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NITROGEN Fertilization OF APPLES

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INTRODUCTION

Annual applications of nitrogen in some form are necessary for the successful production of apples in Ohio. In some cases this application may be made in the form of manure or through the maintenance of a heavy permanent mulch. More often the fruit grower must depend on the use of commercial nitrogen fertilizer to supply this annual requirement.

During the past eight years a great deal of effort has been directed toward determining the kinds and amounts of nitrogen fertilizers which provide good growth, optimum yields, and excellent quality fruit. Concurrently, a thorough evaluation was made of the various indices which may be useful in determining nitrogen status of apple trees. The approach to the problem was by means of a survey to determine the nitrogen status of commercial orchards throughout the state plus detailed controlled experiments involving the application of different kinds and amounts of nitrogen fertilizers. In the evaluation of response to treatments a number of criterion were employed including foliar analysis, terminal shoot growth measurements, leaf color determinations, total yields, fruit color, fruit size, and soluble solids and titratable acids content of the fruit.

It is the purpose of this report to summarize the several individual phases of the work on nitrogen nutrition of the apple and to present the findings interpreted in terms of recommendations to the apple growers of the State.

NITROGEN STATUS OF COMMERCIAL ORCHARDS

From July 12 to August 5, 1948, a total of 47 orchards representing the important apple producing areas of the State were visited for the purpose of collecting leaf samples for chemical analysis for total nitrogen (1). The varieties included in this survey were Stayman Winesap, Delicious, Rome Beauty and Jonathan. The trees varied in age from 7 years to 35 years. With the exception of eight locations, all of the samples were taken from orchards maintained under a sod system of soil management. At least four representative trees were selected at each location and a single composite sample was obtained composed of 25 median shoot leaves from each tree and taken at random from around the tree at approximately eye level. Leaf samples were returned to the laboratory within 48 hours after removal from the trees.

When spray residue or dirt was evident on the leaves, it was removed by wiping with dampened cheesecloth. The samples were dried at 70 degrees centigrade in a forced draft oven, ground to pass a 40 mesh sieve, and stored in capped glass bottles prior to analysis. Total nitrogen was determined by a modification of the Kjeldahl-Gunning method using selenium in the digestion catalyst mixture to reduce the time necessary for digestion. The nitrogen data are expressed on the dry weight basis.

The resulting data for total nitrogen are summarized in Table 1 wherein the range and average value for all orchards included in the survey are given according to variety. Since it was not possible to obtain each of the varieties at each sampling location, the averages included in Table 1 are made up of 44 samples for Stayman Winesap, 34 for Delicious, 8 for Rome Beauty, and 6 for Jonathan.

These data show that under comparable conditions of soil, climate, and management programs, Delicious foliage contained the highest percentage of nitrogen followed in order by Jonathan, Rome Beauty, and Stayman Winesap. These results are in good agreement with data obtained in West Virginia (7) for the varieties Delicious, Rome Beauty, and Stayman Winesap. The results are lower than those reported for Michigan (5) and for Pennsylvania (6).

TABLE 1.—The range and average nitrogen content of leaves from commercial apple orchards in Ohio. 1948

Variety	No. Orchards	Total Nitrogen as Percent of the Dry Weight	
		Range	Average
Stayman Winesap	44	1.51–2.34	1.89
Delicious	34	1.60–2.53	2.04
Jonathan	6	1.64–2.25	1.99
Rome Beauty	8	1.69–2.15	1.94

Other information obtained from the survey concerned the relationship between tree age and nitrogen content of the foliage. For this purpose the trees were classified into three groups: 15 years of age or younger; 16 through 25 years of age; and 26 years of age or older. The resulting data are presented in Table 2.

Previous work reported higher levels of nitrogen with young than with older trees (7). In the present case a higher level of leaf nitrogen was found in the early years of an orchard, followed by lower leaf nitrogen during the period of maximum productive life of the orchard from 16 through 25 years, and a slightly increased nitrogen content during the period from 26 to 35 years of age. This trend was found in each of the four varieties and would seem to coincide with the generally observed cycle of vegetative growth during the early years, heavy production during the middle years, and reduced productivity during the latter years in the life of an orchard.

