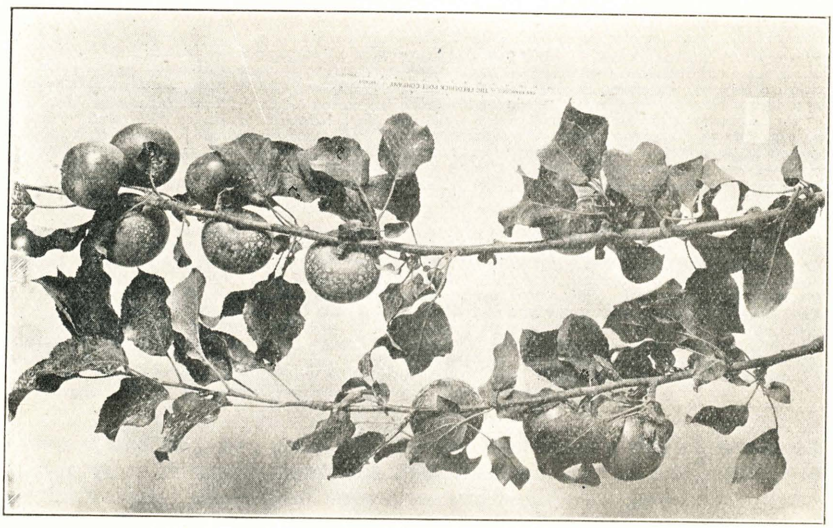
Nitrogen Carrying Fertilizers and the Bearing Habits of Mature Apple Trees
Michigan State University Agricultural Experiment Station
Special Bulletin
F.C. Bradford, Horticulture
Issued January 1924
31 pages

Oakley Lardie

Special Bulletin No. 127 January, 1924

Nitrogen - Carrying Fertilizers and the Bearing Habits of Mature Apple Trees

BY F. C. BRADFORD



AGRICULTURAL EXPERIMENT STATION
MICHIGAN AGRICULTURAL COLLEGE

HORTICULTURAL SECTION

East Lansing, Michigan

Nitrogen-Carrying Fertilizers and the Bearing Habits of Mature Apple Trees

F. C. BRADFORD

". . . . . we ought to ameliorate this soil more or less according to the crops we demand of it, be they beyond its powers or in accord with its ability and to ameliorate it also more or less according to its temper, good or bad; ample manuring, for example, is necessary to produce pot-herbs, which grow in abundance in a short time and follow one another closely in a small compass of ground, which without this might grow barren; on the other hand, it is needed little or not at all to nourish trees, which, being long a-growing, make but inconsiderable crops compared to the ground they occupy and lastly, though they remain a very long time in the same place, nevertheless, by means of their roots, which stretch out to right and to left, make a shift to pick up the nourishment which is proper for them, far and near."—*J. de la Quintinye, Instruction pour les jardins fruitiers et potagers. Paris. 1756. p. 166.*

"Certain gardeners reject manure as injurious to trees and to the quality of the fruits. It is certain that one ought not to manure young trees, which cannot have exhausted the land where they are planted, at least unless it be very bad, in which case it is not suitable for planting to trees, which, even with the help of fertilizers, would never succeed well there. Likewise, manure is useless and could even be harmful to trees which grow with vigor and develop their fruits well. But when the trees are of moderate vigor, it is good to sustain them with a little fertilizer; and when their crops show that they are becoming feeble, or that they are suffering, it is necessary to manure them in order to reanimate them and to furnish them a more abundant subsistence, without fearing lest the quality of the fruits be thereby altered * * * *. Finally, the practice of the most skillful cultivators, authorized by success, leaves no chance of doubt but that, in default of good soil, manure is beneficial to trees."—*Duhamel du Monceau, Traite des arbres fruitiers. Paris. 1768. p. 112.*

One hundred and fifty-five years ago the two best known French works on fruit growing were in nearly complete disagreement on the advisability of manuring fruit trees. Since that time chemical fertilizers have been substituted to a considerable extent for manures, permitting trials of materials of known and more uniform composition than manures, but in the orchards of this day experiences with these materials differ and evidence even from careful experiments is contradictory. In some cases the gains from applications of nitrogenous fertilizers in apple orchards have been outstanding and undeniable; in other orchards it is just as clear that applications of these same materials have been without measurable effect on the crops.

In several Michigan apple orchards, fertilization with nitrogen carriers—chiefly sulphate of ammonia or nitrate of soda—has resulted in such remarkable yield increases that it has become an established practice with many growers and the amount of materials used for this purpose has increased prodigiously since 1920. So alluring is the hope of similar crop increases in other orchards that the practice is likely to become more and more widespread and there is strong probability that enthusiasm will lead to such indiscriminate use of these fertilizers as to cause disappointment and loss in numerous cases.

Many growers are familiar with the manufacture of Bordeaux mixture. They know that if so much copper sulphate and so much lime are properly combined the product is the material known as Bordeaux mixture. If the amounts of ingredients are doubled, the amount of product is doubled, and so on. It is easy and natural to regard the apple tree as a tank containing some substance which, mixed with nitrogen, produces apples. It also is easy and natural to hope that with more nitrogen, more apples will be produced and that this reaction can be repeated indefinitely, anywhere, at any time, with good trees and poor trees, young trees and old trees, good soil and poor soil, good sites and poor sites. There is a tendency toward too much faith that a little waving of the hand spreading the magician's compound will conjure forth apples and more apples and yet more apples, and too little thought about what must happen under the magic cloth to produce those apples. Furthermore, the comparatively small cost per acre and the ease of application of these fertilizers make it easy for the optimist to slight other practices on the assumption that fertilizer will pull him through, to rely on fertilizers producing so many apples that insects and fungi cannot reach them all.

These tendencies combine to render desirable a thorough appraisal of what fertilizers have actually accomplished in some orchards and, through a close scrutiny of the means by which they have acted, a statement of what they may be expected to accomplish in other orchards and under what circumstances these expectations are warranted. It is important to know whether they will accomplish more in a run-down orchard or in an orchard that is in good condition; whether they heal the sick or bless the prosperous trees, whether they should be applied every year to produce extra crops or only in the bearing year to bring the crop from the bud to the barrel, whether they will eliminate the necessity of pruning and cultivation or make these practices more imperative than ever. The whole story probably will be reasonably simple when it is fairly well known; it will, however, be long and complex in the assembling.

HOW FERTILIZERS MIGHT AFFECT YIELDS

Increased yields in apple trees may conceivably be secured in at least four rather distinct ways: (1) through an increase in the size of the individual fruits; (2) through an increase in the percentage of fruits developing ("set") from a given number of blossoms, or, to state it conversely, through a reduction in the "drop"; (3) through an increase in the percentage of buds which develop blossoms, or, what is practically the same thing, an increase in the frequency of fruit bud formation; (4) through an increase in the number of growing points and consequently of potential fruit buds.

WHERE FRUIT BUDS FORM

Since those possible effects of fertilizers which constitute the major portion of the matters under present consideration involve certain modifications of the bearing habit, easily recognized by examination of the branches, a statement of the ordinary bearing habit of vigorous bearing apple trees is given here as a standard of comparison. With due allowance for varietal differences, marked deviations from the normal may be taken as, in some degree at least, symptomatic and consequently valuable in diagnosis and indicative of the desirability of improvements in culture.

Careful study will show that apple trees and branches grow on a definite system and depart from it generally in degree only. At the tip of the main axis is, obviously, the youngest wood. Following the twig down from the tip the careful observer will note a ring extending around the twig and composed of numerous narrow scars arranged transversely to its axis. These are the scars left by the scales which covered, during the previous winter, the bud from which growth started in the spring. If examined while it is in leaf, the twig will show a single arrangement of the leaves; that is, no two comes out at the same point. In the angle between the twig and the leaf stalk, there appears a small lateral bud referred to as the axillary bud. Except at the base of the year's growth and near the tip of very vigorous shoots, there is one of these for each leaf; they persist after the leaves drop. As the summer advances, growth stops and a bud forms at the tip; this is called the terminal bud. That part of the twig between the terminal bud and the first ring of scale scars (called for sake of brevity the "annual ring"), is generally termed the "one-year-wood"; on it are, it has been explained, one terminal and numerous axillary (lateral) buds.

Study of the present two-year-wood (that part of the twig between the first annual ring, marking the end of last year's growth, and the second ring, marking its beginning) shows what has become of the axillary buds of last year. Some of them have not started; incidentally, most of those that have not, never will. From others, however, growths have pushed out. In some cases the growth is rather long, varying somewhat with the age and condition of the branch. More often, however, in bearing trees, the growth is short, and is virtually a rosette of several leaves on a very short axis. These shorter growths are the young spurs.

A forecast of the next year's behavior of these spurs can be secured from examination of those that are a year older. These obviously can be found on the twig in the zone between the second and third annual rings. Here, on a stem that is in its third year, and on spurs that are in their second, fruit will be found, in the appropriate season. In brief, then, the history is this: first season, axillary bud; second season, young spur; third season, fruit. More concretely this may be stated: in 1923, lateral bud formed; in 1924, young spur formed; in 1925, fruit borne; fruit may be expected, then, on wood that is two years old and in its third season.

This condition may be considered ideal. It is, however, an attainable ideal. It is the common condition in young trees just entering heavy bearing and in vigorous older trees; it may be found in trees 50 or 60 years old. The extent of the deviation of a tree from this standard is a measure of its vigor and an index of its future productivity.

After bearing fruit, a spur commonly "rests" a year and bears again in the second year. That is, a spur arising from an axillary bud formed in the even year should bear its first fruit in the next even year, its second fruit in the following even year and its subsequent fruits in the subsequent even years. An axillary bud formed in the odd year should similarly lead to fruit in the odd years. Theoretically and ideally, then, if a tree made, each year, a uniform growth and formed a uniform number of spurs, it would have half of them bearing in the even years and half bearing in the odd years. There would be no off years.

Young trees and new wood on vigorous old trees show an approach to this condition, but sustained production of this sort is very rare indeed. Ordinarily, growers believe that the most they can expect is a crop on most of the spurs one year and little or none the next; actually in many orchards the crop year comes even less frequently. For the purpose of this study the standard condition is considered to be the ordinary alternation of crop year and off year.

