A Historical Review of the Malling Apple Rootstocks in America
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AN HISTORICAL REVIEW of the Malling Apple Rootstocks in America

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FOREWORD

INTEREST IN FRUIT TREES which are smaller and earlier fruiting than the standard of commercial fruit production is now especially keen. The interest is of very long standing; dwarf and semi-dwarf fruit trees have been the objects of trial in North America for at least 150 years.

The records are, however, scattered, sporadic, and incomplete. There has been some need for attempting to bring together as many as possible of the experiences from the past to see what light they may throw upon the problem and what contribution they can make to the future.

Obviously, a complete review of the entire area is more than can be put into a few pages. Accordingly, the material presented in this bulletin has been restricted to the so-called Malling (E.M.) apple rootstocks and their forerunners. Further, not all journals and periodicals have been extracted. Instead, several which have been particularly active in horticultural matters over a period of time have been followed fairly closely as perhaps giving a good general picture of the changing scene.

Many contradictions occur and reoccur. These are doubtless to be associated with the wide variety of climate, soil, and other environmental circumstances. Thus, trees in Virginia may not respond as do similar trees in Canada. For that matter, there is really no way of gauging the degree of similarity. Even the names of the plant materials are open to question, especially for rootstocks, inasmuch as too frequently the only claim to authenticity for such material is the nursery label which it bears. And so the first thought was to eliminate all contradictory material and present only what seems positive and definite. It is difficult, however, to determine what should be included in such an arbitrary category and what should not. Perhaps an important suggestion might be omitted. And so all of the material that has been reviewed has been included.

Happily, there are some clear-cut findings. It is hoped that these will prove valuable. Certainly, it all makes interesting reading and shows the great amount of study and observation that has followed the small-size, early-bearing fruit tree in America. It shows further

the relatively small amount of thorough, fundamental, and long-time study that has been conducted in this field and points up the need for programs of this type.

Perhaps one of the principal values of the material lies in what it shows that is lacking. It may help to encourage the resources and the personnel to move forward with greater confidence in areas that have not been adequately covered.

H. B. T.

An Historical Review of the Malling Apple Rootstocks in America

By DONALD ZEIGER and H. B. TUKEY

DEPARTMENT OF HORTICULTURE

First interest in dwarfing rootstocks in America

THE PARADISE APPLE has been known to horticulturists for several centuries. John Parkinson described it in 1629. His description fits very well those of the Paradise stocks described at a later date. George Bunyard has chronicled the early and European history of these stocks, which is outside the scope of this paper (66).

Colonial America produced no magazines or books devoted exclusively to horticulture and few, if any, containing any material of a horticultural nature. Two books published in the early part of the eighteenth century were reprints of English works. Books of American authorship on agriculture did not appear until after 1750 although almanacs were published as early as 1639. The first American book on pomology made its appearance in 1817 (89). It is not surprising, therefore, that little evidence of the presence in America of the precursors of the numbered Malling rootstocks should be found prior to the Revolution.

At the beginning of the nineteenth century and concomitant with the appearance of the first great American agricultural and horticultural publications, reprintings of articles on Paradise and Doucin stocks from English journals began to appear. This makes it probable, then, that information was available to colonial America even though there were no American agricultural journals and few American books during that time. The first American accounts speak only of the Paradise stock and then only very briefly (70), (93). Whether the Doucin, or Doucain (9), (11), (57), (76), (107), as it was often spelled in American publications, was included in speaking of Paradise stocks was often problematical, (11), (76).

The confusion which Hatton found to exist in the nursery material was also apparent in the nomenclature in some articles in America. Thomas (155) speaks of the "Doucin or French stock", while Warder

(182) refers to it as the "English dwarfing stock". In a sense, both were right. A more serious confusion occurred where Paradise stocks of the French variety and Doucin were conceived to be synonymous. Jaques (97), by suggesting a planting distance of 3 or 4 feet, leaves little doubt that he is speaking of French Paradise stocks. However, he also calls them Doucin.

Many nineteenth century American pomologists and nurserymen were well aware of this confusion in nomenclature and in the mixing of stocks in the nursery. George Ellwanger of Mt. Hope Nurseries, Rochester, New York, spoke of the confusion in English nurseries regarding Doucin and Paradise, saying all were erroneously called Paradise (77). This situation extended to the American nursery industry, though the suggestion is made that much of this might not have been innocent.