TABLE 2.—The influence of tree age on the leaf content of nitrogen in commercial apple orchards in Ohio. 1948

Variety	Total Nitrogen as Percent of the Dry Weight		
	15 yrs. or less	16 thru 25 yrs.	26 yrs. or more
Stayman Winesap	2.04	1.82	1.90
Delicious	2.22	1.98	2.08
Jonathan	2.25	1.87	1.96
Rome Beauty	2.14	1.82	1.91

On the basis of work done in other states and in Ohio, the range of 1.90 to 2.20 percent nitrogen on a dry weight basis is herein considered as an optimum range for total nitrogen in mid-shoot leaves of apple during late July. Using this range as a basis for classifying the surveyed orchards it was possible to estimate the extent of nitrogen deficiency and nitrogen excess in the 47 orchards sampled during the 1948 season. These data (Table 3) show that at least 50 percent of the orchards examined were within the optimum range proposed. In both the Stayman Winesap and Rome Beauty varieties a large percentage of the orchards (43 and 50 percent respectively) were found to be low in nitrogen. Approximately 1/4 of the Delicious and 1/3 of the Jonathan orchards were also below the desired nitrogen level. This indicates the seriousness of the nitrogen fertilization problem as it exists in Ohio orchards, for on the basis of these data it would appear safe to estimate that at least 30 percent of the commercial orchards in the state were suffering from nitrogen deficiency.

None the less important is the problem of excessive use of nitrogen. According to the survey data 4 percent of the Stayman Winesap, 23 percent of the Delicious, and 16 percent of the Jonathan trees in commercial orchards produced foliage with excessive amounts of nitrogen.

The detrimental effects of excessive nitrogen, particularly upon the quality of the fruit, are well known and will be discussed later in this report. At this time attention is merely called to the existence of this condition in certain commercial orchards.

TABLE 3.—The nitrogen status* of certain commercial apple orchards in Ohio. 1948

Variety	The Percentage of Surveyed Orchards in Low, Optimum, and High Nitrogen Status		
	Low	Optimum	High
Stayman Winesap	43	53	4
Delicious	26	51	23
Jonathan	33	51	16
Rome Beauty	50	50	none

*Based on an optimum range of 1.90–2.20 percent nitrogen on a dry weight basis.

FOLIAR APPLICATIONS OF UREA NITROGEN

During 1949, 1950, and 1951 extensive tests were conducted on the use of urea foliage sprays as a possible substitute for soil application of nitrogen. At the outset, it was believed that this method of applying nitrogen fertilizers possessed certain advantages not obtainable with the conventional method of early spring soil applications of nitrogen fertilizer materials.

First, it was thought that the foliar application of nitrogen would represent a distinct savings in labor since the material was compatible and could be applied in combination with the regular insect and disease control sprays. Second, it was thought that the supply of nitrogen could be more closely regulated in consideration of crop and seasonal requirements for nitrogen. During the three year period urea sprays were used on Stayman Winesap, Baldwin, Grimes Golden, Jonathan, and Rome Beauty varieties.

The most extensive tests were conducted on Jonathan and Rome Beauty. In this work three spray applications of urea were made commencing at petal fall and continuing through the first and second cover sprays. The amount of actual nitrogen applied was regulated so as to be equal to a soil application of 1/4 lb. of a 16 percent nitrogen carrier per year of tree age. By careful regulation of the gallonage applied, the amount of urea spray solution which dripped from the trees to the soil surface was held to a minimum.

The spray applications were compared with early April soil applications of equivalent amounts of nitrogen. Typical of the results obtained in this work were those for the year 1950 which are presented in Table 4. These results show that the Rome Beauty and Jonathan varieties responded somewhat differently to foliage applications of urea.

Shoot growth in each case was less with urea nitrogen applied to the foliage than with ammonium nitrate applied to the soil. This reduction in shoot growth was less severe with Jonathan than with Rome Beauty. The nitrogen content of leaves of urea sprayed Jonathan trees was slightly higher than that of ammonium nitrate treated trees, but with Rome Beauty the reverse was true. The yields of both varieties were seriously reduced when nitrogen was supplied with foliar applications of urea.

This condition persisted during the 1951 season as well, and in 1952 an attempt was made to overcome the difficulty by making four urea applications beginning with the pink spray instead of the three applications made in 1950 and 1951. Despite this earlier application of nitrogen supplied by the pink spray, Jonathan yields were well below the average for soil fertilized trees. The failure of urea sprayed trees to produce as well as soil fertilized trees may be due in part to the fact that the nitrogen was supplied too late to affect cell division in the fruit which is normally over by the time of the June drop.