At times other types of fruit bud formation may assume importance. The terminal buds at the ends of the shoots may develop blossom buds;

these are conveniently called "terminal fruit buds," though, to be exact, the fruit buds on spurs likewise are terminal to the spur. This terminal fruit bud formation on long shoots is frequently the source of the first crops on young trees and much of the off-year crop in older trees of many varieties comes from this source. It is, however, obvious that the number of fruit buds possible at the tips of branches is far less than that possible on the spurs ranged along the branches, and, in general, terminal fruit buds are far less important in the constitution of the crop than those on spurs.

The formation of fruit buds in the axils of the leaves on shoots of the current season, bringing blossoms at these points a year ahead of the normal or "ideal" condition recently outlined, is perhaps more common than is generally realized. On young trees of some varieties, as, for example, Wagener, fruit from these axillary (or lateral) fruit buds may constitute,with that from the terminal fruit buds, the early crops gathered before the spurs have settled down to bearing. This type of bearing is common also in older Wealthy trees that are bearing heavily in alternate years. Since it occurs in such cases only in years of heavy blossoming throughout the tree, its only effect is to increase slightly the crop of the bearing year and this is done under circumstances that do not make it particularly advantageous. The percentage of fruit set from axillary blossoms is generally small and in many cases these precocious spurs die, so that instead of live spurs ready to bloom in due season the tree has spurs which have died without bearing fruit. Occasionally, it is true, these buds provide a "consolation prize" when the rest of the crop has been destroyed by a spring frost; they open later than the others and when the blossoms in other positions fail to set fruit the percentage set from these seems to increase. Generally, however, the contribution of axillary blossoms to the apple crop is meagre.

No very involved mathematical analysis is necessary to show that, in a mature apple tree, terminal and axillary fruit buds combined can constitute but a small fraction of the total fruit buds possible. After a tree has, for a succession of years, been forming two or three or more spurs per shoot annually, the proportion of buds on the one-year-wood of the shoots to those on spurs cannot be great. Consequently, aside from possible effects on the size and the set of the fruit, any considerable and consistent increase in the apple crop must be secured through increasing the number and improving the performance of the spurs. These criteria are applied in this paper as the chief measures of the effect of fertilization with nitrogen-carrying materials in three Michigan orchards.

THE TEST ORCHARDS

Since the spring of 1920, fertilizer applications have been made in numerous apple orchards by this Experiment Station and by the Extension Service. In some cases rather detailed yield records are being taken; in others this has been impracticable. Some of these orchards no longer offer comparisons between fertilized and unfertilized trees because the owners, after observing the differences induced by the applications, have been satisfied as to their desirability and, considering the continuance of the unfertilized blocks unnecessary and expensive, have fertilized all the trees. On the other hand, some tests have been discontinued because no effects attributable to fertilizers have been observed.

Among these orchards, three have been selected as offering valid comparisons between fertilized and unfertilized trees under conditions justifying somewhat detailed study.

The Farrand orchard, owned and operated by Mr. Warren Farrand, at Eaton Rapids, Eaton County, affords a very good opportunity for the investigations reported here. The soil would not be classed as particularly productive for general agricultural purposes, though with proper liming adjacent fields have produced good crops of alfalfa; crops growing in this soil type show the effects of drought very markedly. The orchard is composed almost wholly of old Ben Davis trees, in a remarkably uniform stand, set about 35 feet apart, and kept in sod for some years. Some black rot cankers may be found, but the chief disorders of the trees bear close resemblance to drought injury. The trees have been well sprayed for some years; the pruning has been very light. In the past, some very large crops have been produced.

Seven plots are being used in the fertilizer trials in this orchard; one is retained unfertilized, while the others have received fertilizer of one kind or another, singly or in various combinations. One of these plots has been started but recently and was not considered in this study; the others are composed each of three rows of six trees. To guard against possible confusion from overlapping of fertilizer effects through far-reaching roots, though there is no evidence that this has occurred, only the middle row of each plot was studied. The figures reported from this orchard, therefore, were drawn from examination of 36 trees; of these, 24 had received nitrate of soda or sulphate of ammonia, in part singly and in part combined with potash or acid phosphate, while 12 had received no nitrogen, though six had received acid phosphate. Records for each plot were taken singly and summarized singly; but since the differences between the various plots receiving nitrogen appeared trivial and those between the two plots receiving no nitrogen likewise trivial, while the differences between the two groups of plots were striking, the figures are combined for presentation here into two groups, representing conditions respectively in the trees receiving nitrogenous fertilizers and in those receiving no nitrogen.

The Quinlan orchard, in Ottawa County, but near Grand Rapids, is composed of Duchess (Oldenburg) trees, of full bearing age, planted only 16 feet apart, with the tops now interlacing. Soil conditions in those portions of the orchard considered here appear uniform to the eye; the soil is probably richer, for general agricultural purposes, than that in either of the other orchards studied. For some years, at least, cultivation has been practiced more or less each year, but the yields, prior to 1920, had not been satisfactory. In this orchard, closeness of planting is evidently the primary factor limiting productivity.

Numerous plots have received fertilizer; of these, two were selected for the present comparison: the unfertilized plot and that receiving sulfate of ammonia before blossoming. These plots are laid out in three rows each, the two outside rows of each serving, as in the Farrand orchard, for buffer rows. They contain no seriously defective trees; there are no vacancies within the rows studied and only one vacancy adjoining any of the trees included. The figures presented here are gathered from six trees in each plot.

The Abbott orchard, owned and managed by Mr. Charles Abbott, at Fennville, in Allegan County, furnishes the third comparison. This is composed chiefly of Wealthy trees, about 35 years planted. Despite the implication conveyed by some vacancies, the remaining trees are generally in sound condition. For the last five years it has been in sod. The orchard was rather slow in coming into heavy bearing but has lately been very productive, some of the trees bearing in the even years and some in the odd years. The trees were set 33 feet apart; the tops, however, are not meeting. A considerable amount of pruning has been done, chiefly thinning, so that the tops are fairly open.

For experimental purposes, this orchard is the least satisfactory of the three, because the surface is slightly rolling and the trees somewhat variable in size, those in shallow depressions being considerably the more vigorous. Though several fertilizer treatments have been under trial, careful study was confined to six trees receiving five pounds of nitrate of soda and to eight trees which had received no fertilizer until this spring, when all were fertilized. Not all of this latter group were in the check plot as originally laid out; some from outside the trial block were included as substitutes for trees of odd varieties in the check plot and some as, so to speak, a check on the check plot.

In no case were trees at the ends of rows considered.

METHODS OF OBTAINING DATA

The data reported here were gathered from measurements and counts on twenty-five shoots on each tree, except that in one plot in the Farrand orchard, where one tree was missing, thirty shoots from each of the remaining five trees were used. Shoots were selected somewhat at random, the only limitations being that no shoot which had been broken or pruned within six years was chosen and that no shoot was used which came from a limb notably inferior to its neighbors. For the most part, these shoots were the tips of long branches, representing at least ten or twelve years' growth from the parent limb, or, indeed, wherever such selection was possible, they were the tips of the scaffold limbs themselves. Care was exercised to have the various quadrants of the tree's circumference equally represented in the sample. Since the work was done on shoots within reach from the ground, the conditions found may differ from those in the upper branches. For comparative purposes, however, this method of selection seems justifiable, inasmuch as it was followed consistently.

For each shoot, record was made: (1) of the growth in length for each of the years 1918 to 1923 inclusive, (2) of such terminal blossoming as had occurred, (3) of the spurs originating from each year's growth, their lengths, years of blossoming and of dead and broken spurs. From these notes the data here presented are derived.

In addition, records of length growth and years of blossoming were taken from 25 spurs on each tree, selected in a manner like that used in selecting the shoots. Distinction between spur and shoot is at times difficult, as it is occasionally between tree and shrub, though in either case the terms carry rather definite and well understood meanings. Sometimes a certain length growth in any one season is arbitrarily assumed to be the point of demarcation; there is, however, some reason to believe that the number of leaves may be fully as accurate a criterion as the length growth. In collecting the data reported here, though no arbitrary standard was used, difficulty in assigning a twig to one class or the other was rarely encountered.

Twigs proceeding from points on the limbs well back from the tips, generally from wood over ten years old, and not showing marked growth in any single year, were included as spurs. In the Duchess trees, most of these were found near the center of the trees, but in the Ben Davis the density of the outside growth had made spurs in this position very scarce and it was necessary to select the samples from points nearer the ends of the branches. In the Wealthy trees the distribution was intermediate between those of the other two. In all cases, of course, spurs could be found in abundance on the outside of the tree, but since an effort—successful in the main—was made to secure spurs of at least ten years' growth, it was necessary to use those arising farther back.

Effects of Fertilizers

ON THE SHOOTS

On length growth. Length growth of shoots is, regardless of its direct importance, a generally recognized measure of the response of many plants to fertilization. In bearing apple trees, however, even a simple standard such as this must be applied with discrimination. Branches which blossom terminally tend to make less terminal growth during that same season than similar branches which do not blossom; this means that the more fruitful a tree is in its terminal shoots, the smaller its average growth will be. Consequently, comparison of shoot growth in a bearing tree and in a non-bearing tree would not be valid without some uniformity in the type of shoots used as standards. For this reason the comparison between shoot growth in fertilized and in unfertilized trees made in Table I is based on measurements of those shoots which have not blossomed in the current year. Even .this comparison is open to some objections; these, however, are believed not to be of great importance in the present case, and the averages appearing in the data may be considered representative of actual growth.

Table I.—Average Length Growth of Non-blossoming Shoots in Fertilized and in Unfertilized Trees (in Centimeters).

	1918	1919	1920	1921	1922	1923
Farrand Orchard (Ben Davis):						
Fertilized since 1920	8.7	5.4	7.2	8.6	9.0	7.4
Unfertilized	8.7	5.9	6.3	4.7	6.6	3.8
Difference	*0*	*−0.5*	*+0.9*	*+3.9*	*+2.4*	*+3.6*
Quinlan Orchard (Duchess):						
Fertilized since 1920	8.1	4.7	6.6	10.5	11.8	5.1
Unfertilized	7.2	3.7	5.7	5.3	5.0	3.8
Difference	*+0.9*	*+1.0*	*+0.9*	*+5.2*	*+6.8*	*+1.3*
Abbott Orchard (Wealthy):						
Fertilized since 1920	16.9	11.8	14.1	8.8	4.9	4.7
Unfertilized	15.9	12.3	14.1	7.4	3.3	*3.7
Difference	*+1.0*	*−0.5*	*0*	*+1.4*	*+1.6*	....