Ellwanger, who, with Patrick Barry, had one of the leading nurseries in eastern United States, apparently was somewhat of an expert on distinguishing the various dwarfing stocks. This is not overly surprising, considering that he had the largest experimental planting of trees on drawfing stocks in America during the nineteenth century. Not only did he have the commonly used Paradise and Doucins, but he also had tested several of Thomas Rivers' selections, of which Nonsuch Paradise (now Malling VI) was one. He rejected the latter as unsatisfactory (77).

In the earliest book on pomology (89) by William Coxe in 1817, the Paradise apple is described as a variety grown for its fruits. In describing its tree and fruit characteristics, its use as a dwarfing stock is mentioned. However, it could not have been considered as very important, for no mention is made of it in the short chapter on stocks. Also, the *New England Farmer* of October 29, 1830, in listing fruits received by the Massachusetts Horticultural Society, mentions "remarkably fine fruit from a French dwarf tree, name unknown", which was received from a Mr. Manning. Downing in the 1845 edition of "Fruits and Fruit Trees of America" mentions both a Summer Sweet Paradise and a Winter Sweet Paradise. As late as 1869, Paradise seemingly continued to be grown for its fruit. An anonymous statement in the February, 1869 *Gardener's Monthly,* quoting a "Western newspaper", says, "M. A. McMasters of Darien, Walworth County, Wisconsin, raised this year 16 beautiful apples of Paradise, a species of large Siberian crab apples, on a tree only 6 inches high!" Realizing

the Bunyanesque nature of the statement, the correspondent added, "This remarkable fact is vouched for by responsible parties" (23). Here, too, the confusion surrounding the Paradise stocks is evident in the allusion to it as a species of large Siberian crabapple.

C. M. Hovey and Patrick Barry appear to have been the principal proponents of the growing of dwarfing stocks — Hovey by his active advocacy of their use and Barry by the detailed information which he disseminated. Furthermore, Hovey says, "Our object is not at this time to detail all the particulars of dwarf apple culture, but simply to direct attention to what we think has been sadly neglected" (94). Later he says, "Dwarf apple culture deserves the special notice of fruit growers. . . . . Their importance has been altogether overlooked" (95). In 1865 he states, "We have, in our previous volumes, directed the attention of our readers to the importance of the introduction of Dwarf Apple Trees . . . . and strongly urged their more extensive culture, ... it is our intention to devote considerable space to the dissemination of information which will lead to their more extensive culture" (96).

Hovey did not advocate, however, the growing of dwarf trees in commercial orchards. Barry, on the other hand, did recommend both Paradise and Doucin for the commercial orchard (57). He considered the heavy investment in an orchard and the lack of return until about the twelfth year and recommended as a remedy that dwarf trees on both Paradise and Doucin stocks be used as filler trees. Two plans for such use were suggested. Under the one, trees on seedling stocks were to be planted 30 feet apart with two rows of trees on Paradise between. Secondly, on rich, deep soil 35 to 40 feet was suggested for trees on seedling stocks, with two rows of trees on Doucin intervening and a row of trees on Paradise between those on Doucin.

Thomas Meehan of the *Gardener's Monthly* was decidedly sympathetic to the use of dwarf trees in home gardens, but did not promote them as actively as C. M. Hovey did. The pages of the *Gardener's Monthly* from 1860 to 1882 contain some reprints of questions and comments from other domestic and foreign publications (13) (23) (28), but the bulk of the articles and the many answers to readers' questions were informational, but not promotional (10) (11) (145) (1) (25) (26) (27) (76) (107) (29). An editorial in the April, 1865, issue might be relegated to this latter category (17). A. J. Downing,

through the pages of *The Horticulturist,* appears to have been even more passive than Meehan (3) (4) (5) (6).

Shift in interest in dwarf apple trees

Examining the dates of these publications in conjunction with the attitudes of their editors and the publication of articles on the subjects of dwarf apple trees and Paradise and Doucin stocks makes it evident that something was happening about 1855 to 1860 which was causing a change in attitudes and emphasis. This would explain why Downing, who died in 1852, should have published so sparingly and passively concerning dwarf apples, why Hovey's *Magazine of Horticulture,* which began publication in January, 1835, but contained no information on dwarf apples until 1860, should have so actively promoted them and why Meehan's *Gardener's Monthly,* published from 1859 to 1888, should have devoted so much space to dwarf apples and Paradise and Doucin stocks though without an attitude of promotion.

The development of Hovey's positive attitude is explained in the May 1860 issue of the *Magazine of Horticulture* (94). It was apparently associated with his own acquisition and success with two to three hundred dwarf apple trees, each of a different variety, secured from the nursery of Ellwanger and Barry after a visit to that establishment in Rochester, New York. From the description, it appears these were on French Paradise stocks. Ellwanger and Barry's dwarf orchard was set out about 1845. Hovey speaks of having "made great exertions" to have a dwarf orchard years before 1860, but of not having been able to find a good collection (94).