The foliage applied urea was, however, capable of affecting shoot growth and influencing leaf nitrogen content as shown by the data in Table 4. Because of the nature of these results, it does not appear

TABLE 4.—A comparison of the effects of soil (ammonium nitrate) vs. foliage (urea) applications of equivalent amounts of nitrogen to 16-year old Rome Beauty and Jonathan apple trees. 1950

Treatment	Average shoot growth Inches	Average leaf N, 7/24 % dry weight	Average yield Bu. per tree
	Jonathan		
Ammonium Nitrate	6 3	2.34	4.2
Urea	5 8	2.42	2.8
No N	4.8	1.98	2.4
	Rome Beauty		
Ammonium Nitrate	7.0	2.44	6.6
Urea	6.3	2.38	6.0
No N	5.7	2.02	5.8

possible to consider foliage application of urea as a replacement for conventional soil application methods. It is more appropriately considered as a supplemental method of applying nitrogen to apple trees and one which may be useful in the event an unusually large crop of fruit is produced in a season when only a normal amount of nitrogen has been applied to the soil. Urea sprays should not be used after mid-June as they have been found to affect fruit color adversely when applied later than this date.

DIFFERENTIAL NITROGEN FERTILIZER STUDIES

Prior to 1948, work conducted at the Ohio Experiment Station showed that applications of nitrogen at rates three times the amount normally recommended decreased total yield (3). With this as a background, an experiment was initiated in 1948 where ½, 1½, and 2 times normal applications of nitrogen were compared with the normal rate on Baldwin and Stayman Winesap apple trees 26 years of age growing in sod.

The normal rate of nitrogen application is considered as ¼ lb. of a 16 percent nitrogen carrier per year of tree age. This treatment is herein referred to as the 1N treatment as opposed to ½N, 1½N and 2N treatments representing the different rates of application indicated above. These treatments were continued through 1951. In the spring of 1952 all treatments were reversed so that trees which previously received the ½N treatments now received the 2N treatment, those which formerly received the 1N treatment now received 1½N, the 1½N trees now became 1N trees, and 2N trees now became ½N trees.

The purpose of this reversal of treatment was related to the behavior of trees under the 2N treatment with respect to biennial bearing and will be discussed in greater detail under that subject. The treatments as reversed in the spring of 1952 were retained through 1956. During the nine years the experiment has been in progress, a great deal of information on the effects of nitrogen on tree performance has been obtained.

Effect on Leaf Nitrogen

Summary data for total nitrogen in leaf samples taken during late July for the years 1948 through 1955 are presented in Table 5. With minor exceptions, the general trend was for the nitrogen content of the foliage to increase as the nitrogen supply was increased. This trend is shown clearly by the mean values for the nine-year period for each of the varieties. The importance of these differences is indicated by the values for least significant difference accompanying Table 5.

It is especially important to note that with both varieties, the nitrogen content of the foliage of 2N treated trees was significantly higher than that of the 1N or normal nitrogen treated trees. The largest Baldwin crops were produced in 1949, 1951, 1954, 1955, and 1956 (Table 7) and in general it was in these years that the greatest differences between treatments were observed. Similar relationships were not observed in Stayman Winesap, primarily because it tended to be regular rather than biennial in bearing habit.

TABLE 5.—The average total nitrogen content of Stayman Winesap and Baldwin apple leaves from trees receiving different rates of nitrogen applied to the soil from 1948 through 1956

	Total Nitrogen as Percent Dry Weight							
Year	½N	1N	1½N	2N	½N	1N	1½N	2N
	Stayman Winesap				Baldwin			
1948	1.93	2.06	2.09	2.25	1.84	1.85	2.09	2.15
1949	1.79	2.04	1.99	2.15	1.87	2.02	2.12	2.20
1950	1.72	1.89	2.10	2.27	1.94	2.03	2.15	2.38
1951	1.62	1.73	1.85	2.10	1.72	1.94	2.04	2.18
1952	1.98	1.87	1.86	2.11	2.02	1.91	1.93	2.04
1953	2.01	1.91	1.99	2.05	1.79	1.89	1.93	1.89
1954	1.67	1.86	1.86	1.93	1.85	1.93	2.00	2.12
1955	1.92	2.21	2.24	2.29	1.98	2.25	2.16	2.27
1956	1.92	2.09	2.05	2.22	2.06	2.31	2.13	2.30
Mean	1.84	1.96	2.00	2.15	1.90	2.01	2.06	2.17

L.S.D. for treatment means—5% Stayman Winesap .09 Baldwin .08
1% Stayman Winesap .12 Baldwin .11

It was found that the correlation between leaf nitrogen and yield was highly significant for both the Stayman Winesap and Baldwin varieties (Stayman Winesap $r = 0.500$, Baldwin $r = 0.440$ for leaf nitrogen versus yield). Thus, within the limits of leaf nitrogen and yield encountered in this experiment as leaf nitrogen increased, yields also increased. This would indicate that apple trees producing a heavy crop of fruit need larger amounts of nitrogen than those producing lighter crops.