*All trees in the Abbott Orchard were fertilized with nitrate of soda (7 lbs. per tree) in 1923.

The data presented in Table I permit comparisons of growths made by shoots in unfertilized trees and by shoots in fertilized trees, both before and after the first applications, in 1920. In the Farrand and Quinlan orchards the marked differences between plots, shown from 1921 on, indicate strongly a fertilizer effect, while the absence of materially more pronounced differences after fertilization in the Abbott orchard, indicate the lack of any effect on growth attributable to these applications.

Table II.—Percentage Distribution of Length Growths of Shoots in Ben Davis Trees in the Farrand Orchard. (Wood of 1921 and 1922.)

Length Growth (in cm.).	Non-blossoming Shoots.		Blossoming Shoots.	
	On trees receiving nitrogen.	Not receiving nitrogen.	Trees receiving nitrogen.	Not receiving nitrogen.
Less than 1.0	3.69	4.72	1.89	10.34
1.0–2.9	16.21	27.14	17.45	72.40
3.0–4.9	10.93	20.14	10.61	3.45
5.0–6.9	15.48	17.86	15.56	6.88
7.0–8.9	10.07	9.45	10.61	....
9.0–10.9	13.39	9.63	12.03	3.45
11.0–12.9	8.35	5.25	11.32	3.45
13.0–14.9	6.02	3.50	8.73	....
15.0–16.9	6.27	1.41	5.66	....
17.0 or more	9.58	0.86	6.13	....
	99.99	99.96	99.97	99.97

In Table II the data used in compiling some of these averages for the Farrand orchard are subjected to the closer scrutiny of a percentage grouping of shoots into various classes according to their length growths in 1921 and 1922. These arrays, despite some minor unevenness, show that the averages reported in the first table reflect real differences. In the non-blossoming shoots, the growths below 9 cm. comprise 56 per cent of the total in the fertilized, and 79 per cent in the unfertilized, trees; in the blossoming shoots the difference is still greater, namely, 56 and 93 per cent respectively. The frequency distribution varies little between blossoming and non-blossoming shoots in the fertilized trees; in the unfertilized trees the contrast is pronounced.

On spurs produced. The significance and importance of these differences in length growth begin to appear on study of the data shown in Table III, compiled from the material used in assembling Table II. In this case, as in the preceding table, the spreading of the data over numerous frequency classes has produced some minor breaks in the smoothness of the distributions. The general trend, however, shows clearly that, under the conditions of this study the number of spurs formed on a given shoot one year has a general relation to the growth that shoot made in the previous year, or, in other words, the greater the growth made in one year, the more spurs formed the next year. It is possible that spur formation is related more closely to leaf number than it is to shoot growth, but since these in turn are fairly parallel, the length growth serves as a fairly satisfactory index. It should, however, be stated that Ben Davis, the subject of this study, does not push forth spurs as readily as many other varieties and though the general relationship is probably common, the exact relationship is not to be expected in other varieties, or, indeed, in Ben Davis under other conditions.

Table III.—Spurs Originating from Shoot Growths of Various Lengths, Made in 1921 and 1922, in Ben Davis Trees, Farrand Orchard. (Average number per shoot per year.)

Length Growth (in cm.).	Non-blossoming Shoots.		Blossoming Shoots.	
	On trees receiving nitrogen.	Not receiving nitrogen.	Trees receiving nitrogen.	Not receiving nitrogen.
Less than 1.0	0	0	0	0
1.0–2.9	0.20	0.11	0.27	0
3.0–4.9	0.82	0.50	0.33	0
5.0–6.9	1.13	0.87	0.68	1.00
7.0–8.9	1.81	1.33	0.91	....
9.0–10.9	1.72	1.73	1.35	1.00
11.0–12.9	2.18	2.47	2.23	1.00
13.0–14.9	2.67	2.95	2.62	....
15.0–16.9	3.75	3.13	3.04	....
17.0 or more	5.92	2.80	4.11	....
Average all spurs	1.85	0.89	1.31	0.07

Another difference between shoots of fertilized and unfertilized trees, indicated by these data, is worthy of mention here, namely, the tendency toward greater spur formation in shoots of a given length on fertilized than on unfertilized trees. This difference occurs in those frequency classes which contain the greatest numbers; above 9 cm., where the numbers of individuals fall off rapidly, the figures become rather erratic. Though worthy of mention, this difference is not pronounced enough or based on sufficient data to warrant assumption of its general occurrence.

Terminal blossoming, which has been shown (Table II) to cut down length growth under some conditions, is shown in Table III to cut down spur formation to a point below that of the shoots on unfertilized trees. Apparently, then, terminal blossoming may increase the immediate crop, but it is likely to cut down growth and decrease subsequent spur formation and consequently to exert a somewhat unfavorable effect on crops to come.

Table IV translates, for all three orchards, the differences in length growth already shown into terms of differences in the number of spurs actually produced. In this respect, as in the length growths, the differences in spurs produced are much more pronounced in wood formed after fertilization began than in that formed earlier, in two orchards, while the third orchard shows even less difference with fertilizer applications than before.

Table IV.—Average Number of Spurs Formed Per Shoot on Wood of Each Year

	On Wood of:						
	1918	1919	1920	1921	1922	1918–19 (Av.)	1921–22 (Av.)
Farrand Orchard (Ben Davis):							
Fertilized since 1920..........	1.43	1.14	1.38	1.79	1.51	1.29	1.65
Unfertilized..................	1.47	1.29	1.16	.76	.96	1.38	.86
Difference..................	*−.04*	*−.15*	*+.22*	*+1.03*	*+.55*	*−.09*	*+.79*
Quinlan Orchard (Duchess):							
Fertilized since 1920..........	2.35	1.15	1.70	3.41	3.11	1.75	3.76
Unfertilized..................	1.99	1.06	1.51	1.50	1.24	1.53	1.37
Difference..................	*+.36*	*+.09*	*+.19*	*+1.91*	*+1.87*	*+.22*	*+1.89*
Abbott Orchard (Wealthy):							
Fertilized since 1920..........	3.84	3.02	3.26	2.17	.83	3.43	1.50
Unfertilized..................	3.36	2.80	3.02	1.92	.55	3.08	1.23
Difference..................	*+.48*	*+.22*	*+.24*	*+.25*	*+.28*	*+.35*	*+.27*

In addition to this effect, it should be noted that, even in those shoots showing response to fertilizers in the growths made subsequent to the first applications, there is no evidence of any effect on the number of spurs formed on growths made prior to the beginning of the treatments. Latent buds were not stimulated to growth in any quantity; in other words, few or no new spurs were formed on old wood.

On spur blossoms. The increased growth in fertilized trees, through the associated increase in the number of spurs formed, affords opportunity for the ultimate formation of a greater number of fruit buds. That the differences already shown in growth and in spur formation are paralleled by like differences in the number of blossom buds formed is shown by the data presented in Table V. These figures cover the crops of 1921, 1922 and 1923 only, since the number of blossoms in the 1920 crop could not have been affected by fertilization.

For the sake of conformity with the other data, the figures are presented in terms of blossoms per shoot; they would, perhaps, be more striking with the decimal point set over to express them in terms of blossoms per one hundred shoots. On this basis the 1921 crop in the fertilized Ben Davis would be 60 blossoms per hundred shoots, 34 on wood formed in 1918 (three-year-wood), 22 on wood of 1919 (two-year-wood) and four on wood of 1920 (from axillary buds). This would compare with the unfertilized crop of 24.3 blossoms per hundred shoots, distributed at the rate of 14 on the 1918 wood, 10 on the 1919 wood, and three to a thousand shoots on the 1920 wood. Or, reading vertically: wood formed in 1920 on the fertilized trees has produced in three years 90 blossom buds to a hundred shoots, as compared with an average of 43.6 on the same number of shoots in the unfertilized trees.

Table V.—Average Number of Spur Fruit Buds Per Shoot

	Year of Blos-soming.	Wood of:					Total Fruit Buds.
		1918	1919	1920	1921	1922	
Farrand Orchard (Ben Davis):							
Fertilized since 1920..........	1921	0.34	0.22	0.04	....	....	0.60
	1922	0.22	0.21	0.20	0.03	....	0.66
	1923	0.79	0.61	0.66	0.46	0.06	2.58
		1.35	1.04	0.90	.49	.06	3.84
Unfertilized..................	1921	0.14	0.10	0.003	....	....	0.243
	1922	0.03	0.03	0.003	0	....	0.063
	1923	0.59	0.53	0.43	0.13	0	1.68
		0.76	0.66	0.436	0.13	0	1.986
Difference..................	....	*+0.59*	*+0.38*	*+0.464*	*+0.36*	*+0.06*	*+1.854*
Quinlan Orchard (Duchess):							
Fertilized since 1920..........	1921	0.47	0.13	0.09	....	....	0.69
	1922	1.01	0.40	0.59	0.18	....	2.18
	1923	1.03	0.46	0.80	1.82	0.05	4.16
		2.51	0.99	1.48	2.00	0.05	7.03
Unfertilized..................	1921	0.57	0.11	0.01	....	....	0.69
	1922	0.19	0.07	0.01	0	....	0.27
	1923	1.33	0.66	0.99	0.85	0.02	3.85
		2.09	0.84	1.01	0.85	0.02	4.81
Difference..................	....	*+0.42*	*+0.15*	*+0.47*	*+1.15*	*+0.03*	*+2.22*
Abbott Orchard (Wealthy):							
Fertilized since 1920..........	1921	0.49	0.35	0.16	....	....	1.00
	1922	2.69	1.85	1.93	0.53	....	7.00
	1923	0.49	0.31	0.26	0.33	0.07	1.46
		3.67	2.51	2.35	0.86	0.07	9.46
Unfertilized..................	1921	1.09	0.88	0.69	....	....	2.66
	1922	1.34	1.02	0.79	0.21	....	3.36
	1923	1.24	0.97	0.81	0.83	0.11	3.96
		3.67	2.87	2.29	1.04	0.11	9.98
Difference..................	....	*0*	*−0.36*	*+0.06*	*−0.18*	*−0.04*	*−0.52*

In addition to the increased blossom formation on shoot growths made under the influence of fertilizers, the Ben Davis trees present evidence (Table V) of a notably increased blossom formation on spurs produced immediately before fertilizer applications, despite the slight inferiority in the number of spurs on these earlier growths shown in Table IV. Spurs on 1918 wood have produced 135 blossoms per hundred shoots on fertilized, and 76 in a like number of shoots on unfertilized, trees; for the 1919 wood the respective figures are 104 and 66. Even in the 1920 wood, where the differences in shoot growth and number of spurs are inconsiderable, the differences in blossom production are pronounced.

