BULLETIN No. 647 JULY, 1934

New York State Agricultural Experiment Station

Geneva, N. Y.

WINTER INJURY OF BALDWIN APPLE TREES AND ITS RELATION TO PREVIOUS TREE PERFORMANCE AND NUTRITIONAL TREATMENT

R. C. COLLISON AND J. D. HARLAN

PUBLISHED BY THE STATION
UNDER AUTHORITY OF CORNELL UNIVERSITY

ABSTRACT

An experimental Baldwin apple orchard on a nitrogen-responsive, low-lime soil which received during the preceding 4 years, 17 different fertilizer treatments, was studied as to the relation between these treatments and past yield performance and the extent of injury due to the low temperatures of the winter of 1933–34.

There was a significant tendency for high yields of the preceding season to accompany extensive winter injury. This tendency was the reverse, however, when the 4 years' yields were considered.

After the variation due to the 1933 yields and that due to soil had been eliminated, there still remained a highly significant relation between the fertilizer treatments and the percentage of injury.

Those treatments which had already been found to affect yields and growth most greatly also significantly lowered the extent of winter injury, as compared with those treatments which had least affected the growth and yield of the trees.

On this acid, low-lime soil, the carriers containing nitrogen in nitrate form and those which furnished available lime best fortified the trees against winter injury, regardless of the fact that they were also the carriers of nitrogen which had the most pronounced effect on yield and growth.

Those fertilizer materials which carried nitrogen predominantly in ammonia form without addition of lime and those which were fall applied or applied only in alternate years, in general, were less effective in reducing the extent of winter injury.

Apparently, good orchard soil management is an effective preventative of extensive winter injury, even in a susceptible variety such as Baldwin.

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R. C. COLLISON, *Chief in Research (Pomology)*, AND J. D. HARLAN, *Associate in Research (Pomology)*

INTRODUCTION

The severe winter of 1933–34 caused considerable and in some cases very serious injury to many fruits in New York. Among apple varieties the Baldwin apparently suffered very severely. Older trees of this variety were more injured than younger ones, even in the same orchard. Furthermore, the low temperatures, which in some cases reached —30° F and even lower in orchard sections of the state, gave an excellent opportunity to study the relations of various environmental factors to the extent and degree of injury.

For the past 4 years this Station has had under experiment an especially well-located and uniform Baldwin orchard near North Rose in Wayne County, N. Y., about 5 to 6 miles from Lake Ontario. This orchard has been fully described in Bulletin No. 646 of this Station, hence only a brief description of the orchard and its treatments will be given here.

THE ORCHARD AND THE FERTILIZER TREATMENTS

The trees in the orchard are some 40 years old, are set 30 x 40 feet, are well cared for, and are exceptionally uniform in size and general character. The general care of the orchard has been well above the average. The soil is an Alton stony loam, well drained, rather light in texture, and quite level and uniform over the whole orchard. Perhaps the most important feature of this soil in relation to the present experiment is the fact that it was low in lime and quite acid in reaction. The soil is usually disked in the spring, but not close to the tree trunks, and then weeds allowed to grow from midsummer on. Previous to 1930 all trees received nitrate of soda liberally for some years.

Since 1930, the trees have been variously fertilized, 17 different fertilizer treatments being employed. The results of these treatments on yields and tree characters and their relation to the acid character of the soil, as well as the arrangement of blocks and methods of application, have been fully set forth in the publication noted above.

This exceptionally uniform Baldwin orchard and the large number of fertilizer treatments presented an unusual opportunity to study the relation between the nutritional treatment of the trees and the degree of winter injury sustained during the winter of 1933–34. The fact that the 10 trees of each treatment were scattered practically at random over the orchard also minimized any differences in injury which may have been caused by variations in soil or exposure. The further fact that, altho 1933 was the "on" year for this orchard, many of the trees had their "off" year in 1933, gave an additional opportunity of studying the relation of size of crop to the degree of winter injury. An endeavor has been made to bring out these relationships by various analyses of the data.

METHOD OF DETERMINING DEGREE OF INJURY

Some observations made in late winter of 1933–34 indicated that the trees were considerably injured. This was shown by the dark-colored bark and wood on many of the lower limbs of the trees. On May 18, 1934, after the leaves and blossoms were fairly well out, the lower branches showed the injury very conspicuously. The leaves on these branches were small, brown or missing entirely and presented a striking contrast to the remainder of the tree. Two observers on the various sides of the tree estimated the percentage of injured branches in relation to the total branch system of each tree. In most cases the estimates agreed within 5 to 10 per cent and in many cases were identical. When different, the mean was taken. Absolutely no attention was paid to the treatments during the estimations.