The factor which seems logically to explain this overall change was the success in growing the pear as a dwarf on quince stocks. The movement toward growing pears on quince stocks seems to have developed some impetus about 1850 and to have continued to the turn of the twentieth century. In 1896, Lodeman (103) stated that 50 percent of the pears in the eastern states were grown as dwarfs. The letter of transmittal by Liberty Hyde Bailey for the same publication (103) states, "The interest in dwarf pears continues to be unabated in this state".

General early problems associated with dwarf fruit trees

In spite of the awakening literary interest in dwarf apples and Paradise and Doucin stocks, they did not "catch on". In May, 1860,

Hovey (94) finds difficulty in explaining why dwarf apples had not received more attention, but conjectured that it may have been because attention was not called to their growth and to the fact that good fruit could be obtained very cheaply. He also suggests that it might be attributed to a belief that it "would not pay". Apparently apples were rather plentiful and cheap at this time, whereas pears were more sought after and were more expensive (94). Perhaps this is a reflection of European interest in pears during this period. The situation must have remained very much the same for the next 35 years, for Bailey remarked in Bulletin 116 of the New York Agricultural Experiment Station at Cornell (103) that they were unable to answer, from American experience, questions as to whether dwarf apples would not be as profitable as dwarf pears. He further states, "Dwarf apples have been grown in this country chiefly as single or specimen trees and not in plantations of commercial extent; and even as specimen trees they are comparatively little known". Demand for information at this time apparently reached such proportions that, in the absence of experimental data, E. G. Lodeman wrote a bulletin of 30 pages on dwarf apples (103) composed mostly of the experiences of backyard gardeners.

The voices of caution and derogatory opinion are extremely potent in determining the acceptance of a practice or of new plant material in horticulture. None was more belittling of dwarf trees for any other than ornamental purposes than G. Jaques. In his "A Practical Treatise on the Management of Fruit Trees, etc.", published in 1856 (97), he says, "They are very pretty garden pets in the midst of a flower bed, or at the corners of alleys, or elsewhere where fancy may locate them. They seldom bear more than a dozen or 20 apples, and therefore the economical orchardist, looking to profit alone, ought not to consider them as worthy of his attention".

J. A. Warder, in "American Pomology—Apples", published in 1867, discriminated between the use of trees on Paradise and trees on Doucin stocks (182). He regarded the Paradise as producing quite satisfactory trees for the home garden. The Doucin was not recommended because it did not dwarf the tree enough and because it did not bear earlier or very little earlier, in his experience, than trees on standard stocks. J. A. Warder's most important argument bore not so much on the characteristics of dwarf trees, but on the plentitude of land and the salubriousness of the American soil and

climate for growing fruit trees in the open with a minimum of care and protection. Withal, he recognized that the uncertainty of winters in some locations provided reason why those with a talent for giving dwarf trees the extra care he deemed necessary should grow them.

An article reproduced in the August, 1852 issue of *The Horticulturist* (7) from the *Albany Cultivator,* which was commenting on an article in the *Genesee Farmer,* raises a question of economics with regard to dwarf trees. Apples generally were rather cheap at that time. After making the point that apples grew rather larger on dwarf trees than on standards, the *Albany Cultivator* asked at what price one could afford to sell them in comparison with the general run of apples on the market. Apparently it suspected they would be "priced out" of a market.

Dr. L. H. Bailey took a similar viewpoint in 1896 (103). He stated that he had been familiar with dwarf apples for approximately 20 years and had observed some good commercial results. It was his opinion that if dwarf apples were planted at all they should be confined to those suitable for a fancy trade. Other American horticultural writers of the nineteenth century recommended a limited list of specific varieties of apples (6) (20) (77) (97) (156) for dwarfing. The basis for these recommendations is not always clear. This would, however, have the effect of deterring somewhat the planting of trees on Paradise and Doucin. George Ellwanger, listed desirable varieties for dwarfing (77), but his list is so long as to appear much less selective than the others.

Nurseries can and have by their promotional efforts and by their handling or failure to handle plant materials influenced the acceptance or rejection of varieties or kinds of plants. Although the extent to which the nursery attitude or attitudes was a factor in the course of history of the Paradise and Doucin stocks in America is not clear, certain facts give direction to conjecture.