In the Duchess trees the influence on spurs laid down before fertilization is considerably less marked. This may be attributed to some difference in the materials used. In recording the number of spurs formed, broken spurs were counted; but in recording blossoming, only the complete spurs were considered. Since the number of spurs broken in picking apples is generally considerable, it is probable that the number of blossoms recorded is materially lower than that actually produced. The other data indicate that this reduction would bear more heavily on the fertilized trees than on the unfertilized and would tend to minimize rather than to accentuate the actual differences. This consideration, coupled with the heavier bearing of the Duchess, affording greater opportunity for the loss of spurs, indicates that the same difference actually obtains in the Quinlan orchard.

Table VI.—Average Number of Fruit Buds Per Spur in 1922 and 1923 on Each Year's Shoot Growth. (On Spurs formed since 1919.)

	On Wood of:				
	1918	1919	1920	1921	1922
Farrand Orchard (Ben Davis):					
Fertilized since 1920	0.96	0.91	0.69	0.30	0.03
Unfertilized	0.54	0.50	0.40	0.17	0
Difference	*+0.42*	*+0.39*	*+0.29*	*+0.13*	*+0.03*
Quinlan Orchard (Duchess):					
Fertilized since 1920	1.36	1.48	1.03	0.67	0.02
Unfertilized	1.03	0.97	0.80	0.61	0.02
Difference	*+0.33*	*+0.51*	*+0.23*	*+0.06*	0
Abbott Orchard (Wealthy):					
Fertilized since 1920	1.14	0.97	0.83	0.46	0.09
Unfertilized	1.22	0.99	0.75	0.57	0.20
Difference	*−0.08*	*−0.02*	*+0.08*	*−0.11*	*−0.11*

Some of this uncertainty is removed by the figures showing blossom production per spur, presented in Table VI. Even this calculation is doubtless affected by the greater chance of loss of the most productive spurs and of survival of the less productive. Despite this obscuring influence, however, the superior productiveness of the spurs on the fertilized trees, including those spurs originating before fertilization, is obvious and in this case the superiority of the earlier formed spurs is clear in Duchess as well as in Ben Davis. These figures, it should be noted, cover the biennial period 1922 and 1923 only, in order to secure equal representation of odd and even year-bearing trees, which would be difficult with figures for a three-year period. It should be borne in mind, also, that in no respect has fertilization yet been shown to affect the Wealthy trees.

On annual bearing. One more aspect of the data shown in Table V should receive consideration, namely, the effect of fertilizers in bringing branches into the state of having some spurs blossoming each year. This, it will be recalled, is the ideal condition set forth in a preceding page, with each season's two-year wood contributing a crop, along with the four-year, six-year, wood and so on, while the one-year, three-year and five-year, wood is to produce a crop the next year, when it becomes two-year, four-year and six-year respectively. A much more common occurrence under ordinary conditions is that in the bearing year the two-year and three-year wood produce their first crops; in the off year no crop is produced on that season's two-year wood, which does not bear until the next year, when it is three-year wood. Consequently, biennial bearing is the general condition, even in the new wood.

The data for the unfertilized Ben Davis and Duchess trees, given in Table V, show biennial bearing in a most pronounced manner. In 1922, an off year for the trees generally, these shoots bore less than they did in 1921, despite the greater number of spurs available and the greater age of the wood; the total spur blossoms per hundred shoots for 1921, 1922 and 1923 respectively in the Ben Davis were 24, 6 and 168, and, in the Duchess, 69, 27,

385. In contrast to this condition, the fertilized trees of these varieties showed increases for 1922 over 1921, and for 1923 over 1922; in these shoots there was no off year.

That this sequence is not an accident, due to the mixture of trees with different bearing years, is shown by the data presented in Table VII. The fertilized trees evince a marked superiority in the percentage of branches showing bearing in two or three consecutive years, as well as a marked reduction in the percentage of those which have furnished no blossoms at all. In the Duchess trees, where the percentages blossoming in the crop years, 1921 and 1923, are substantially equal, the differences in consecutive bearing are the more pronounced.

Table VII.—Extent of Annual Bearing as Measured by Percentages of Branches Bearing Spur Blossoms in Various Years on Wood Formed Since 1918

	1921	1922	1923	1921–1922	1922–1923	1921–22–23	No blossoms.
Farrand Orchard (Ben Davis):							
Fertilized	32.0	30.9	68.5	17.5	20.8	12.9	20.0
Unfertilized	17.5	4.4	56.0	2.5	2.5	1.8	40.3
Difference	*+14.5*	*+26.5*	*+12.5*	*+15.0*	*+18.3*	*+11.1*	*−20.3*
Quinlan Orchard (Duchess):							
Fertilized	42.7	68.7	81.3	32.0	56.0	28.7	4.0
Unfertilized	40.0	12.7	84.0	8.0	11.3	8.0	13.3
Difference	*+2.7*	*+56.0*	*−2.7*	*+24.0*	*+44.7*	*+20.7*	*−9.3*
Abbott Orchard (Wealthy):							
Fertilized	30.0	84.0	14.7	7.3	2.0	1.3	0.7
Unfertilized	51.0	50.5	48.0	3.0	0.5	0.5	0.5
Difference	*−21.0*	*+33.5*	*−33.3*	*+4.3*	*+1.5*	*+0.8*	*+0.2*

The Wealthy trees, fertilized or unfertilized, show little inclination toward consecutive bearing by branches. The apparent evenness shown from year to year in the unfertilized trees is due to an even division of the trees involved between odd- and even-year bearers and the apparent uniformity is, paradoxically, an expression of almost complete alternation of bearing, a fact brought out by the very small percentages of consecutive bearing.

These differences between the Wealthy orchard and the others may be and probably are, partly at least, attributable to varietal peculiarities. However, no little significance must be attributed to the fact that in the last two or three years the Wealthy trees have shown a marked falling off in vigor of growth, while the fertilized trees of the other varieties have maintained or even, in some respects, surpassed the performance of five or six years back. With the impetus of recent cultivation, the Wealthy trees may be conceived to have maintained growth for a time under sod, but this marked alternation of bearing may be indicative of a downward trend in vigor, not arrested by the fertilizers as applied.

The fertilized Ben Davis and Duchess trees, however, may be considered to show distinct tendencies toward annual bearing, though not of the "ideal" type outlined. That the spurs formed in the immediate future under like conditions will continue to furnish this off-year crop is probable. How long they, or the recently formed spurs, will continue to produce a crop each year cannot be stated from available data. Consequently, assuming that present growth conditions are maintained, continuance of annual bearing may be expected, but the extent of the fruiting wood which can be held to yearly production cannot be forecasted. At present, of course, the proportion of new spurs, which furnish an annual crop, to old spurs, which do not, is small and the off-year crop is correspondingly small. Whether it will increase as the number of spurs formed under fertilization increases, or remain confined to the youngest bearing wood, is for the future to answer.

Blossom formation represents the climax and the practical significance of this series of effects of nitrogen-carrying fertilizers; in two cases the application of these materials has induced greater length growth leading to the formation of a greater number of spurs which are individually and collectively more productive and it has increased the productivity of spurs formed shortly before fertilization began. In briefer terms, the nitrogen-fertilized trees have the potentiality of bearing more apples through having more new spurs and through the greater productivity of these spurs. The gain in productiveness, moreover, is not temporary only; the increased fruiting wood will maintain the enhanced yields.

On Terminal Blossoming. Terminal fruits buds have been mentioned as increasing the present crop somewhat at the expense of future crops, but their relation to the crop of any one year has been stated only in general terms. As a sample of this relationship, a comparison drawn from the Duchess trees will serve. Considering only the wood formed in and since 1918: obviously in 1918 and 1919 terminal blossoms constituted 100 per cent of the crop. In 1923, however, these same shoots on the unfertilized trees had 61 terminal fruit buds per hundred shoots and 385 spur fruit buds; in the fertilized, the respective numbers were 21 and 416. In the latter case the proportion of terminal fruit buds to all fruit buds had fallen in four years from 100 to less than five. If older wood were considered, involving more spurs, the proportion would become smaller, since the shoot, whatever the number of spurs, has but one terminal, at least until it sends out a side shoot, which begins a repetition of the process just outlined.

Table VIII.—Percentages of Shoots Flowering Terminally

	1918	1919	1920	1921	1922	1923	1918–19	1922–23
Farrand Orchard (Ben Davis):								
Fertilized since 1920	8.7	10.0	6.7	32.3	28.7	54.0	9.4	41.4
Unfertilized	2.7	9.3	6.0	7.0	2.7	37.3	6.0	20.0
Difference	*+6.0*	*+0.7*	*+0.7*	*+25.3*	*+26.0*	*+16.7*	*+3.4*	*+21.4*
Quinlan Orchard (Duchess):								
Fertilized since 1920	5.3	12.7	4.7	24.0	29.3	20.7	9.0	25.0
Unertilized	5.3	1.3	1.3	14.7	1.3	61.3	3.3	31.1
Difference	*0*	*+11.4*	*+3.4*	*+9.3*	*+28.0*	*−40.6*	*+5.7*	*−6.1*
Abbott Orchard (Wealthy):								
Fertilized since 1920	63.3	17.3	51.3	13.3	77.3	13.3	40.3	45.3
Unfertilized	42.5	43.5	36.5	45.0	48.5	43.5	43.0	46.0
Difference	*+20.8*	*−26.2*	*+14.8*	*−31.7*	*+28.8*	*−30.2*	*−2.7*	*−0.7*

Nevertheless, fruit borne from terminal buds may be of economic importance, since the percentage of set in these blossoms is generally high, and the fruit borne in these positions of good appearance. In some cases this fruit makes a fair addition to the main crop and occasionally it gives a fractional crop in the off year, when the spurs are bearing little or none.