The optimum range for leaf nitrogen referred to in a previous section covers the range of from 1.90 to 2.20 percent of the dry weight. At first, this may appear to be a rather wide range but in light of the variations which occur between seasons and crops, it is believed to represent as close an estimate as is possible at the present time. In evaluating leaf analysis data for nitrogen, concentrations falling within this range must be reviewed with crop size in mind. For trees carrying a light crop a level of 1.90 percent nitrogen is very likely adequate. On the other hand, for trees carrying a heavy crop of fruit, a level of nitrogen near the 2.20 percent limit would appear to be more nearly adequate.

Effect of Nitrogen on Leaf Color

It has been recognized for many years that changes in the nitrogen supply were reflected in changes in leaf color. In 1945 (2) workers in New York devised a method for extracting the chlorophyll from apple leaves and by relating the quantity of green coloring matter to the concentration of nitrogen in the foliage, were able to prepare color standards for the McIntosh apple which could be used in estimating nitrogen status.

This technique was used for two years as a means of measuring response to nitrogen treatment both in the urea foliage spray work and in the differential nitrogen tests. Following this, an electrical device which measured reflectance from the green color of apple foliage was employed in place of extracting the chlorophyll (4). With both of these methods it was possible to obtain high correlations between the leaf nitrogen content and leaf color. Unfortunately, however, the leaf color values varied so greatly during the season and from one season to another that the quantitative measurement of leaf color as a means of diagnosing nitrogen status was discarded in 1953.

It should be emphasized that the technique was discarded as a research tool because it lacked the precision obtainable with chemical analysis for total nitrogen. This need not distract in any way from the observation of leaf color by growers in estimating the nitrogen needs of their orchards. It should be pointed out, however, that leaf color may be affected by factors other than nitrogen such as insect infestations or by deficiencies of elements other than nitrogen. It is true also that some varieties such as Rome Beauty produce foliage that is not as dark green in color as that of other varieties.

Effect of Nitrogen on Shoot Growth

Measurements of average terminal shoot growth were taken for six years beginning in 1950 (Table 6). For this purpose, twenty terminal shoots selected at random from around the tree were measured following the formation of terminal buds. These data were then summarized to obtain an estimate of the average growth made by terminal shoots by variety and by treatments for each year. The data are presented in Table 6.

TABLE 6.—The average terminal shoot growth of Baldwin and Stayman Winesap apple trees grown under differential nitrogen treatment

Year	Average Length of Shoots in Inches			
	½N	1N	1½N	2N
		Stayman Winesap		
1950	4.8	5.5	7.9	9.9
1951	7.4	7.8	10.5	11.5
1952*	6.7	7.5	7.2	7.1
1953	6.6	7.5	7.2	8.7
1954	6.9	8.1	9.1	9.6
1955	6.6	9.5	9.2	10.9
Mean	6.5	7.6	8.5	9.6
L S.D. for treatment means—5 % — 1.2 1 % — 1.6				
		Baldwin		
1950	6.0	6.6	7.8	10.0
1951	8.0	9.8	10.8	10.7
1952*	6.9	8.0	7.7	6.8
1953	6.6	8.4	8.5	8.5
1954	7.3	9.2	10 2	9.4
1955	7.1	11.0	9.7	8.6
Mean	7.0	8.8	9.1	9.0
L.S.D. for treatment means—5 % — 1.1 1 % — 1.6				

*The year in which treatments were reversed.

The general trend was for shoot growth to increase as the nitrogen application increased from ½N to 2N. This is apparent in the six-year means (Table 6) of both varieties. In the case of the Stayman Winesap variety, there was an average difference in shoot growth of about three inches from the lowest to the highest nitrogen treatment. With the Baldwin variety a two-inch difference was found. Shoot growth is considered as an additional index of nitrogen status and is one which fruit growers will find useful in evaluating their nitrogen fertilizer program.

In estimating shoot growth it is necessary to measure at least 20 representative terminal shoots per tree. These shoots should be selected from points around the entire tree. On mature bearing trees the average terminal shoot growth should be from 8 to 10 inches in length while on younger trees, terminal growth should average from 12-14 inches in length. According to data obtained on a number of varieties, these values would seem to apply to all standard varieties.

Effect of Nitrogen on Yield

For many years recommendations for nitrogen applications for apples were based on the "rule of thumb" of ¼ pound of a 16 percent nitrogen carrier per year of tree age. In so doing, it was recognized that this amount was too little in some cases and too much in others. It was, in fact, an application rate aimed at the average orchard and did not take into account that orchards below average in fertility needed more nitrogen fertilizer while those above average in fertility required less nitrogen fertilizer.

The purpose in setting up nitrogen treatments which bracketed this normal nitrogen application was to attempt to further refine the nitrogen requirements of mature bearing apple trees. One of the most important factors in evaluating response to treatment is yield. Since yields are influenced by many other factors including weather conditions preceding, during, and following bloom, and since these factors vary from year to year, the best possible estimate of the influence of nitrogen on yield may be obtained by evaluating the production records over several years. In the present work a total of nine years of yield records have been summarized in Table 7.