In September, 1848, A. J. Downing answering a query from a Mr. Stanford of Clarkeville, Georgia, stated (3) that young Paradise stocks could be obtained reasonably from leading English nurserymen. He was unaware that they were grown commercially anywhere in the United States. Two months later, in response to a question from Vermont, Downing (4) refers to the price of Paradise apple stocks in the catalogue of Van Houtte of Ghent as 30 francs per thousand.

This observation of A. J. Downing's was confirmed by the absence of offerings of Paradise or Doucin stocks or dwarf trees in the numerous nursery advertisements in such as the *Gardener's Monthly*, the *New England Farmer* and other American agricultural and horticultural magazines of the nineteenth century. Though such trees were not generally available, certain nurserymen were propagating and testing such stocks, as attested previously by C. M. Hovey's statement (94).

What dwarfing stocks were to be found in most American nurseries were apparently Doucin. The *Gardener's Monthly* asserted (27) that these Doucin stocks were sold for Paradise stocks in many American nurseries and that the names "Doucain" (as they spelled it) and "dwarf" were synonymous. It appears, however, that few of these were sold in comparison with the French Paradise.

Warder (182) alludes to the possible role of the tree peddler as regards the vicissitudes of dwarf trees in the nineteenth century. It appears that thousands of trees on Paradise stock were sold to farmers for orchard trees by these peddlers, according to Warder. He says, "They (trees on Paradise stocks) are wholly unsuited for orchard planting, as many a poor deluded purchaser has found out to his sorrow, a few years after having been beguiled by the smoothspoken tree peddlers". It is possible that this was a situation peculiar to the Middle West with its characteristic hot summers and cold winters or that the thousands of trees represent very scattered and very small plantings. Be that as it may, it does point up the role of the tree peddler as against the nurseryman in the dissemination of trees on Paradise stocks.

Whatever indications there are in the literature of a dwarf apple "industry" in the nineteenth century show that it was rather widespread in its distribution if not extensive in acreage. Orchards of any size on dwarf stocks were those of Ellwanger and Barry at Rochester (94) (77) and Hovey near Boston (94), as previously mentioned. When about 30 years old, trees on French Paradise in the Ellwanger orchard were reported to be producing 3 to 4 bushels per tree in favorable seasons (77). This was potent rebuttal to those of the time who claimed that such trees were unproductive (97) and should have deterred later critics who said they were short-lived (185) (85). A Mr. William Reid of Elizabethtown, New Jersey, had a collection of dwarf trees about 1860 (94). Little information is

supplied on the extent of the planting or the nature of the operation. Hovey described it simply as "a pretty collection of the best varieties".

In 1869, the Fruit Grower's Association of Ontario disseminated a questionnaire to fruit growers which contained one query as to whether dwarf apples, pears or cherries had been planted in the vicinity and, if planted, how successful they had been. In tabulating replies the province was divided into nine divisions of similar climatic conditions. The replies indicated that they had been tried in all areas and had failed in those where trees of standard size were not hardy (22). There was no indication that the plantings in any areas had reached commercial proportions.

In the decade just prior to 1860, which has been indicated earlier in this paper as a turning point in attitudes toward and interest in dwarf apple trees, many plantings of dwarf apples and pears appeared in California around San Jose, Oakland, Stockton and Sacramento (89). Hedrick attributes this to the high prices paid for fruits in that area and the desire of orchardists to profit from that demand as quickly as possible. He records a case of 15 dwarf pear trees producing a crop worth $1600. In 1857, a Mr. Fountain of near Oakland had about 1600 of these trees two years of age. This appears to have been the largest planting in the state. Hedrick characterizes the interest of this short period of time as a "craze" (89) and states that it quickly ran its course.

While facts showing the extent of plantings and success with dwarf trees in other areas are lacking, letters to horticultural magazines requesting and supplying information were numerous enough to indicate a widespread interest. Queries or statements were recorded in 1848 from Georgia regarding the nature of the Paradise Apple (3); in 1850 from Pennsylvania regarding the best varieties to dwarf on Paradise stock (6), in 1852 from Rochester, New York, regarding the performance of Fall Pippin as a dwarf tree (7), in 1853 from Illinois concerning preference of "Doucain" or common stock for producing low-headed trees to avoid the effects of high winds (9); and in 1862 from Provo, Utah, with respect to propagating Paradise and "Doucain" stocks (11). The above also indicate the range in the nature of the questions and statements.