Terminal flowering seems clearly, from the data presented in Table VIII, to have been increased in one orchard by fertilization, and to have been unaffected in another, with the effect doubtful in the third (the Quinlan). Comparison with the figures showing the percentage of blossoming in old spurs (Table XIII) shows that much, or most, of the fluctuation in blossoming in the shoots, is parallel to the fluctuations in the rest of the tree; in other words, in these trees fertilizers have not had any considerable effect in producing a terminal crop independently of the spurs, and off-year crops are produced from terminal buds only when some other part of the tree produces them. This parallelism is shown very well in Table IX which is assembled from the data summarized for the Abbott orchard in Table VIII; in this case, however, the trees are arranged according to the year of bearing. Viewed in this way, terminal bearing in these trees is substantially as dependent on mass action of the tree as is spur bearing and has served chiefly to increase the crops of the bearing years.

Table IX.—Percentages of Shoots Flowering Terminally in Wealthy Trees Grouped According to Bearing Years. Abbott Orchard

	1918	1919	1920	1921	1922	1923
Fertilized since 1920:						
Group bearing in even years	74	6	59	2	92	1
Group bearing in odd years	12	72	12	72	4	76
Unfertilized:						
Group bearing in even years	77	1	71	0	97	0
Group bearing in odd years	8	86	2	90	0	88

This view is supported by the figures presented in Tables X and XI. The first of these shows a rather consistently greater percentage of terminal fruit buds formed in the shoots of greater lengths; it shows also, in shoots of equal length, considerably greater percentages of terminal fruit buds formed in the fertilized trees. How widely this relation of length growth to terminal fruit bud formation is prevalent cannot be stated from available data. That it is not universal is shown by the performance of four Wealthy trees presented in Table XI. These trees formed no terminal fruit buds for 1922, the off year. In the year previous, the greater number of fruit buds were borne on the longer shoots, apparently because most of the growths that year were long. In the year following, short growths prevailed, and fruit bud formation was greatest on the shorter shoots, but fruit buds were formed just as abundantly. For the off year, regardless of the growth of the shoot, no fruit buds were formed. This behavior points to the condition of the tree as an important factor in determining the action of the terminal shoots in this orchard. Similarly, the differences in the behavior of shoots of equal length in the fertilized and the unfertilized Ben Davis trees (cf. Table X), may be considered as due to differences in these trees back of the shoots.

Table X.—Percentages of Terminal Blossoming in Shoots of Various Lengths in Fertilized and in Unfertilized Ben Davis Trees. 1921-1923

Length of Shoot (cm.).	Fertilized.	Unfertilized.
Less than 1.0	9.1	3.4
1.0–2.9	28.7	10.8
3.0–4.9	38.8	7.1
5.0–6.9	42.2	15.3
7.0–8.9	47.4	27.3
9.0–10.9	51.6	26.4
11.0–12.9	59.2	26.5
13.0–14.9	57.6	50.0
15.0–16.9	71.3	38.9
17.0 or more	71.7	57.1

There are undoubted cases of shoots forming terminal fruit buds when the spurs do not. There are, too, cases of very exuberant growth, when the relationship between growth and fruitfulness shown in Table IX does not hold, or is, perhaps, even reversed. These conditions, however, have not been found in the orchards under present consideration.

Table XI.—Number of Terminal Fruit Buds Formed in 100 Shoots in Four Odd-Year-Bearing Wealthy Trees

Year of Blossoming.	Length of preceding growth (cm.).										Total cases.
	Less than 1.0	1.0–2.9	3.0–4.9	5.0–6.9	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0 or more	
1921	—	1	0	5	6	15	13	14	17	19	90
1922	—	0	0	0	0	0	0	0	0	—	0
1923	8	35	18	11	8	2	4	1	1	—	88

Whatever the directness or the indirectness of the influence, the important fact for immediate purposes is that nitrogen applications in one orchard have increased the amount of terminal fruit bud formation, as they have increased spur fruit bud formation on wood of recent growth and also that in the orchard where they have failed clearly to show an effect on spur fruit bud formation they have likewise failed to affect terminal fruit bud formation. Where they have enhanced terminal blossoming, they have at the same time overcome its depressing influence on spur formation sufficiently to effect a decided increase in spur formation and performance.

ON OLD SPURS

Growth. The effect of fertilization on the spurs of more recent origin has been shown to be rather pronounced in the Ben Davis and Duchess trees. The response of the older spurs, as measured in length of annual growth, is indicated in Table XII, which shows the average growth made each year by those spurs which did not blossom that same season. In the Ben Davis spurs there is a consistent, and at times marked, superiority in the growths on the fertilized trees. In the Duchess spurs, where growths were substantially equal before 1920, those on the fertilized were equal in length to those on the unfertilized trees one year, greater in two years and decidedly shorter in one, making any fertilizer effect doubtful in this case. In the Wealthy trees, the spurs on the unfertilized made better growth than those on the fertilized trees.

Table XII.—Average Growth of Non-blossoming Old Spurs on Trees Receiving Nitrogenous Fertilizers and on Unfertilized Trees. (No fertilizers applied till spring of 1920.)

	1918 (cm.)	1919 (cm.)	1920 (cm.)	1921 (cm.)	1922 (cm.)	1923 (cm.)
Farrand Orchard (Ben Davis):						
Fertilized since 1920	2.1	1.4	2.2	1.6	3.0	2.0
Unfertilized	2.1	1.2	1.8	1.2	2.2	0.9
Difference	*0*	*+0.2*	*+0.4*	*+0.4*	*+0.8*	*+1.1*
Quinlan Orchard (Duchess):						
Fertilized since 1920	0.8	0.6	0.9	1.8	1.5	0.9
Unfertilized	0.9	0.5	0.9	1.1	1.2	1.7
Difference	*−0.1*	*+0.1*	*0*	*+0.7*	*+0.3*	*−0.8*
Abbott Orchard (Wealthy):						
Fertilized since 1920	5.9	3.4	4.4	2.6	0.9	1.4
Unfertilized	7.4	3.7	6.5	2.5	1.6	*2.0
Difference	*−1.5*	*−0.3*	*−2.1*	*−0.1*	*−0.7*	....

*Fertilized in spring of 1923.

Blossoming. Comparisons of blossom bud formation in old spurs on fertilized and on unfertilized trees are shown in Tables XIII and XIV. The Ben Davis plots are comparable in Table XIII, since their bearing years coincide; in the other two orchards the division between even- and odd-year-bearing trees is such that fair comparison is possible only on a biennial basis, as is afforded in Table XIV.

Table XIII.—Percentages of Old Spurs Blossoming in Fertilized and in Unfertilized Trees

	1918	1919	1920	1921	1922	1923
Farrand Orchard (Ben Davis):						
Fertilized since 1920	35.3	32.4	5.2	49.5	17.7	70.5
Unfertilized	30.0	20.7	3.4	34.4	3.4	58.4
Difference	*+5.3*	*+11.7*	*+1.8*	*+15.1*	*+14.3*	*+12.1*
Quinlan Orchard (Duchess):						
Fertilized since 1920	21.3	24.0	10.0	30.0	52.0	46.0
Unfertilized	14.7	8.7	3.3	34.0	4.0	84.0
Difference	*+6.6*	*+15.3*	*+6.7*	*−4.0*	*+48.0*	*−38.0*
Abbott Orchard (Wealthy):						
Fertilized since 1920	80.7	16.0	77.3	16.7	80.0	15.3
Unfertilized	48.5	47.5	48.0	49.0	50.0	47.0
Difference	*+32.2*	*−31.5*	*+29.3*	*−32.3*	*+30.0*	*−31.7*

Either set of figures indicates a distinct gain from the use of nitrogen in the Ben Davis orchard; it should be noted, however, that this gain results from the arrest of the downward trend evident in the unfertilized trees and that the percentage of blossoming in the fertilized trees in 1922-1923 is the same as that in the same spurs ten years earlier, while that in the unfertilized trees is notably less (cf. Table XIV).

Table XIV.—Percentage of Old Spurs Blossoming, by Biennial Periods, on Trees Receiving Nitrogen Applications in 1920 and Thereafter, and on Unfertilized Trees

	1912–13	1914–15	1916–17	1918–19	1920–21	1922–23
Farrand Orchard (Ben Davis):						
Fertilized since 1920	45.6	38.1	34.2	25.8	27.3	44.1
Unfertilized	49.2	33.4	29.4	25.4	18.9	30.9
Difference	*−3.6*	*+4.7*	*+4.8*	*+0.4*	*+8.4*	*+13.2*
Quinlan Orchard (Duchess):						
Fertilized	40.0	30.0	31.0	22.7	20.0	49.0
Unfertilized	35.0	24.0	27.7	11.7	18.7	44.0
Difference	*+5.0*	*+6.0*	*+3.3*	*+11.0*	*+1.3*	*+5.0*
Abbott Orchard (Wealthy):						
Fertilized	45.4	48.0	47.7	48.3	47.7	47.7
Unfertilized	40.1	54.2	55.6	48.0	48.5	48.5
Difference	*+5.3*	*−6.2*	*−7.9*	*+0.3*	*−0.8*	*−0.8*

In the Duchess trees the differences recorded can scarcely be attributed to fertilization, since the margin of superiority in the fertilized plot for the last biennium is exactly the same as that in the first, which ended seven years before the earliest fertilizer applications were made, and, though the percentage of blossoming is higher in the last biennium, it is higher also in the unfertilized trees. The figures for the years 1922 and 1923 in the fertilized trees (Table XIII) indicate an approach to annual bearing, but it is paralleled in the same spurs in the figures for 1918 and 1919, and is due, in large measure, to the mixture of odd- and of even-year-bearing trees in the plot. It is impossible yet to state definitely that nitrogen has had no effect on the blossoming of these old spurs, but certainly it is likewise impossible to state that it has.