It is fully recognized that the injury which was superficially apparent on the dates of observation and which was largely confined to the limbs and branches which will later have to be removed from the trees, may not fully represent the whole injury which the trees have suffered. Trees may be injured by cold in ways which are not superficially apparent at all, and which may be reflected in poor performance thruout the remaining life of the tree. Later observations will be made on this type of injury.

OBSERVATIONS OF MAY 18

Table 1 gives the estimated percentage of injury for each tree and the mean injury for each fertilizer treatment. The estimated injury varies for individual trees from none to 80 per cent, while for the orchard as a whole the figure is 22.42 per cent. It is quite probable that a number of the highest percentages on individual trees are due to the trees being below normal in vitality irrespective of treatment or previous crop. This is borne out by the fact that in the orchard are eight or ten trees which on account of being somewhat undersized or not up to normal in some other way were not included in the experiment. In almost every case, these trees showed greater injury than any others.

Nine treatments out of the 17 showed injuries of less than 20 per cent, namely, the three nitrates spring applied, nitrate of soda both fall applied and the double application, ammonium sulfate with and without lime, Cyanamid spring applied, and complete fertilizer, treatment 10. Only one of these nine treatments contained all its nitrogen in ammonia form without addition of lime. The addition of lime to sulfate of ammonia cut the injury in half and gave the lowest percentage injury of any of the treatments. The remaining eight treatments show percentages of injury varying from 23 to 34, while one treatment showed an injury of 42 per cent. This figure is high due to the incorporation of two trees carrying 80 per cent injury. As already noted, those trees which seem out of line with the others receiving the same treatment are probably trees which were somewhat below average in vigor irrespective of fertilizer treatment.

The trees receiving fall applications as well as the alternate year application showed greater percentages of injury with the exception of fall-applied nitrate of soda. It would appear that the slower acting forms of nitrogen when fall applied or those which are less available due to soil acidity fortified the trees against low temperatures to a less degree than those which are quickly available and are readily absorbed, or those which carry lime.

TABLE 1.— PERCENTAGE OF INJURY TO BALDWIN TREES, MAY 18, 1934.

No.	TREATMENT FERTILIZER	PERCENTAGE INJURY PER TREE										
		1	2	3	4	5	6	7	8	9	10	Mean
1	Nitrate of soda, 10 lbs. spring	5	2.5	15	2.5	30	10	2.5	20	20	40	14.75
2	Calcium nitrate, 10 lbs. spring	5	5	40	25	30	20	5	20	0	10	16.00
3	Ammonium sulfate, 7.5 lbs. spring	10	60	20	20	20	20	5	15	0	20	19.00
4	Urea, 3.4 lbs. spring	5	5	40	15	40	35	50	35	1.0	20	24.60
5	Urea, 3.4 lbs. fall	15	35	60	35	50	40	40	10	30	25	34.00
6	Calnitro, 7.5 lbs. spring	0	25	50	40	20	20	5	30	20	20	23.00
7	Potassium nitrate, 11 lbs. spring	0	5	25	10	30	25	10	20	35	0	16.00
8	Ammo-Phos (11–48–0), 13.5 lbs. spring	2.5	10	20	50	15	50	30	60	10	1.0	24.85
9	Cyanamid, 7.5 lbs. fall	2.5	10	30	40	40	40	20	60	30	20	29.25
10	Complete mixed fertilizer, 14.5 lbs. spring	20	25	20	5	15	30	1.0	1.0	70	10	19.70
11	Cyanamid, 7.5 lbs. spring	10	5	15	60	15	10	25	5	10	5	16.00
12	Nitrophoska (15–30–15), 10 lbs. spring	15	20	25	25	25	60	30	50	5	20	27.50
13	Nitrophoska (15–30–15), 10 lbs. fall	80	80	40	30	40	20	15	50	40	25	42.00
14	Nitrate of soda, 20 lbs. spring	20	20	10	20	40	10	1.0	25	20	10	17.60
15	Nitrate of soda, 10 lbs. alternate years	60	40	5	50	15	5	50	60	5	2.5	29.25
16	Nitrate of soda, 10 lbs. fall	20	35	10	5	50	10	15	5	5	25	18.00
17	Ammonium sulfate, 7.5 lbs. spring + lime.	15	5	25	10	10	1.0	5	20	2.5	2.5	9.60

RELATION OF PRECEDING YEAR'S CROP TO WINTER INJURY

It is generally recognized that a heavy crop of fruit may leave a tree in less vigorous condition than one which has not used up its reserves in fruit production. Any influence which lowers tree vigor, on the other hand, is thought to lower the tree's resistance to low temperatures. Since 1933 was the bearing year for this orchard and especially since, as has already been noted, an appreciable number of the trees bear in what is the "off" year for the remainder, a very valuable study can be made here of the above relation.