These yield data are comprised of two distinct periods, (Table 7), since all treatments were reversed in the spring of 1952. Differences in average yield between treatments were highly significant for the period from 1948 through 1951 for both varieties. For Stayman Winesap the 2N treatment averaged 5.9 bushels per tree more fruit than the normal nitrogen treatment and for Baldwin the advantage of the 2N treatment was represented by an 11.4 bushel per tree gain.

Following reversal of treatment in 1952, it was apparent that yields were influenced just as greatly by the nitrogen treatment of the previous four years as by the new nitrogen application rates. In 1952 the highest yields from both varieties were obtained under the ½N treatment. These trees had, for the previous four year period, received the 2N treatment and the carry-over effect is evidenced by the higher yields for 1952. In fact, with the Stayman Winesap variety the fruiting behavior since treatment reversal in 1952 never became positively associated with nitrogen treatment as was true from 1948 through 1951. This indicated that the influence of previous nitrogen fertilization treatment on flower bud formation and fruit production was not overcome entirely in as long a period as five years.

TABLE 7.—The influence of differential nitrogen fertilization on the yield of Stayman Winesap and Baldwin apple trees from 1948 through 1951 and from 1952 through 1956

	Average Yield in Bushels per Tree							
	½N	1N	1½N	2N	½N	1N	1½N	2N
	Stayman Winesap				Baldwin			
1948	9.5	9.6	7.3	18.9	1.2	1.9	3.1	10.0
1949	1.2	2.4	3.1	4.7	21.4	20.0	28.5	26.3
1950	0.1	0.2	1.5	3.9	0.3	0.7	5.1	24.0
1951	2.8	5.7	8.4	14.0	16.2	20.9	22.3	30.8
Mean 1948-51	3.4	4.5	5.1	10.4	9.8	10.9	14.7	22.3
1952	7.2	4.6	4.2	5.5	4.7	0.9	3.1	1.6
1953	7.6	6.4	10.3	9.4	0.8	1.6	5.3	4.1
1954	5.8	3.6	5.4	3.7	18.9	14.9	22.0	18.3
1955	17.0	11.8	15.1	12.1	10.8	12.3	15.0	21.9
1956	22.0	5.1	12.5	9.6	25.6	17.3	19.5	12.6
Mean 1952-56	11.9	6.3	9.5	8.1	12.1	9.4	13.0	11.9

L.S.D. for 1948-51 treatment means: 5% Stayman Winesap 3.7, Baldwin 6.9
1% Stayman Winesap 5.3, Baldwin 9.9

L.S.D. for 1952-56 treatment means: 5% Stayman Winesap N.S. Baldwin N.S.

With the Baldwin variety, following reversal of treatment, it was not until 1955 that yields increased as the nitrogen application increased. It would appear that the heavier production of the Baldwin over that of the Stayman Winesap variety brought about this change more quickly and it is suggested that heavy fruiting used up the reserve nitrogen stored within the tree during the first four-year period when high rates of nitrogen were applied.

It is more likely that the carry-over effect of high nitrogen applications resulted from reserves within portions of the tree other than leaves rather than from reserves of nitrogen in the soil.

Considering only total yield, there seems to be no question as to the advantage of twice normal applications of nitrogen. It must be recognized, however, that these results apply to the particular set of conditions under which the experiment was performed. In other locations, comparable results might be obtained with either more or less nitrogen than applied in this instance.

Just as important as the effect of 2N nitrogen applications on total yield is the finding that high rates of nitrogen application for several years may exert a residual effect on the fruiting behavior of apple trees for a number of years after the treatment is changed to a lower rate. The length of this period appears to be dependent somewhat upon the rate at which fruit production uses up these nitrogen reserves.

Effect of Nitrogen on Biennial Bearing

So closely associated with the matter of yield that it can hardly be separated is the matter of biennial bearing. Of the two varieties included in this study, Stayman Winesap is usually considered as an annual or regular bearing variety, while Baldwin is an alternate bearing or biennial variety. During the first four-year period of the experiment it was noted that when 2N applications of nitrogen were made beginning in the spring of the off-bearing year and continuing each year thereafter, regular annual crops were produced (Table 7).

In addition to gaining information regarding the carry-over effect of previous nitrogen treatment referred to in the previous section, one of the primary reasons for reversing treatments in 1952 was to determine if 2N applications of nitrogen could again induce regular bearing on the Baldwin variety.