A part of this early interest was associated with questions of a fundamental nature demanding experimental proof. One of these was the influence of the scion or "graft" on the stock. The *Gardener's*

Monthly records two such experiments involving the use of Paradise and Doucin stocks. In March, 1867 Dr. J. Stayman of Leavenworth, Kansas, the originator of the apple bearing his name, reported (145) that Paradise grafted on common apple roots and Paradise and Doucin on Domine were not precocious. These facts were presented in support of his hypothesis that if the natural vigor of the stock exceeds that of the scion, the maturity of the scion will be delayed. Another part-time experimenter with Paradise stocks was a Mr. D. W. Adams of Wawkon, Iowa. He reported on his research relative to the effect of the scion on the nature of the root system of the stock in the May, 1867, issue of the *Gardener's Monthly* (1). It was stated that the budding of a portion of a population of Paradise stock with the variety St. Lawrence had altered the root system from one having numerous, fibrous roots to one having a few, very large roots.

Early problems with pruning

Throughout the early American literature, prior to introduction of the "Malling series" of rootstocks, recommendations relative to pruning and other treatment of the tree came from practices of the European garden. Possibly this was due to the frequent reprinting of foreign articles making such recommendations (2) (14) (15). Certainly there is no evidence in articles by American authors that anyone tried any other system or questioned that the English tree farms and practice of summer pinching might not be best under American conditions (94) (96) (155) (57) (70) (56). The only question of the applicability of these intensive garden systems of growing dwarf trees to orchard practice, was raised in an article by an anonymous English contributor to the *Gardener's Chronicle.* This was reprinted in the March, 1868 issue of the *Magazine of Horticulture* (21).

It may, of course, be questioned whether much American thought was given to growing dwarf apples outside the rather extensive gardens. The European idea of training and pruning was well enough entrenched so that the method which approximated it closely was used in what was probably the first formal test of Paradise and Doucin stocks in America (85). Lodeman, who authored a Cornell bulletin on the subject of "Dwarf Apples" a few years earlier (in 1896) did not suggest summer pruning or pinching, which was an important feature of the European systems, but did recommend, as

a substitute, pruning off in winter considerable of the past season's growth. He wrote, "Each year's growth, if vigorous, should be cut back at least one-half or two-thirds, and generally more may be removed with perfect safety", (103).

It may be inferred from this that the backyard gardeners from whom Lodeman drew the information for his bulletin and probably Lodeman himself, from his own informal tests at Cornell, had begun to perceive what Hedrick reported in 1915 (86) from extensive formal tests with trees on Paradise and Doucin stocks. Summer pruning and pinching produced weak, spindly second growths which were frequently killed by the cold the next winter. Other European practices recommended here were the lifting and replanting of established trees (28) and trenching of the soil 2 to 3 feet deep at planting time (94). Such recommendations would tend to discourage commercial planting in America, where labor has rarely been as plentiful and inexpensive as in Europe. However, even as late as 1924 the practice of lifting and replanting trees was recommended (115), but at that time for the purpose of removing and replanting filler trees rather than for checking growth, as was the purpose earlier.

There were probably others, but Patrick Barry was one of the more prominent earlier writers who appear to have departed from recommending the practice of summer pruning. At least, he did so in "The Fruit Garden", published in 1857 (57). An article five years earlier still advocated the practice (56).

The San Jose scale menace and revival of interest in dwarf apple trees

Various crises in horticulture have given impetus to the use of materials or practices extant for some time. Apparently, up to about 1890, the Paradise and Doucin stocks did not give promise of correcting any critical situation for fruit growers. At least, no large segment of the group saw them in this light, although Hovey (96) saw these dwarf stocks as making easier the destruction of canker worms by the application of whale oil soap, and in 1882, a New Brunswick, New Jersey correspondent of the *Gardener's Monthly* wrote that his dwarf apple trees were less subject to borers than other trees (29).

The crisis which gave Doucin and Paradise stocks greater prominence and more serious consideration for commercial planting was the spread of the dread San Jose scale and the difficulty in con-

trolling it. Beach (58) said, in 1902, "Entomologists are unanimous in the opinion that it cannot now be exterminated (from the scattered localities in which it was established). It is expected that this pest will eventually overspread all of the fruit-growing sections of the state". The only known method of control was by covering the tree with a large canvas and fumigating with cyanide gas. But such procedure was not practical with large trees.

In 1897, to meet the situation, the Experiment Station at Geneva, New York, had begun experimenting with Doucin stocks with the object of more thorough spraying and easier fumigation in mind (58). A few years later trees on Paradise stocks were added to the test plot.

At the meeting of the Western New York Horticultural Society in 1902, S. A. Beach invited the society to appoint a committee to confer with Director Jordan of the Experiment Station on a site for a cooperative test with a grower in that area. Committees from the New York State Fruit Grower's Association and the Eastern New York Horticultural Society also participated. As a result, three widely separated sites were selected for the test. The trees were planted in the autumns of 1903 and 1904 (86). U. P. Hedrick took over the direction of the experiment from Professor Beach in 1905.

