonous action of the copper in the bordeaux. But the manner of spraying, kind of nozzle used and quantity of the mixture applied are also important agencies in influencing the extent of the injury; while it is probable that any factors, like rich soil, good cultivation and young thrifty trees, that favor rapid development of foliage will make the leaves more succulent and tender and consequently more susceptible to injury. "At any rate, the most thrifty, best kept orchards, in which foliage is abundant and healthy, seem most susceptible to bordeaux injury."

Bordeaux injury manifests itself in two general ways: By spotting the leaves, often to such an extent as to defoliate the trees to a noticeable degree; and by marking and deforming the fruit.
On the foliage, bordeaux injury greatly resembles the leaf spot supposed to be caused by fungi. Dead, brown spots first appear, which may be small, circular or roundish, or larger and of irregular shape as though several small spots had run together. The living and dead tissue are separated by a distinct line, so that the spotting is very conspicuous. Later, if the injury is severe, the leaf turns yellow over more or less of its surface and finally drops off as in natural falling. Many of the orchardists reporting place the amount of defoliation during 1905 at one-half or more of the leaves; while in a few instances nearly all of the first leaves fell.

On the fruit the injury first appears as minute, round, black or brown spots or specks, less than pin-head size, which are clustered either (1) at the apex of the fruit if the injury results from spraying before the little fruits have turned down, or (2) at the base of the fruit if the injury results from later sprayings. Subsequently the characteristic “spray russetting” or “cork russetting” appears. The plant cells injured by the spray form thick, corky tissue, which roughens or russets the apple, the extent of the marking varying with individual fruits. These characters give the fruit the appearance of having been attacked by a fungus. Brightly colored fruit is much marred, both by the russetting and by a decreased brilliancy of the unspotted areas. Badly injured specimens are always more or less distorted in shape, the affected areas being usually shrunked. Occasionally unsightly, teat-like malformations are produced, or gaping cracks in half-grown fruits which heal over as the fruits develop, leaving rough sunken scars.

These injuries affect the keeping qualities of the fruits to a marked extent, the moisture being rapidly given off, in dry rooms or cellars, through the corky tissue, so that the flesh below shrivels or becomes mealy, or in extreme cases may turn brown as if bruised or exposed to the air. In such cases decay sets in rapidly. With late-keeping apples this phase of the injury is very important, as the keeping quality is affected, no matter how slight the russeted area.

In cold storage the depreciation of russeted apples is not very
PLATE II.—GREENING APPLES RUSSETED AND CRACKED BY SPRAYING.
rapid, but such fruit is not wanted by retailers, as it keeps very poorly when brought from storage into a dry atmosphere.

Injuries similar to that from bordeaux. Certain injuries to foliage and fruit may be confused with bordeaux injury, though usually there are points of difference easily separating them.

In the arsenites, when used in too great quantity, when improperly prepared, or under very unfavorable circumstances, may injure foliage as does bordeaux mixture; and in some cases where paris green or london purple is used the injury may be indistinguishable from bordeaux injury. But this occurs very rarely, and only under conditions which would produce bordeaux injury. Any direct poisoning by the arsenites results in an immediate effect, the damaged parts becoming blackened within a day or two, in large blotches or over the entire leaf. If only part of the leaf is affected the remaining portion quickly withers.

Frost causes a similar russetting of the fruit, but the injury in this case usually extends about the apple in bands of greater or less width, midway between base and apex. In most cases the russeted layer is not so thick and is smoother than that caused by spraying. Usually only a few fruits in an orchard will be marked with frost injury, these being on trees in low frosty situations; and these frost injuries to the fruit are associated with others to the foliage which are characteristic and differ markedly from bordeaux injury to foliage. On foliage, frost causes distortion of the leaf, the margins being drawn downward, while the upper surface is wrinkled and puckered, due to separation of the leaf tissue from the lower skin of the leaf in a large cavity or blister. The tissue does not usually blacken or turn yellow as in bordeaux injury, but remains green throughout the season.