The similarity of behavior between fertilized and unfertilized Wealthy trees shown heretofore extends unmistakably to the performance of the old spurs. The apparent differences in percentages of blossoming indicated in Table XIII are due to unequal composition with respect to trees bearing in the odd or the even years. Rearranged according to the bearing year (cf. Table XV) these data show no more difference than the figures for biennial periods.

Table XV.—Percentage of Old Spurs Blossoming, by Years, in Even Year- and in Odd year-Bearing Wealthy Trees

	1918	1919	1920	1921	1922	1923
Odd-Year-Bearing:						
Nitrate (1 tree)	0	92	0	100	0	92
Unfertilized (4 trees)	0	94	0	98	0	94
Even-Year-Bearing:						
Nitrate (5 trees)	97	1	93	2	96	0
Unfertilized (4 trees)	97	1	96	0	100	0

Attention has been directed to the fact that in the old Ben Davis spurs, the only group showing a distinct response to fertilization, the percentage of fruit bud formation in the fertilized trees has merely been restored to the level of these spurs when they were considerably younger. Worthy of mention, and probably significant, is the further fact that the percentage in the fertilized Ben Davis trees, where the response to fertilizers is evident, is no greater than that of the unfertilized Duchess and Wealthy trees, where the response of old spurs to fertilizers is doubtful or wholly absent.

In recapitulation: the data so far presented have shown in two cases a distinct effect of nitrogenous fertilizers on the formation of new fruiting wood and on the formation of fruit buds on this wood; in one of these cases they have restored the old spurs to their former productivity, in the other the old spurs have returned to their old productivity without fertilizers. The third orchard, judged by any standards used, has consistently failed to show any benefit from fertilization, but its trees, unfertilized or fertilized, have generally compared well with the fertilized trees of the other orchards.

ON FRUIT SETTING

Though the formation of fruit buds is a necessary preliminary to an apple crop, buds do not necessarily imply a crop. The familiar couplet about the cup and the lip might well be paraphrased to the effect that there's many a snarl 'twixt the bud and the bar'l. Indeed, particularly abundant fruit bud formation may be symptomatic of a condition antagonistic to the maturing of a crop. Trees in this condition may blossom very freely and bear but little, through failure of the blossom to "set" fruit. Some of the most remarkable crop increases recorded from fertilization with nitrogen-carriers have been secured in trees of this class, simply from an increase in the number of fruits developing from a given number of blossoms.

The methods used in this investigation preclude the possibility of gathering information on the percentage of fruit set prior to 1923, and, since all trees in the Wealthy orchard were fertilized, leaving no opportunity for comparison, figures for this year are presented only from the Ben Davis and Duchess orchards. These figures, presented in Table XVI, show, with one exception, a higher percentage of set in the fertilized trees, whether old spurs, young spurs or terminal shoots are considered.

Table XVI.—Percentage of Blossoming Spurs and Shoots Setting at Least One Fruit, Season 1923

	Old Spurs.	New Spurs.	Terminals.
Farrand Orchard (Ben Davis):			
Fertilized	44.0	22.6	39.0
Unfertilized	36.6	10.1	44.7
Difference	*+7.4*	*+12.5*	*−5.7*
Quinlan Orchard (Duchess):			
Fertilized	47.8	28.3	58.1
Unfertilized	22.7	12.4	44.6
Difference	*+25.1*	*+15.9*	*+13.5*

The terminals on the fertilized Ben Davis trees show an abnormally low percentage of set, when compared with the old spurs or with the terminals in any of the other groups, fertilized or unfertilized. In all three of the other groups the terminals show a higher set than the old spurs; only in this case is the order reversed. There is some reason to believe that when the data for this plot were taken, some cases of frost injury were recorded as failure to set. Whether or not this accounts for this discrepancy, the relative importance of the terminal fruit buds is small and the spurs, in which reliance must be placed for most of the crop, show uniform and rather distinct increases in set of fruit from nitrogen applications.

The uniformly lower set in the newer spurs is unexpected, in fact, contrary to expectations and must, for the present, be recorded without attempt at explanation. That it is not due to an excess of nitrogen is indicated by the greater set in the fertilized trees.

From the experimenter's point of view, it is unfortunate that no comparative figures on fruit setting could be secured from the Wealthy trees, which have shown no effect of fertilization in other respects. However, since the owner fertilized the orchard after three years of comparison between fertilized and unfertilized trees, it seems fair to assume that he had observed some effects of the applications. Since improvement by other means is precluded by the data already reported, the only inference possible is that the superiority of the fertilized trees must have come from an increase in the percentage of set or in the size of the fruit. Of the two, the influence on set seems the more likely in trees of this kind. This, of course, is not direct evidence, but an effect of this kind in trees of this kind would not be novel.

DISCUSSION OF EXPERIMENTAL EVIDENCE

Other papers will show the effects of fertilizers on the yields and size of fruit, and some indirect effects, in the Farrand and the Quinlan orchards. The data presented here indicate that in two of the three orchards the use of nitrogenous fertilizers has increased the number of new spurs formed, increased the number of fruit buds formed on these spurs; in one orchard, it increased the number of terminal fruit buds formed and the number of fruit buds formed on old spurs and in two orchards increased the percentage of buds that not only blossom but also produce apples.

This catalogue of benefits reads like a testimonial for a restoring medicine. To a large extent it is just that, since, excepting possibly the increase in the set of fruit, every effect is restorative in nature and in extent. The more recently formed spurs are no more productive than the older spurs were in their first years, but the new spurs are more numerous and more productive than they would have been without fertilization. Practically every shoot examined, practically every spur of age sufficient for comparison, bore evidence of just as good growth, just as abundant spur formation, just as frequent blossoming, many years back, before any fertilizers were applied, as it has manifested in the years since these applications began. On the other hand, without fertilizers the performance in recent years would have been inferior to that of earlier years. Fertilization has been effective and profitable in these two orchards, but it has been effective and profitable principally because it has brought the older wood back to former productiveness and maintained the formation of new fruiting wood to replace the wastage of the old. It has not yet made good trees into super-trees, but it has made poor trees good or kept good trees from becoming poor.

There is every reason to believe that the good results obtained in these two orchards can be duplicated in other orchards where the trees are in similar condition for similar reasons—the slowing down accompanying full maturity, insufficient standing room, or lack of tillage. There is every reason to believe that these results cannot be duplicated in trees that are growing poorly because of insufficient drainage or because of serious winter injury to the collars—an occurrence of unfortunate frequency. There is very good reason to believe that comparable increases cannot be secured in trees that are already in thoroughly vigorous condition, whether it be through youth or favoring soil or tillage. Fertilization has, apparently, not acted directly by supplying an ingredient to a reaction whose direct result is blossoming; it has, however, returned trees to, or maintained them in, a condition permitting more abundant blossoming. If trees are in that condition—as many undoubtedly are—through other agencies, fertilization is apparently superfluous, except possibly to induce an increased set of fruit.

Soil depletion or increasing requirements? One aspect of orchard fertilization that has escaped general recognition is brought out in these trials. Mention has been made that the very trees which have responded to fertilization, particularly the Ben Davis, exhibit every evidence of having grown vigorously and borne freely long before fertilizers were applied. This may mean that the soil has been exhausted, its supply of plant nutrients depleted. There seems, however, good reason to concede equal or greater plausibility to the conception that the demand on the soil changes even more than the soil itself.

This same phenomenon of slackening growth is found in the mature forest, where, as the forester well knows, growth reaches a maximum and then diminishes, until finally the new growth does not keep pace with the natural wastage. This presents just as convincing a picture of soil depletion as does the ageing apple orchard. Yet the removal of the old trees is followed by exuberant growth of young forest, or, with the stumps removed, the land passes into cultivation, as virgin soil, with the productivity that the term connotes.

This conception is of great practical importance. The precise action of the fertilizer, whether as neutralizer of toxins or improver of physical condition or renewer of depleted stores of nutrients is not pertinent at this point. It is, however, important that the grower realize that the same soil which will support a young tree in vigorous condition may not suffice for an old tree and that, without a material change in soil fertility, an orchard may pass from a stage where it does not require fertilizers to a stage where the need is very great. It is not safe to assume that because no effects of fertilization can be observed in trials made now, fertilization will be equally fruitless five or ten years hence.

This conception carries another implication. Assuming that the fertilizer has marked effect in pushing out new growth, it is thereby increasing the tree's requirements and consequently making the continuance of fertilization the more imperative.

Fertilization may involve other practices. The ultimate consequences of long continued fertilization may be the subject of conjecture. Whether the continued use of sulfate of ammonia will increase soil acidity to an extent injurious to apple trees is one matter. That it will have an injurious effect on alfalfa or clover sod for the same reason is a more immediate possibility. That it will make pruning much more important, in many cases, at least, is already evident.

In the Quinlan orchard, where the planting is very close, many shoots on the fertilized trees show, even now, a reduced growth in the last year or two, in consequence of the meeting and interlacing of the terminals from adjacent trees. Aside from the mechanical injuries thus induced, such as loss of spurs and fruit from constant rubbing, the shoots are suffering from shading. The increased density of the tops and the absence of light from the middles, will before long cause the shading out of the lower limbs, and the productive area of these trees will be migrating up into the air much faster than that of the unfertilized trees.

The condition that is now approaching an acute stage in the Quinlan orchard will be reached, though more slowly, in other orchards. Obviously the wider the spacing of the trees the longer the time required for this condition to obtain. However, unless other factors intervene, the time must come in most orchards when the limbs of adjacent trees meet and the dying out of the lower limbs begins and the fruiting area mounts higher and higher. In cases of very close planting, this will mean that the orchard becomes a collection of umbrellas with apples on the ribs, or a cathedral with apples on the rafters. Then, with the reduced bearing area per tree, fertilized and unfertilized trees will flourish alike, or if fertilizers be effective, they have little on which to be effective. Fertilization, it should be remembered, will hasten this condition.

This is not said to discourage fertilization. Large present returns should not be sacrificed from fear of reduced crops in years to come. Moreover, proper pruning will not only permit good present yields, but prevent the curtailment of later crops. In fact, with the increased density of the trees induced by fertilization, pruning may become, in a short time, necessary for proper spraying and color in the fruit if for no other reason. Consequently, where fertilization is found profitable it should be continued, but with the realization that the continuance is likely to involve careful attention to pruning.