At this point it should be noted that the violent interest in dwarf trees which centered around the problem of San Jose scale, lost most of its impetus with the introduction of lime-sulfur between 1906 and 1910 which effectively controlled the pest. Interest in dwarf trees again returned to problems of commercial fruit production. The tests were not, after 10 years, considered a success (85) (86). Commercial crops were borne little, if any, earlier than on seedling stocks, many trees winter-killed; surface-rooting and suckering were serious, and many trees blew over or failed to make good unions. Hedrick conceded that many of the difficulties encountered could be attributed to the manner of handling the trees. For instance, because of low budding the clonal trees were planted shallow. The shallow rooting resulted in suckering and, Hedrick stated, contributed materially to winter injury to the roots and the blowing over of the trees. He also believed that summer pruning and heavy winter pruning had resulted in winter injury and delayed production. Scion-rooting was also considered as a very likely explanation of discrepancies in expected size between trees on Paradise and Doucin stocks and those on seedling.

Professor Hedrick summarized the extensive tests by saying (86), "It would seem that the efforts expended and the money spent in

this 10-year test of dwarf and standard apples should give decisive results. But the conclusions that can be drawn are far from final. . . . . We have learned in the test . . . . how best to care for dwarfs, especially in the matter of summer pruning and in preventing the disastrous surface rooting". Here it should be noted that the plantings were, unfortunately, not located in the most favored fruit sections of the state, the soil being light and the winters relatively severe.

Hedrick, apparently, was somewhat influenced in his evaluation of the usefulness of the available dwarfing stocks not only commercially, but for the home gardener, by the mixing of stocks in horticultural commerce. He believed that many so-called dwarf trees were not even on dwarfing stocks. Earlier horticulturists had noted the mixing of clonal stocks, but it does not appear to have dissuaded them from recommending Paradise and Doucin for the gardener, at least. This was such a factor, as far as Hedrick was concerned, that, in an article in the *American Fruit Grower* of March, 1920, he recommended using seedling trees for the severely-trained fruit tree forms developed in Europe (87).

George Powell, a fruit grower located at Ghent, New York, in the upper Harlem Valley at the foot of the Berkshire Mountains, vigorously disagreed with the generally negative conclusions relative to dwarf trees on Paradise and Doucin stocks and especially the experiments in New York State initiated by Beach and completed by Hedrick (185) (114). Except for Patrick Barry, Mr. Powell appears to have been one of the first individuals who believed such trees commercially useful and certainly the first person who departed very sharply and generally from long-accepted practices in growing trees on Paradise and Doucin stocks. In addition to a means of controlling San Jose scale, Powell saw in dwarf trees possibilities for increasing the proportion of high-grade fruit on the tree and a rapid means of testing new varieties (113). Had he been located in a major and more favorable fruit area his enthusiasm might have been more contagious.

Probably Mr. Powell's most novel approach to the subject of dwarf trees was the idea that a dwarf tree need not remain such throughout its life (185). With this idea in mind, apparently, he suggested that the graft union be placed 4 inches below the ground line and that the effects of scion rooting be minimized and delayed by deep cultivation (113) (114). He credited this practice of deep planting with minimizing suckering, winter injury to roots, breaking at the

graft union and blowing over of trees (114). In 1908, Mr. Powell believed in heavier pruning for dwarf trees than for standards and summer pinching, but in decreasing amount as the trees became older (113). By 1918 he had altered this view, saying that little pruning was necessary for the first six years, except to give the trees good form (114). An article published in 1924 in the *Rural New Yorker* indicated an extension of the formative light pruning of dwarf trees to the ninth or tenth year (115).

The beginning of critical evaluation of dwarf fruit trees

The upsurge of interest in dwarf apple trees about 1900 mirrored by the formal research and changing ideas about their culture also brought the first two books devoted exclusively to dwarf trees. The first of these was F. A. Waugh's *Dwarf Fruit Trees*, published in 1906. The treatment of the subject was complete, but aimed at the home gardener. Practices recommended were the classic ones of Europe, which Powell was questioning (183). Another, and very interesting paper-bound book, was A. W. Thornton's *The Suburbanite's Handbook of Dwarf Fruit Tree Culture*, published in 1909. The purpose of the book was quite evidently promotional (157). At the time it was being written, Thorton was establishing the Suburbanite's Dwarf Fruit Tree Nursery at Ferndale, Washington. It seems probable that Dr. Thornton's experience with dwarf trees was limited, particularly in certain areas. Considerable ingenuity in promotion is exhibited in the book. Dwarf trees are recommended to the suburbanite for rapid testing of hybrids, ostensibly of the suburbanites own origination. Apparently so that ignorance of the techniques of hybridizing would be no obstacle to the employment of dwarf trees in this manner, the author outlined the process.