In order to secure a definite figure representing the degree of this relationship between the preceding crop and the extent of winter injury, the yields of the individual trees for 1933 were correlated with the percentages of injury. For the May 18 observations this gave a correlation coefficient of $+ .278 \pm .047$. This is a low coefficient but quite significant in relation to its probable error, the number of paired observations being 170. This indicates that, altho there was some relationship between yields and injury, this relation was very much less than might be expected. The correlation coefficient, however, does not show the entire effect of yield on the extent of injury as is indicated by the following analysis of the data.

There were 29 trees in the orchard which had a yield of less than 10 bushels and averaged 3¼ bushels. These 29 trees had less than 3 per cent injury. Further, there were 35 trees in the orchard which showed over 40 per cent injury and averaged 50 per cent injury. These 35 trees yielded an average of about 18 bushels per tree. Here, then, are 64 of the trees which show a high degree of relationship between yield and winter injury. On the other hand, there were 61 trees in the orchard which yielded an average of 12 bushels per tree, yet showed an average of only 5 per cent injury. The effects of these two groups of opposite response have given a comparatively low correlation coefficient when combined in their effect.

These facts raise the question of what can be considered a large or small crop for the trees. None of the yields are large for the size of trees, yet it seems probable that a crop of 10 bushels may be as exhausting to one tree as 30 bushels to some other tree. This is borne out by the fact that among trees of very little if any yield the injury was very small, while the intermediate group in yield contained trees with intermediate yields and extensive injury as well as trees of large yields and comparatively little injury. These facts further indicate that the individual tree is a unit with individual characteristcs of its own and again that the fertilizer treatments have had some very definite effects on the extent of injury irrespective of the yields of the preceding season.

It is significant that among the group of 61 trees noted above which showed less than 10 per cent injury there were 16 trees which had a crop of over 20 bushels the preceding season. These 16 trees received the following fertilizer treatments: Four of them received spring-applied Cyanamid, three potassium nitrate, two spring-applied nitrate of soda, two a double application of the same fertilizer, two nitrate of soda in the fall, one calcium nitrate, one ammonium sulfate and lime, and one complete mixed fertilizer.

The average injury for each of these treatments was less than 20 per cent; in other words the eight fertilizer treatments which these trees received were those treatments which gave the lowest mean percentage of injury. This fact shows that, altho high yield in many cases was associated with a high percentage of injury, in other cases some of the fertilizer treatments counteracted this tendency to a marked degree. The problem involved here is to separate the effects of two factors, *viz.*, yield and fertilizer treatment. Fertilizers apparently had two effects. Those treatments which increased yields most markedly decreased the tree's vitality thru larger fruit production, but at the same time increased vigor by furnishing abundant plant food to the vegetative parts of the tree. On the other hand, those fertilizer treatments which did not produce such high yields, perhaps decreased vegetative vigor somewhat, but at the same time the decreased crop gave the trees less susceptibility to winter injury. The estimated percentages of injury are therefore the resultants of these various interacting forces.

These points were further brought out by correlating the yields of each individual treatment with the corresponding percentages of winter injury. In this analysis it was found that sulfate of ammonia, fall-applied urea, Calnitro, Ammo-Phos, and alternate year nitrate of soda showed coefficients from +.529 to +.768 and all were significant in relation to their probable errors. This means that these treatments were least effective in counteracting the effect of the previous crop on winter injury. An intermediate group, consisting of spring-applied urea, fall-applied Cyanamid, Nitrophoska, both spring and fall applied, and sulfate of ammonia plus lime, showed correlation coefficients from +.336 to +.490, which were not significant, indicating some, but not a marked effect on previous yield relation. On the other hand, nitrate of soda, spring and fall applied as well as the double application, also calcium and potassium nitrate, complete mixed fertilizer and spring-applied Cyanamid gave coefficients from —.501 to +.288, indicating that these treatments were most effective in counteracting the effect of the previous year's crop on winter injury. All of this last group of treatments gave positive coefficients, except Cyanamid, which indicates that this latter treatment was especially effective on this acid soil.