The advisability of fertilization in specific cases, then, cannot be determined by any rule of thumb. Proper spray materials, properly applied at the proper times, will insure sound apples, but even the right fertilizer, properly applied, will not always produce more apples. Fertilizer will not restore a rotted tree trunk or drain a soggy soil; when it is found to make trees that are already bearing heavily bear much more heavily or much more frequently, the fact will be reported. It is not yet shown that orchard fertilization can overthrow the economic law of diminishing returns.

Though profitable returns from fertilization in every orchard cannot be guaranteed, it is certain that the practice will be profitable in many. In some, which are composed of distinctly weak, but sound, trees, benefits will be manifold and will extend to all parts of the tree, old spurs, new growth and percentage of set of fruit. Others, as the Quinlan orchard, in somewhat better condition, will show benefits chiefly in new growth and percentage of fruit set. Another group is composed of orchards in still better condition, where fertilization may not be justified through increased production of fruit buds in old wood or in new wood, but may, nevertheless, be profitable through increasing the percentage of fruit set.

The better the condition of the trees, the more discriminating must the application of fertilizers be, if profit is to be secured. In the orchards where an attempt is made to induce formation of new fruiting wood, fertilizers may well be applied every year, but in others, where the chief benefit to be secured is a heavier setting of fruit, fertilization in the bearing year is the only practice which can be recommended at present. Even this application must be made with care, for it has been known to increase the set to the point where the size of the individual fruits is greatly diminished. Accordingly, thinning may be a necessary companion of fertilization in these orchards.

Certain probabilities may be stated. Other things equal, orchards in sod are more likely to respond to fertilization, because they are more likely to need it than cultivated orchards. Old trees are more likely to respond than younger trees, because they have exploited the soil more thoroughly and their demands are greater. In all cases, however, the application or withholding of fertilizers should be done only after careful observation of the trees and close appraisal of their performance, as revealed by study of their fruiting habits.

For this purpose, the performance of the shoots is perhaps the best single index, though no one part of the tree should receive exclusive attention. The figures submitted in this paper indicate that vigorous condition of the shoots implies a vigorous condition of the spurs; if the shoots are making good growth and forming new spurs freely, the remainder of the tree may be presumed to be in good condition; if it is not, it is generally pruning that is needed, rather than fertilizers. The data from the Quinlan orchard, showing marked response to fertilizers in the newer growths and extremely doubtful response in the old spurs, indicate, possibly, that the effects are realized more quickly near the tips of the branches, but they indicate also that these regions were showing the greater need of fertilization. Deficient shoot growth is not a sign that a tree is unproductive; it is a sign, however, that it is going to be unproductive, since the wastage of older wood through shading and broken spurs is not being repaired. Vigorous shoot growth is not a sign that a tree is productive, but it is a sign that it is going to be, provided the older spurs receive proper opportunity. If these qualifications are kept in mind, and allowance made for age and variety, the newer wood can be made a useful indicator of the tree's condition and prospects.

The color of the foliage is a generally recognized, but not always correctly applied, index of condition. Observation of the dark green leaves so common in fertilized trees has sold many tons of fertilizer. This color is so fascinating to the fruit grower that its significance should be understood. It is characteristic of vigorous growth and of rapid food utilization, but, if field observation has any value, it is not the color accompanying the storage that is necessary for fruit bud formation. The heavily bearing tree has foliage of a darker shade than that of the tree in its off year; next year the latter will bear, the former will not. Distinction should be made between the yellowish shade which accompanies small leaves, small growth and scanty utilization on the one hand, and the somewhat pale green which characterizes the tree storing carbohydrates for the next year's crop. Dark green promises well for ultimate yield and may be found in trees which bear well, but alone it has less significance than is generally accorded it, and tree growths can be studied in the winter about as advantageously as in the summer.

Rule-of-thumb methods for the application of these principles are far away; in all probability they will never be realized to any high degree of exactness. Were all orchards composed of one variety, and growing under the same conditions, it might be possible to state that trees of a certain age should average so many new spurs per shoot each year, and those of the next age class so many less because there are so many more shoots, and so on. But with the endless combinations of varieties and the various elements which constitute environment, a standardized measuring stick is a vision seen from afar, likely to prove a mirage. Nevertheless and even because of this, each grower can well undertake his own study of this sort. An hour now and then spent in this way may be the most remunerative in the year. With practice he will come to form associations of various growth conditions with past and present and future performance and he can learn about the requirements of his own trees from those trees.

One other point should be made. The full effect of fertilization will not be apparent for several years in some orchards. If the first applications are made in the bearing year, an increase in the set may give a considerable and immediate increase in the yield. However, the full benefit cannot be realized until the fertilizer has had time to increase growth (first season), increase the number of new spurs (second season), and increase the number of blossoms (third season). For some time after that the gains may be cumulative.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the encouragement and constructive suggestions of Professor V. R. Gardner in the preparation of this paper. To Professor R. E. Marshall he is indebted for numerous suggestions, for patient and cheerful assistance in gathering the data, and for the observations on the differences in foliage color between bearing and off-year trees.

SUMMARY

1. Fertilization with sulfate of ammonia or nitrate of soda has resulted in clearly increased shoot growth in two orchards, but has had little effect in the third.

2. Increased growth has led to more abundant spur formation.

3. In Ben Davis spur formation has been more abundant in the shorter growths of the fertilized trees than in growths of equal length in the unfertilized trees.

4. In the unfertilized Ben Davis trees, growths made by shoots blossoming terminally have been less productive of spurs than growths of equal length on shoots which did not blossom terminally.

5. Associated with greater spur formation, the branches on the fertilized trees of Ben Davis and Duchess have produced more fruit buds than those on the unfertilized.

6. Young spurs on fertilized Ben Davis and Duchess trees have produced more fruit buds per spur than those on unfertilized trees of these varieties.

7. Younger branches on the fertilized Ben Davis and Duchess trees show a strong tendency toward the production of annual crops. In unfertilized trees of these varieties the young branches are strongly biennial in their bearing.

8. Nitrogen-carrying fertilizers have restored old spurs of Ben Davis to their former productivity. In the other varieties the old spurs had not fallen off seriously in their performance and they were not affected by fertilization.

9. In the Ben Davis and Duchess trees in 1923 the percentage of fruit set to fruit buds formed was greater in the fertilized trees. Comparison was impossible in the Wealthy orchard.

10. Falling off in vigor becomes apparent first at and near the ends of the branches; fewer new spurs are formed and their fruitfulness is low. Diminution of vigor may later extend to the old spurs.

11. With the possible exception of an increase in set of fruit, the fertilizer effects recorded in this project are confined to restoration of former vigor and fruitfulness or the prevention of diminution in these qualities.

12. Fertilization may be unnecessary at one stage in an orchard's development and quite desirable in the same orchard later.

13. Fertilization may increase the need of attention to pruning and thinning.

14. There is little or no evidence in these records of a specific effect of fertilization in inducing fruitfulness. The effects have been, for the most part, indirect, though clear. Vigorous growth means ultimately high fruitfulness. If vigorous growth can be secured or maintained as readily by other means, fertilization appears superfluous, except possibly to increase the set in the year of a heavy crop. On the other hand, it should be considered that fertilization may be the cheapest means of maintaining the vigorous growth that is necessary for continued high production.

Appendix

THE USE OF NITROGEN-CARRYING FERTILIZERS

The most satisfactory nitrogen-carriers for the orchard are ammonium sulfate and nitrate of soda. Used in proper amounts, these materials appear to give equally good results, so far as concerns the trees themselves. Continued use of ammonium sulfate may, however, prove injurious to clover or alfalfa sod; this effect can be obviated by liming or by alternate use of nitrate of soda and ammonium sulfate.

So far as the present knowledge indicates, these fertilizers should be applied in the apple orchard, as nearly as can be estimated, one to two weeks before blossoming. Since they are soluble in water, they may be broadcasted on top of the ground and left for natural moisture to dissolve. Most of the material should be spread in a broad ring, approximately under the tips of the branches or even beyond. The amounts requisite vary with the size of the trees; sulfate of ammonia may be used in quantities varying from four ounces per tree for two- or three-year-old trees to seven pounds for a full-sized bearing tree. When nitrate of soda is used, the ration should be one-third greater by weight than the allowance of sulfate of ammonia. Other things equal, rather more should be used on sod than in cultivated soil.

At the risk of repetition it must be emphasized that though nitrate fertilization may be in part a substitute for cultivation, it is not a cure-all. It apparently will not make good trees into super trees. It will restore weak trees to a vigorous and profitable condition, if they are sound, but it will not undo the irreparable; it will not make rotted trees whole again or strengthen weak crotches or remove cankers or repel fungi or chase insects away.