Also at the turn of the century and shortly after the initiation of dwarfing rootstock studies in New York State, the Agricultural Experiment Station at the Virginia Polytechnic Institute began doing such work (33). Its motivation was "considerable agitation in favor of the so-called 'half-dwarf' apple tree for commercial work". Seventy-four varieties were tested on the Doucin stock, making it the most comprehensive test during that period of scion varieties grown as dwarfs. The conclusions were similar to those made in New York — that, except for Yellow Transparent, bearing was not earlier than on seedling stocks, that the acre yields would not exceed those of standard trees, that root growth was rather superficial, and that suckering

was plentiful. Recommendations arising from this experiment were that such trees were useful in the home garden and that use in commercial orchards should be limited to filler trees and then only with certain varieties. By contrast with the results of the experiment conducted by Hedrick, the Virginia experiment showed that the dwarf tree produced larger fruit of better color.

A year after the establishment of the dwarf orchard on Doucin stocks, a planting of the English variety, King of Pippins, worked on Paradise stocks, was also set out at the Polytechnic Institute. These, as well as some trees on Doucin and seedling stocks, were subsequently used in a study of the effect of pruning, root pruning, ringing and stripping on fruit bud formation in dwarf apple trees (74). This, apparently, resulted from the rather disappointing results in securing early fruit bearing on dwarf trees. It may have represented the first experimental attempt at a departure from the classic method of handling these trees.

At about the same period, several other state experiment stations were beginning to test Doucin or Paradise stocks or both, but none tested them at that time on the scale of the stations in New York and Virginia.

Work begun by F. A. Waugh at the Massachusetts Agricultural Experiment Station prior to 1908, had as its main objective, an evaluation of dwarf trees for commercial fruit production. Yet, the data presented from these studies indicates an interest in other and related problems, such as methods of propagation. Stock and scion relationships, both in fundamental and practical aspects, continued for many more years to interest investigators at the Massachusetts Agricultural Experiment Station. J. S. Bailey reported in 1926 on an experiment started in 1912 to attempt to eliminate variability in orchard trees (55). In addition to own-rooted trees and stocks produced from several cultivated apple varieties, English Paradise was used. It was observed that while trees were smaller on Oldenberg stocks than on English Paradise (Doucin), in no instance were they as precocious.

A preliminary report by Shaw in 1917 was devoted chiefly to outlining the experimental plan for a long-term experiment intended to elucidate the effects of scion on stock as well as stock on scion (127). English Paradise was used as a stock as were eight varieties commonly grown as scions. Shaw also reported in 1919 on an unusual experiment in which French and English Paradise nurse roots were employed in an attempt to secure better scion rooting for the produc-

tion of own-rooted trees (128). With French Paradise nurse roots, better scion roots were produced than with crab nurse roots, but the stand was poorer.

In addition to Waugh, Bailey, and Shaw, several other researchers of the early twentieth century used Paradise or Doucin purely as experimental tools. Probably the earliest such use reported was that of Blake and Voorhees in New Jersey in 1907 (62). They used five scion varieties on Doucin stock, in an effort to obtain more immediate results in fertilizer and cover crop studies. Dorsey published results in 1918 (72) of a study designed to determine if the stock could influence the hardiness of the scion. Four stocks, of which "Paradise" was one, and a maximum of 73 different scion varieties were tested. He concluded that if the stock transferred any hardiness on the scion it was so slight as not to be detectable.

In 1932, both the New Haven Station of the Connecticut Agricultural Experiment Station and the Davis County Station of the Utah Agricultural Experiment Station reported on work with the forerunners of the Malling stocks. In the former case (37), recommendations based on their own tests were made for the use of Paradise and Doucin stocks by the home gardener. Utah reported on studies of propagation methods (39). They found that if layers of Paradise stocks were slit diagonally at the base in October and covered with German peat moss before being covered with soil, the layers were fairly well rooted by the following April.

The Malling Rootstocks

Early introduction of Malling rootstocks to America

The era of the vaguely delineated Paradise and Doucin rootstocks came to an end about 1930. However, their "offspring" had been "born" 18 years earlier, when, in response to long standing tangible, but largely inarticulate uneasiness concerning the composition of clones offered for sale, the East Malling Station began a survey of the stock in English nurseries from various sources, (84) and found the confusion to be very great.