The effects of fertilizer treatments on injury, irrespective of the effects of yields, can be determined by the analysis of variance method of Fisher. This is done under the discussion of the observations of June 4.

OBSERVATIONS OF JUNE 4

About three weeks later a second series of estimates was made in the same way as those of May 18. These are presented in Table 2. It will be immediately noted that practically all trees have greatly improved in condition. The percentage of apparent injury was cut almost in half, the mean of the 170 trees being 12.69 per cent. Many branches on which foliage was extremely sparse on May 18 had come out fairly well by June 4, and other branches on which the leaves had come out only ¼ to ½ inch on the earlier date and then withered and turned brown were, on the later date, developing entirely new leaves. This was true regardless of the fact that the bark and wood on such branches were still quite brown and the rainfall had been practically nothing.

Regardless of this general improvement the same difference between fertilizer treatments still persisted. The same nine treatments which showed injuries of less than 20 per cent on May 18 now showed less than 11.3 per cent. Sulfate of ammonia plus lime showed only 4.8 per cent injury, while the fall application of nitrate of soda showed only 6.0 per cent. Cyanamid, double application of sodium nitrate, calcium nitrate, and single application of sodium nitrate were very similar and showed the next smallest percentage injury.

The degree of relationship between the injury and the preceding crop of fruit was practically identical with that of the earlier date,

TABLE 2.— PERCENTAGE OF INJURY TO BALDWIN TREES, JUNE 4, 1934.

No.	TREATMENT FERTILIZER	PERCENTAGE INJURY PER TREE										
		1	2	3	4	5	6	7	8	9	10	Mean
1	Nitrate of soda, 10 lbs. spring	2	0	5	1	20	5	1	20	10	30	9.4
2	Calcium nitrate, 10 lbs. spring	1	1	40	7	15	15	2	5	0	2	8.8
3	Ammonium sulfate, 7.5 lbs. spring	2	30	15	15	15	15	5	5	0	10	11.2
4	Urea, 3.4 lbs. spring	0	2	25	8	20	25	40	25	1	15	16.1
5	Urea, 3.4 lbs. fall	5	10	50	30	20	30	15	2	15	5	18.2
6	Calnitro, 7.5 lbs. spring	0	20	25	35	7	10	0	15	5	5	12.2
7	Potassium nitrate, 11 lbs. spring	0	4	25	2	15	15	5	15	20	0	10.1
8	Ammo-Phos (11–48–0), 13.5 lbs. spring	0	7	15	30	5	35	20	50	5	0	16.7
9	Cyanamid, 7.5 lbs. fall	0	2	15	20	30	20	5	25	25	13	15.5
10	Complete mixed fertilizer, 14.5 lbs. spring	2	15	10	0	10	15	1	0	40	8	10.1
11	Cyanamid, 7.5 lbs. spring	5	1	10	40	5	2	15	2	3	1	8.4
12	Nitrophoska (15–30–15), 10 lbs. spring	5	5	20	10	15	50	15	40	1	15	17.6
13	Nitrophoska (15–30–15), 10 lbs. fall	50	50	35	10	30	10	5	25	30	20	26.5
14	Nitrate of soda, 20 lbs. spring	15	15	0	7	20	4	0	15	5	5	8.6
15	Nitrate of soda, 10 lbs. alternate years	25	35	0	25	5	0	30	35	0	0	15.5
16	Nitrate of soda, 10 lbs. fall	5	15	1	1	15	3	5	3	2	10	6.0
17	Ammonium sulfate, 7.5 lbs. spring + lime	5	3	15	3	4	1	1	15	1	0	4.8

the correlation coefficient being +.277 ±.047. The same facts which were noted in the discussion under the observations of May 18 held true for those of June 4.

Altho fruit production by the tree is an exhausting process, yet it would seem that internal vigor in a tree should be reflected in larger fruit production and therefore that fruit production over a period of years should not necessarily mean a weaker tree. In order to determine if this is true, the total fruit yields of the trees for the past four years were also correlated with the percentages of winter injury for June 4. The correlation coefficient in this case was —.148 ± .050. Although this coefficient is not significant in relation to its probable error, the fact that it is negative instead of positive is significant and shows that, altho a tree is weakened temporarily by a heavy crop, in the long run and over a period of years the heavier producing trees are the most vigorous. The very fact that some trees produce much smaller crops year after year shows that they are either inherently low producers or that they are not up to normal in internal vigor.