From the data in Table 7 it is obvious that the ½N trees from 1948 through 1951 were producing alternate light and heavy crops. In the spring of 1952 these ½N trees were reversed in treatment and thereafter received the 2N treatment. In 1952 and 1953 light crops of fruit were produced by Baldwin trees of all treatments. In 1954 trees of all treatments produced a relatively heavy crop. The following year trees receiving the ½N, 1N, and 1½N treatments produced less fruit than in 1954 while the 2N treated trees produced a slightly larger crop than in the previous year. In 1956 the yield of the 2N Baldwin trees was lowest of any treatment but still did not characterize a typical biennial bearing pattern. Certainly, there appears to have been some benefit from 2N applications of nitrogen in helping smooth out the biennial bearing habit even during the second cycle of the experiment following treatment reversal in 1952.

It is not implied that this is the only method of helping prevent or of correcting biennial bearing. Other practices helpful in correcting the trouble include fruit thinning, pruning, or other cultural methods. Heavy annual applications of nitrogen, have, in this case, appeared to be of help and are suggested as another possible means of avoiding successive light and heavy crops of fruit on varieties which tend to bear biennially.

Effect of Nitrogen on Fruit Quality

With the ever increasing demand on the part of consumers for high quality apples, attention has been focused on the effects of various production practices upon the quality of the fruit produced. Among fertilization practices the use of nitrogen fertilizers have come under the sharpest criticism in this regard. This is due in part to the fact that nitrogen fertilizers are more widely used than other fertilizer materials.

Actually the problem resolves itself to this question—how much nitrogen fertilizer can be applied so as to promote good growth and highest possible yields without seriously sacrificing fruit quality? The answer lies in the evaluation of the effect of nitrogen treatment upon the various factors which contribute to fruit quality. In the work discussed herein the quality factors taken into consideration were fruit color, fruit size, the total acid content, the soluble solids content, and the ratio of soluble solids to acids. These data are summarized in Table 8.

Fruit color was determined on a randomly selected 50-fruit sample taken at harvest time from each tree of each treatment. For the Stayman Winesap variety the fruit color data appearing in Table 8 represent an average for the years 1948, and 1951 through 1955. In 1948 fruit with 50 percent or more of the surface colored red were considered well colored. From 1951 through 1955 only those fruit with 66 percent or more of their surface colored red were considered well colored.

TABLE 8.—A summary of fruit quality indices of Stayman Winesap and Baldwin apples grown under differential nitrogen treatment. Wooster, Ohio. 1948 through 1955

Treatment	Percent well-colored fruit	Bushels well-colored fruit	Average weight per fruit pounds	Percent of fruit 2¾" and larger	Percentage		Soluble solids acids ratio
					Titratable acids	Soluble solids	
			Stayman Winesap				
½N	70	4.4	0.361	59	0.563	13.23	24.38
1N	61	3.4	0.357	66	0 559	13.10	24 13
1½N	50	3 5	0.354	63	0.560	13.45	24.40
2N	43	3.9	0.366	74	0.563	12.77	22.45
			Baldwin				
½N	58	5.3	0.384	77	0.782	13 38	17.39
1N	49	4.5	0 406	84	0.766	12.69	16.77
1½N	40	5 2	0.402	80	0.760	12.99	17.50
2N	34	5.8	0.401	85	0.772	12.72	16.70

For Baldwin the fruit color data represent the average for the years 1948 through 1955. From 1948 through 1951 fruit with 50 percent or more red surface color were considered well colored while from 1952 through 1955 only those fruit with 66 percent or more of their surface colored red were considered well colored. The bushels of well-colored fruit were obtained by multiplying the average total yield (Table 7) by the percentage of well-colored fruit.

With each variety the percentage of well-colored fruit decreased as the nitrogen rate increased. This has been observed in many instances and is commonly construed to mean that the application of nitrogen fertilizers lowers the production of well-colored fruit. However, when the increased yield resulting from nitrogen application is considered it will be noted that the total production of well-colored fruit was greater in the case of the 2N treatment than under the normal nitrogen treatment for both of these varieties (Table 8). Therefore, from the standpoint of fruit color, the 2N treatment appeared to be the most advantageous.

The average weight per fruit (Table 8) was obtained from the same 50 fruit sample used for color estimations. The Stayman Winesap data include the years 1948 and 1951 through 1955 while the Baldwin data are for the years 1948 through 1955. The average weight per fruit did not vary greatly between nitrogen treatments. For Stayman Winesap the smallest fruit weight for the six year average was obtained under the 1½N treatment and the largest with the 2N treatment. With the Baldwin variety the smallest fruit weight occurred under the ½N treatment and the largest under the 1N treatment.