Scab and other fungi cause russetting and malformation of apples and pears, particularly the latter, which resemble bordeaux injury very closely and which in some cases may be distinguished from the latter only by careful examination; but well-sprayed trees should not show the presence of much scab, while these same trees may show much bordeaux injury. On leaves, the condition
known as leaf spot has commonly been ascribed to one or more fungi found growing in the spots; but it is more than probable that in many cases, on sprayed trees, the first injury was due to the bordeaux and that the fungi came later as saprophytes or harmless dwellers rather than as destructive parasites. This phase of the question, however, requires further careful study. In some cases the lenses formed by drops of water on leaves may condense the sun's rays to such an extent as to burn and spot the leaves; but conditions liable to produce such injuries are rare; and the same conditions would be likely to produce serious bordeaux injury if the trees had been sprayed just before those conditions arose.

That lime may be the cause of such injuries is claimed by some; but in all observations made by the Station, no injury from properly slaked lime has been noticed even where the lime is in great excess. Unslaked lime upon foliage or young shoots may cause severe burning, but the effects of this are very different from bordeaux injury, there being no spotting or yellowing. The leaves and shoots wither and dry up immediately and the leaves drop.

From the letters received it was quite evident that the bordeaux mixture itself, not any insecticide used with it, was the cause of injury; and most of those reporting with reference to weather conditions said the injury was greatly increased by rain following the spraying. If this be true, then the harm must be due to some chemical or physical change in the bordeaux caused by moisture and produced after the mixture has dried on the fruit or foliage. Professor Bain, of the Tennessee Station, has made careful studies along this line, particularly upon peach foliage, which is peculiarly subject to bordeaux burning. His latest conclusions upon the subject are about as follows: The lime, only, of bordeaux mixture retards the injurious action of the copper sulphate. When the mixture is first dried on the trees most of the lime exists as the hydrate of lime, which is very soluble; while a short exposure of the dried mixture to moist air, as to a heavy dew, changes the hydrate of lime to the carbonate of lime, which is much less soluble. If, however, a rain falls before the change
to carbonate has occurred, the soluble hydrate of lime is washed away, leaving the copper salts free to exert their poisonous influence upon fruit or foliage. "Following rains or dews will thus cause much greater injury than would have occurred if a few dews had followed the spraying before the occurrence of the rain."

Bordeaux injury, or "spray injury," has been quite injurious locally in New York State at various times, notably in 1894 and 1904; but in 1905 such serious damage was reported from all the apple-growing sections that the Station was impelled to make a thorough investigation of the matter. Preliminary information was secured through circular letters sent to leading orchardists. The replies to these letters show clearly that the harm was widespread and great. Some growers believe the spraying in 1905 to have been a damage rather than a help, and others report defoliation to the extent of half or more of the leaves in large orchards and losses of fruit ranging up to 100 barrels.

The replies indicated clearly several important facts; and the direct experiments of the Station were planned to ascertain the truth or falsity of these indications. First, a large majority of the correspondents ascribed the injury to bordeaux; second, 55 of the 69 men who reported "spray injury" had used an excess of lime in making the bordeaux, and 7 of them from two to three times as much lime as required, without materially reducing the injury; third, 57 replies gave wet weather as a marked contributory cause of the injury.

The test by the Station, as planned and carried out, gave positive evidence along each of these lines. The work was done in the Station orchard upon 27 Rhode Island Greening and 18 Baldwin trees. These trees are about 50 years old and were selected from a much larger number of trees of the same kind, in the same orchard, so that uniform plants might be compared. As these trees had all been sprayed with the lime-sulphur wash for San José scale, the first of the usual three applications of
bordeaux was omitted as unnecessary, but all the trees except the checks were sprayed once just after the blossoms fell and again about ten days or two weeks later with bordeaux containing varying amounts of copper sulphate and of lime, with arsenate of lead to control codling moth.

The trees were divided into 9 lots or plats, each of five trees. On plats 1 to 4 the bordeaux contained equal amounts of copper sulphate and lime, while on plats 6 to 9 twice as much lime was used as of copper sulphate. Plat 5 was a check, sprayed only with arsenate of lead. On Plat 1 and Plat 6, the bordeaux contained 1 pound of copper sulphate in 50 gallons of water; and the strength of the mixture was increased by successive additions of one pound of sulphate, so that Plat 4 and Plat 9 were treated with 4 pounds of sulphate in 50 gallons of water. The ingredients were all weighed, measured and combined by the Station Horticultrist, the mixture being made by uniting dilute solutions as called for by latest and most carefully tested methods. The applications were made with a power outfit, using Vermorel nozzles, care being taken to spray from all directions and to cover the trees thoroughly, \textit{without drenching}.