Now in order to separate the effects of yield from those of fertilizer treatment, the results of June 4 were subjected to the analysis of variance. In handling the data two groupings were made. In one, the figures for the percentage injury were arranged under each treatment in the order of lowest to highest fruit yield for 1933, and in the other grouping they were taken just as they occur in the 10 blocks in the orchard. The analysis of variance in the first grouping eliminates the effects of previous crop, while that for the second grouping eliminates variation due to soil differences. The remaining variation is then due to differences in fertilizer treatment. It is not necessary here to go into details of the analysis of variance since the method is adequately described in the excellent papers of R. A. Fisher and his co-workers and also by Snedecor[1]. Table 3 gives the results of the analysis.

INTERPRETATION

In the first place, the analysis of variance clearly shows that there are two major factors which have contributed to the percentage of winter injury. The fruit yield of 1933 had a highly significant effect on injury, that is the tendency was for high yields to accompany

[1] Snedecor, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. *Ames, Iowa: Collegiate Press, Inc.* 1934.

TABLE 3.— ANALYSIS OF VARIANCE IN PERCENTAGE OF WINTER INJURY DUE TO SOIL, PREVIOUS YIELD, AND FERTILIZER TREATMENT ON BALDWIN APPLE TREES.

DUE TO	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F* CALCULATED	F* TABLE
1933 yield..........	9	2946.593	327.40	treatment/error =2.18	1.75 2.18
Blocks (soil)........	9	1126.236	125.14	blocks/error =0.92	1.96
Fertilizer treatment.	16	4726.576	295.41	yield/error = 2.42	2.55
Error..............	135	18255.071	135.22		

* From tables by Snedecor.

Standard error of difference between pairs of mean values =

$$\sqrt{\frac{135.22 \times 2}{10}} = 5.2$$

extensive injury. The soil variations in the orchard had a very insignificant effect on the extent of injury. The other major factor is fertilizer treatment. When the effects of the previous year's yield and the soil effect are both eliminated, fertilizers in general had a highly significant effect in decreasing winter injury. The F test of Snedecor, which is based on Fisher's z test, shows that the figure would be exceeded in random sampling only once in a hundred trials.

Not all of the fertilizer treatments, however, show this effect, and in order to determine which ones are most responsible, the mean treatment yields must be compared with the appropriate standard error of the difference. The standard error of the difference is 5.20 which multiplied by the calculated value of t according to Fisher's tables, gives 10.0. This means that to have real significance the difference between any two treatment means must exceed 10 per cent.

On examining in this way the figures for mean injury in Table 2, it will be found that there is a group of six treatments giving low percentage injury which, in order of increasing injury, is as follows: Ammonium sulfate plus lime, nitrate of soda in the fall, Cyanamid in the spring, double application of sodium nitrate, calcium nitrate, and a single application of spring-applied sodium nitrate. There are no statistically significant differences among any of this group, altho the lowest is only one-half the percentage of the highest. The mean of this group is 7.7 per cent. The next group showing somewhat greater injury contains the following four treatments with a mean of 10.9 per cent: Potassium nitrate, complete mixed fertilizer (treatment 10), ammonium sulfate, and Calnitro. Altho this group shows greater injury than the preceding, the difference is not significant. The third group shows considerably greater injury with a mean of 18.0 per cent and contains Cyanamid fall applied, nitrate of soda in alternate years, urea in spring, Ammo-Phos, Nitrophoska in spring, and urea and Nitrophoska in the fall. This group shows significantly greater injury than group one and also greater injury than some treatments in group two. This last group it will be noted contains materials with nitrogen predominantly in ammonia form, or the slower acting materials, or those applied only in alternate years. The first group, on the other hand, contains the materials with nitrogen in nitrate form and those which furnish available lime, which have proved more effective on this acid soil.

It is significant, therefore, that fertilizers in general have reduced winter injury and that on the low-lime soil of this orchard those treatments which were found to give higher yields of apples and better growth, namely, those which carried nitrate nitrogen or furnished available lime, were the ones which also best fortified the trees against low temperature regardless of the fact that high yield of the preceding year had a definite tendency to increase winter injury.

The fact that the odd trees in the orchard which received no fertilizer showed the greatest injury, indicates that fertilizers generally reduced the injury. Some of the treatments had specific effects, due to their action under the particular soil conditions of this orchard, which indicates that the nitrogen carrier should be fitted to the orchard soil and perhaps to the apple variety.

The results show further that good soil management is at least one factor effective in fortifying trees against extensive injury from low winter temperatures.

One month later, on July 5, a third series of observations was made on the trees. Their status had not changed appreciably from that of June 4, altho the larger leaves and new growth gave the trees generally a somewhat improved appearance. Individual differences remained the same.