In the Baldwin variety, the individual yearly data showed that the largest fruit were produced in years when light crops were produced and the differences in fruit weight between heavy and light crop years were much greater than those associated with differential nitrogen treatment. During years of light crops the average fruit weight for Baldwin was 0.432 lbs. while in heavy crop years it was 0.372 lbs.

Although the average fruit weight was not closely associated with nitrogen treatment, the percentage of the crop of good size did appear to be influenced. From 1952 through 1955 a 50 fruit random sample from each tree of each treatment was carefully graded as to size and these results are summarized in Table 8. With Stayman Winesap 66 percent of the fruit of the 1N treated trees were 2¾″ in diameter or larger, while the 2N treated trees produced 74 percent of their fruit of this size. In the case of Baldwin, the difference was not as great but the 2N treatment still produced the highest percentage of large apples.

Thus from the standpoint of fruit size the 2N treatment appeared to offer the greatest likelihood for producing a higher percentage of large fruit.

The same fruit samples used for fruit color and weight estimations were finally pressed to obtain the juice on which soluble solids and titratable acids could be determined. Soluble solids were determined with the Abbe refractometer and a 10 Ml. aliquot of the juice was titrated to pH 8.3 with 0.1N NaOH to determine acids which are expressed as percent tartaric acid. The differences in acid content of the fruit juice resulting from differential treatment were not of sufficient magnitude to justify the drawing of conclusions (Table 8).

The soluble solids content of Stayman Winesap fruit appeared to be lowered by the 2N treatment. With Baldwin any nitrogen treatment larger than the ½N treatment appeared to have been associated with a slight decrease in the soluble solids content of the fruit. The soluble solids-acids ratio is believed to be indicative of edible quality because it represents the balance of sugar to acid in the fruit. These ratios show that for Stayman Winesap the 2N treatment resulted in a slight reduction in the ratio of sugars to acids in the fruit which probably was associated with a slight decrease in edible quality.

In the case of Baldwin the differences were less pronounced but it would appear that acceptable ratios were obtainable when as much as 1½ times the normal application of nitrogen were made. Because these differences are small for both varieties and because the exact interpretation which should be placed on such data are not known it is doubtful if a great deal of significance can be placed on the differences noted herein.

Because of the alternate bearing exhibited by the Baldwin trees, it was possible to make certain observations on the influence of crop size on fruit quality. For this purpose the seven years of data on soluble solids, titratable acids, and the soluble solids-acids ratios were grouped into two categories according to years of light versus heavy crop production.

When these data were summarized it was found that during the light crop years the fruit contained 14.11% soluble solids, 0.8490% acids and had a soluble solids acids ratio of 16.79. In heavy crop years the fruit contained 12.20% soluble solids, 0.7188% acids, and had a soluble solids-acids ratio of 17.29. In other words, heavy production was associated with a reduced solids and acids content of the fruit, but proportionately, the acids showed a greater decrease resulting in a slightly higher ratio during heavy crop years.

The effect of differential treatment on soluble solids, titratable acids, and on the soluble solids-acids ratio were slight. In view of the more consistent influence of the differential nitrogen treatments used in this experiment on yields, fruit size, and quantity of well colored fruit produced, the practical significance of the influence of treatment on the soluble solids and acid content of the fruit is seriously questioned.

Effect of Nitrogen on the Accumulation of Other Elements

This experiment offered an excellent possibility to study the influence of differential nitrogen treatment on the accumulation of certain other essential nutrient elements in apple foliage. In 1948, and from 1951 through 1955 foliage samples of these two varieties taken primarily for total nitrogen determinations were subjected to total quantitative analysis for calcium, magnesium, and potassium. The 1953 through 1955 leaf samples were also analyzed for total phosphorus. The results are presented in Table 9.

TABLE 9.—The influence of differential nitrogen treatment on the accumulation of phosphorus, potassium, calcium, and magnesium by Stayman Winesap and Baldwin apple leaves sampled in late July

Treatment and variety	Phosphorus percent of dry weight	Potassium percent of dry weight	Calcium percent dry weight	Magnesium percent dry weight
		Stayman Winesap		
½N	0.172	1.32	1.45	0.308
1N	0.163	1.29	1.45	0.310
1 ½N	0.151	1.19	1.40	0.306
2N	0.163	1.09	1.51	0.337
L.S.D. 5 %	N.S.	.09	N.S.	N.S.
1 ½	N.S.	.12	N.S.	N.S.
		Baldwin		
½N	0.186	1.46	1.32	0.282
1N	0.186	1.33	1.35	0.317
1 ½N	0.158	1.24	1.34	0.294
2N	0.169	1.23	1.46	0.305
L.S.D. 5 %	.02	.09	N.S.	N.S.
1 %	N.S.	.12	N.S.	N.S.