On these trees, even those sprayed under the most unfavorable conditions, no injury to \textit{foliage} resulted; but the \textit{fruit} was badly affected. In discussing this injury exact figures are given; for the fruit was twice sorted, apple by apple, both picked and windfalls, and graded as to spray injury and as to scab injury. In sorting for bordeaux injury, no fruit was counted as injured unless it had a sufficient amount of russetting or malformation to detract from its general appearance; but in sorting for scab, a well-defined scab spot classified the apple as scabby. The crop was harvested between September 24 and October 13, and averaged 10\textsuperscript{2} bushels per tree for the 45 trees.
Bordeaux Injury and Scab on Apples Differently Sprayed.

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<tr>
<th>Plat No.</th>
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<th>Percentages of fruit, by weight—</th>
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*Chemicals in 50 gallons of water in all cases. †Numbers in ( ) are percentages corrected by omitting results from one tree in Plat 1 showing abnormally great injury, and from one in Plat 9 showing much less injury than others in the plat.

Does bordeaux cause the injury? There can be no doubt that bordeaux produced injury in this case. While the foliage was unspotted on all the trees, the fruit on the different sprayed sections showed from 1.9 per ct. to 16.4 per ct., with an average for all the trees on all the plats of 7.8 per ct. The check trees, sprayed with arsenate of lead, showed no injury.

When we compare the injury on plats 1 to 4, where the lime and sulphate in the bordeaux were equal, with that on plats 6 to 9, where twice as much lime was used, we find no advantage for the excess of lime. The average percentage of injury in the first section was 8.8 per ct., while in the second
it was 7.0, a difference so slight in favor of the excess of lime that it may be purely fortuitous. Indeed, if we leave out one tree which had an abnormally high percentage of injury (22 per ct. as compared with 4.1 per ct. for the other trees of the plat), and another abnormally low (2.5 per ct. as compared with 13.3 for its companions), the slight difference in favor of the large excess of lime vanishes. Considering the results as a whole, and the testimony of the large number of orchardists reporting, it is doubtful if a great excess of lime is of any value in protecting either fruit or foliage. A slight excess above what is needed to neutralize the copper sulphate,—an excess which is provided when equal weights of the two materials are used,—may be of advantage in wet seasons in causing greater adhesiveness; but to use larger quantities of lime than this has decided disadvantages. A gritty lime wears out spraying machinery; and a mixture containing more than 4 or 5 pounds of lime to 50 gallons is harder to apply uniformly, makes pumping difficult, and deposits on the foliage large particles of lime which offer a resisting surface to drops of water so that more of the mixture is washed from the trees. This is an important point, for a fungicide is of value in proportion to its adhesive power and it is certain that this power is greatly reduced by any considerable excess of lime.

To test the effect of rain during or soon after the application of the spray, one tree in each plat was spraying not sprayed with the other four, but was left increases until just before or during a rain, and then sprayed with the same mixture used on other injury. trees of the plat. The time intervening between spraying four trees in each plat during dry weather and one tree during wet weather was short at each spraying; so that differences can properly be ascribed to the differences in weather conditions. At the first spraying the “wet-sprayed” trees were treated during showers of a thunder storm which was followed by other showers for about two days; while a week of rain followed the second “wet-spraying.”

In the daily observations it was noticed from the start to the finish of the experiment that the injury was greater on the trees
sprayed during rain than on those sprayed during dry weather. With both applications of the bordeaux considerable injury appeared immediately on the trees sprayed in rain; and on those sprayed in dry weather only traces of injury were found until rain had fallen. The inevitable conclusion to be drawn from observation, quite aside from the numerical results, is that wet weather favors the production of bordeaux injury.

Examination of the fruit of 8 Rhode Island Greening trees, (one in each of 8 plats) sprayed during wet weather, showed 14.6 per ct. of injured fruit; while 16 trees of the same variety (2 in each of 8 plats) sprayed in dry weather showed only 7.8 per ct. of injury. If we omit the two abnormal trees previously referred to, the figures are 15.3 per ct. and 7.6 per ct. respectively, or twice as much injury on the trees sprayed during the rain.