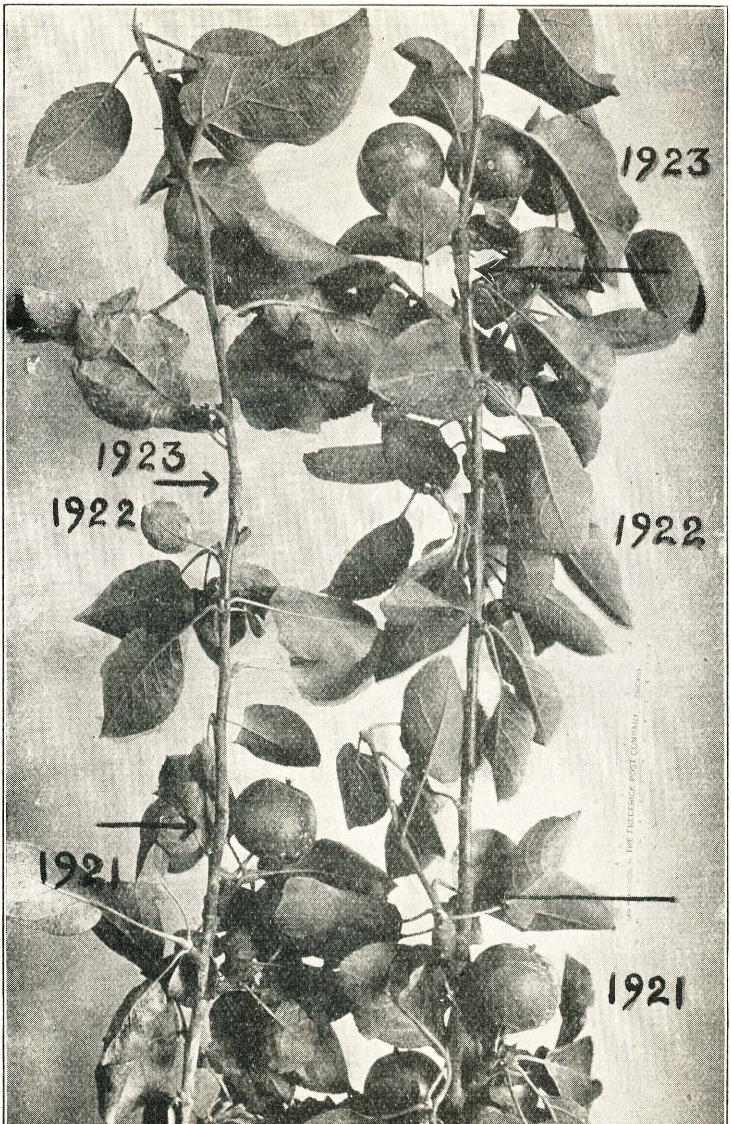


Fig. 2.—Fruiting habit in vigorously growing apple tree (Baldwin). Stages shown: axillary buds (1923 wood); young spurs (1922 wood); fruiting spurs (1921 wood). Arrows point to annual rings. The branch on the right is bearing also from a terminal fruit bud, formed at the tip of the 1922 wood.

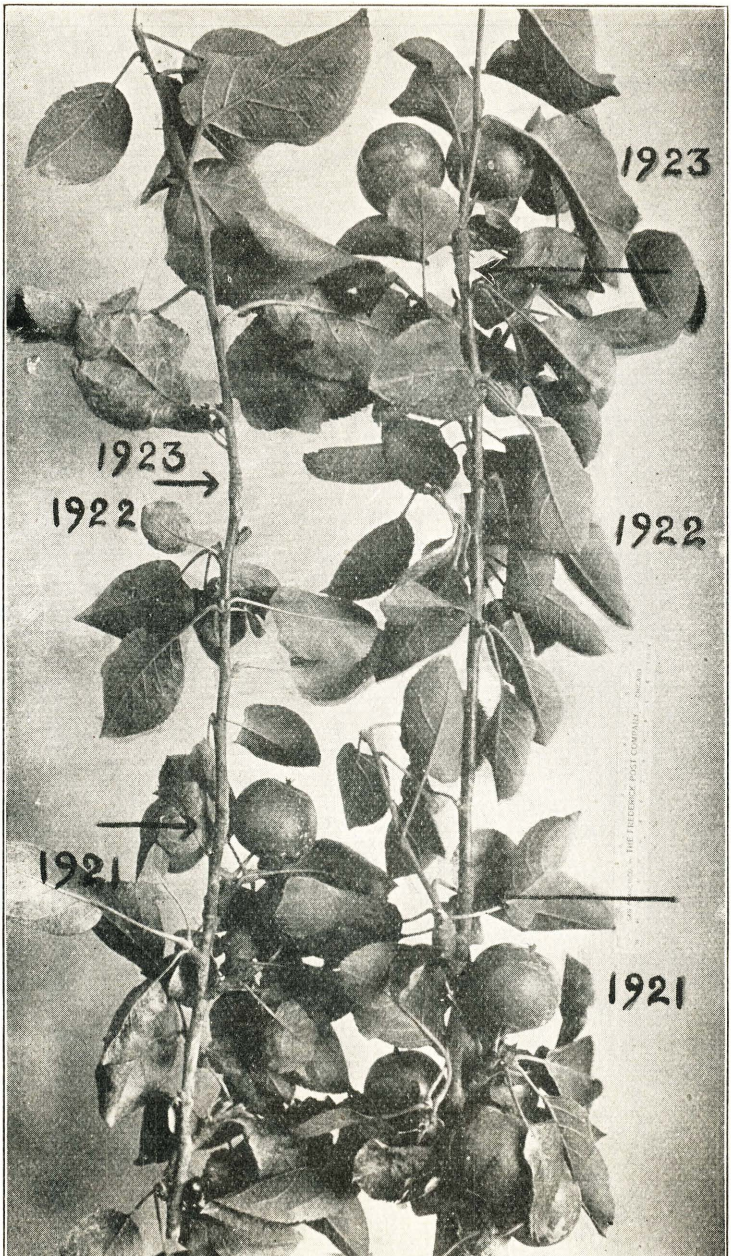


Fig. 2.—Fruiting habit in vigorously growing apple tree (Baldwin). Stages shown: axillary buds (1923 wood); young spurs (1922 wood); fruiting spurs (1921 wood). Arrows point to annual rings. The branch on the right is bearing also from a terminal fruit bud, formed at the tip of the 1922 wood.

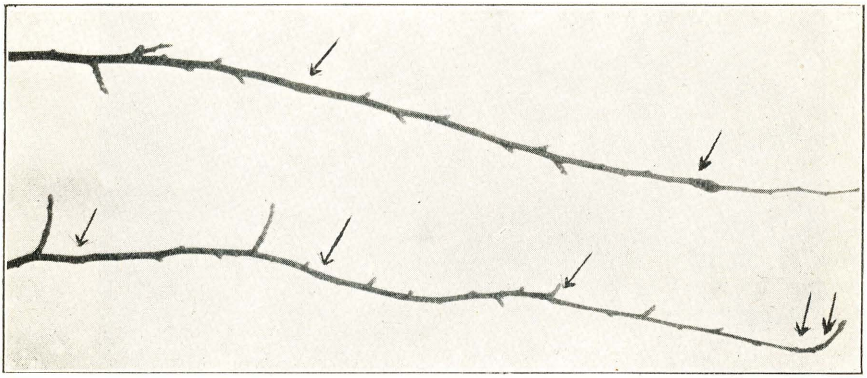


FIG. 3.—The branch above has made as much growth in three years as the other has made in six; the former has blossomed at five points in three years, the latter has not blossomed in six years.

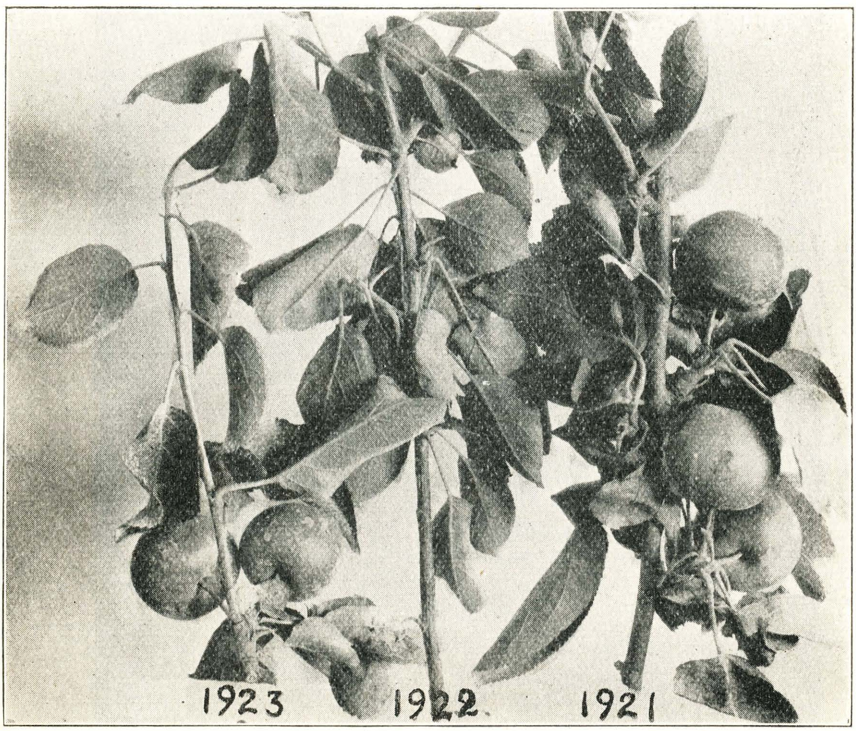


FIG. 4.—Closer view of branch on right in Figure 1, cut into segments of a year's growth each.

FIG. 5.—Wealthy, in its crop year (1923), may bear from axillary buds of last year (1922 wood), as well as from spurs (1921 wood).

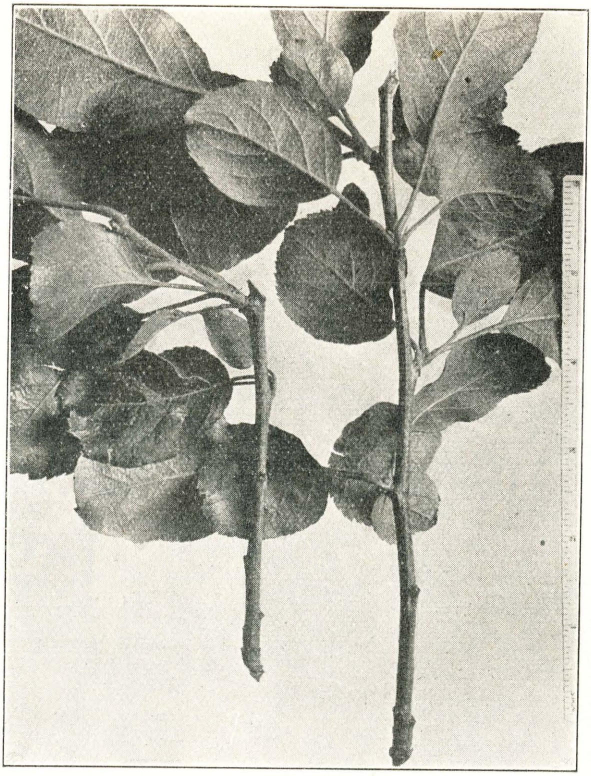


FIG. 6.—The longer growths of last year produce more spurs this year; consequently they will have opportunity of being more productive next year and thereafter.