These data show that under the conditions of this experiment, considering the elements calcium, magnesium, potassium and phosphorus, only potassium was affected significantly. In this case there is clear evidence that as the nitrogen rate increased the accumulation of potassium in the foliage decreased. The potassium content of the foliage of Stayman Winesap trees which received the 2N treatment closely approached the level of potassium considered as critical. This could be interpreted to mean that under conditions of heavy fertilization with nitrogen, potassium may become limiting.

It certainly means that growers following a heavy nitrogen fertilizer program should observe carefully for the occurrence of potassium deficiency. Although the difference between treatments for the other elements were not highly significant, the tendency may be noted for calcium and magnesium to increase with increasing rates of nitrogen and for phosphorus to decrease as nitrogen was increased from ½N to 1½N and then to increase under the 2N treatment.

RECOMMENDATIONS FOR NITROGEN FERTILIZATION

1. Annual applications of nitrogen are required for the successful production of apples in Ohio. Unless nitrogen is supplied by applications of manure or by the maintenance of a permanent mulch, the annual requirements must be met by applications of commercial nitrogen fertilizer materials.

2. The most reliable and precise indicator of nitrogen needs found in these experiments was foliar analysis for total nitrogen. For this purpose, mid-shoot leaves sampled during late July were used. The optimum nitrogen content of these leaves is believed to be from 1.90 to 2.20 percent of the dry weight.

3. Nitrogen needs were found to vary within these limits from season to season and with size of crop. In years when light crops are produced, levels of leaf nitrogen near the lower limit of 1.90 percent appear to be adequate. When large crops are produced, better growth and production are obtainable when the July leaf nitrogen content approaches the 2.20 percent level.

4. Leaf nitrogen was found to vary with tree age. Young vigorously growing trees up to 15 years of age were found to produce foliage which was highest in nitrogen. During the period from 16 through 25 years, the leaf nitrogen content was lowest. Trees 26 years and older were found to produce foliage with intermediate nitrogen contents.

5. Unless accurate methods for leaf analysis for total nitrogen and for the interpretation of the results are available, growers are urged to evaluate their nitrogen fertilizer program by careful observations of tree response. For this purpose leaf color, shoot growth, fruit size, color and quality at maturity, and total yield should be examined.

6. All of the readily available forms of commercial nitrogen carriers are suitable for supplying the nitrogen needs of apple trees. The primary consideration in selecting a nitrogen carrying fertilizer should be the cost per unit of nitrogen contained in the material. In the present work soil applications of sodium nitrate, ammonium sulfate, and ammonium nitrate were used without any observable difference. For foliage application the easily soluble urea form of nitrogen was used. On the basis of these experiments, foliage applications must be considered as a supplement to rather than a substitute for soil applications.

7. Soil applications of nitrogen should be made in the early spring each season about 6-8 weeks preceding bloom. Soil applications of nitrogen should not be made after June 1st as they are likely to stimulate excessive growth which will not mature adequately before cold weather. Late applications are also more likely to prevent good fruit color development. In applying nitrogen fertilizer materials to the soil, the material should be carefully measured as to the quantity per tree and should be spread uniformly over an area extending from a foot or two from the trunk outward to beneath the tips of the branches.

8. How much nitrogen to apply: As has been indicated, this was found to vary with tree age, and size of crop. It will also vary with general conditions of soil fertility. The rate of ¼ lb. of a 16 percent nitrogen carrier per year of tree age is a good average recommendation, but in certain cases this amount is inadequate while in others it may be too much. It is recommended as a beginning point with the understanding that the grower must observe shoot growth, leaf color, fruit size and quality, and total yield, and may then wish to adjust the rate of application so as to obtain the best response under conditions of soil and environment prevailing in his orchard.

9. Nitrogen fertilization in relation to biennial bearing: The results of the present work indicate that twice normal applications of nitrogen were of decided benefit in helping correct biennial bearing of Baldwin apples. It is suggested that growers experiencing this difficulty may wish to try this procedure in their own orchards. If so, the initial application should be made in the spring of the off-bearing year and continued each year thereafter. Since the results of the present work apply only in the particular orchard where the test was conducted, the exact rate of application can not be forecast for all conditions. As an average recommendation, the rate of ½ lb. of a 16 percent nitrogen carrier or its equivalent per year of tree age is suggested.

10. Nitrogen fertilizer application was shown to influence the accumulation of other essential elements, particularly that of potassium. For this reason, orchards under a high nitrogen fertilizer program should be carefully observed for the occurrence of potassium deficiency. The indications are also that low nitrogen status is likely to be conducive to the occurrence of magnesium deficiency.

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