These observations and results, taken in connection with the reports of many orchardists and the tests of other station horticulturists and botanists, give the strongest confirmation of the belief that wet weather favors development of bordeaux injury.

In both series of plats, with lime equal to the copper sulphate and with lime double the amount of sulphate, there was a successive increase of the strength of the bordeaux, so that in the last plat in each series four times as much copper sulphate was used as in the first plat. This gave opportunity to study the effect of mixtures of different strength upon both bordeaux injury and scab. With one exception (the plat containing one tree showing 22 per ct. of injury from the weakest mixture), and upon trees of both Baldwin and Greening, an increase in bordeaux injury accompanied an increase in the amount of copper sulphate used. On the trees sprayed in wet weather, omitting the one abnormal tree, doubling the amount of sulphate practically doubled the amount of injury; and on the trees sprayed in dry weather, the injury increased with the stronger mixtures but not in direct proportion to the amount of sulphate.

On the other hand, while the general results favor the stronger mixtures for controlling the scab, there is but slight difference in
effectiveness between the mixture containing 3 pounds of sulphate and that containing 4 pounds.

The proof is positive that the greater the amount of copper sulphate the more the bordeaux injury; if, then, there be but little difference in the amount of scab on trees sprayed with 4–4–50 and 3–3–50, and if this should be in favor of the former mixture, the less amount of injury from the weaker solution may more than offset the increase in the percentage of scabby fruit. This Station has used the 3–3–50 formula in the home orchards and in a ten-acre Baldwin orchard near South Greece with apparently as good results as when much stronger mixtures were used.

These investigations, taken as a whole, show that, in the absence of a better fungicide, the use of bordeaux mixture is essential to the growth of perfect apples; and that with the use of bordeaux is associated a certain amount of spray injury. We can not give a perfect method of preventing such injury, but the following suggestions will aid in reducing it.

(1) Distinguish, in spraying, between varieties very susceptible to spray injury and those resistant or less susceptible. Among such susceptible varieties, which must be sprayed with great care, are:—Baldwin, Ben Davis, Gravenstein, Jonathan, Rhode Island Greening, Twenty Ounce, Wagener, Wealthy, Yellow Newtown, Yellow Transparent. Among those less susceptible are:—Alexander, Esopus Spitzenburg, Fall Pippin, Hubbardston, Northern Spy, Red Astrachan, Red Canada, Rome, Roxbury, Tolman Sweet, Tompkins King, Yellow Bellflower.

(2) Varieties resistant to scab should receive light applications of bordeaux, especially if they are very susceptible to injury by the copper sulphate. Among such scab resistant varieties are: Alexander, Ben Davis, Gano, Hubbardston, Oldenburg, Red Astrachan, Rome, Roxbury, Sutton, Tompkins King, Tolman Sweet, Wealthy, Yellow Newtown and Yellow Transparent.

(3) It will probably be best to use less copper sulphate. On this point it is not possible at present to speak positively; but the Station recommends a thorough trial of the 3–3–50 (or 1–to–16) formula.
(4) An excess of lime will not prevent bordeaux injury nor greatly lessen it, therefore it is not advisable to use more than one part of lime to one part of copper sulphate in making the mixture.

(5) Use moderation in spraying. Since the injury increases with the amount of copper sulphate, an excessive application that leaves, by evaporation, larger amounts of the chemicals on the tree, will be more harmful than lighter applications. *Spray to cover the foliage and fruit with a thin film and yet not have the trees drip heavily.*

(6) *Avoid spraying in rainy, foggy, damp weather.* Applications made just before showers are quite certain to produce injury; hence the bordeaux mixture should be used, as far as possible, only in dry weather. If necessary to spray in wet weather, it may be advisable to increase slightly the proportion of lime in the mixture.

Bordeaux mixture is still the best fungicide.

**Conclusion.** Spray injury is a serious matter, but apple scab is worse. *No fruit grower can afford to give up the use of bordeaux mixture in fighting apple scab.* It is to be feared that because of the very small amount of the apple scab fungus during the past few years, and because of spray injury, some who have previously used the copper compound will not use it in the future. Such a course will be a mistake, for there are sure to be years with apple scab and corresponding losses in unsprayed orchards.