Wellington and Hatton selected and studied and subsequently designated by Roman numerals, 16 types of rootstocks (84):

Malling I. Broad-leaved English Paradise (of Rivers) – Of English origin, selected by T. Rivers as a chance seedling about 1860.

Malling II. Doucin, of the best French nurseries; often called English Paradise.

Malling III. Dutch Doucin; also called Hollyleaf Paradise and Königs Splittapfel. — A common stock, widely distributed in Europe.

Malling IV. Holstein Doucin, or Dutch Doucin. — Originally identified as *Malus pumila;* common in Holland and Germany.

Malling V. Doucin Amélioré; also called Improved Doucin in English nurseries and Red Paradise in Dutch and German nurseries. — A common stock in Europe.

Malling VI. Nonsuch Paradise (of Rivers); also known as Rivers' Paradise. — Selected by T. Rivers in England as a chance seedling about 1860.

Malling VII. Unnamed. — Long known in English nurseries as a mixture in Doucin stock.

Malling VIII. French Paradise. — Common on the Continent.

Malling IX. Jaune de Metz (of Dieudonné); also called Yellow Metz. — Selected as a chance seedling in France about 1879.

Malling X. Unnamed. — Selected and named Doucin U.1 by Späth, Berlin.

Malling XI. Unnamed. Also known as Green Doucin and Pracht's Doucin from England about 1900.

Malling XII. Unnamed. — Seedling selected from crab stock at East Malling, England.

Malling XIII. Black Doucin. — Selected and named Doucin U.2 by Späth, Berlin, about 1890.

Malling XIV. Unnamed. — Selected and named Doucin U.5 by Späth, Berlin.

Malling XV. Unnamed. — Selected and named Doucin U.6 by Späth, Berlin.

Malling XVI. Ketziner Ideal. — Selected and named Doucin U.3 by Späth, Berlin.

Of this series of rootstocks, R. D. Anthony of the then Pennsylvania State College imported EM XII in 1920 (54). This, apparently was the first North American acquisition of any of these stocks under number. These EM XII rootstocks were not used for a study of Malling performance, but rather as a tool in a fertilizer experiment

conducted in large metal cylinders, handled in this manner because of the variability in results occurring in orchard fertilizer experiments begun in 1908 in several parts of Pennsylvania with trees propagated on seedling rootstocks. As a consequence of this variability, it was not possible to obtain statistical significance (53). It was hoped that by using clonal rootstocks, any variability due to rootstock might be eliminated.

In 1922, the same station received from England specimens of EM I, VI, IX, X, XII, XIII, XV, and XVI, which were used for propagation studies. Later, in 1927 and 1930, supplies of EM I, II, IX, XII, XIII, XV, XVI, were purchased from East Malling and worked to Stayman for a study of commercial orchard performance. The first of these stions were planted in an experimental orchard in 1929 (54).

Meanwhile, in the spring of 1928, Shaw of the Massachusetts Experiment Station set out an orchard of McIntosh and Wealthy budded to all Malling types except EM VII, XI, and XIV (34) (129). Seedling stocks and own-rooted trees were included for comparison. This, apparently was the first orchard test of the Mallings under number in America. The Massachusetts Station had, however, imported these stocks in the spring of 1924 (129).

Among the other early acquisitions of stock from England was that of the New York Agricultural Experiment Station at Geneva in 1928 by Tukey (164) (174). The Ontario station set out an orchard of five varieties on Malling types EM I, II, IX, and XVI in the fall of 1929, but it is not clear from the record whether the stocks were obtained from England, or procured elsewhere in this hemisphere (178).

In 1930 further importations were forbidden in order to preclude the introduction of foreign pests into the United States (134). This placed a heavier burden on domestic facilities to supply such demand as existed for these stocks. Largely, the early demand was from other experiment stations wishing to test the Malling series. After its acquisition of Malling rootstocks, Tukey and Brase of the New York Station at Geneva had a major part in disseminating material for testing. In 1937, plant material was supplied to the United States Department of Agriculture, Maine, Vermont, New Hampshire, Massachusetts, Pennsylvania, Ohio, Illinois, Indiana, Michigan, Idaho, Oregon, Washington, and Nova Scotia (44). Most of these materials were sent to the experiment stations of the respective states. Nursery-

men and fruit growers also received a limited amount of material made available to them at this time.

While most of the rootstock material which was disseminated by Tukey and Brase of the Geneva Station was for the purpose of helping the recipients to propagate rootstocks and so establish a domestic supply, most of those who received them either used them as lining-out stock upon which to bud or graft desired scion varieties, or they failed in their attempts at establishing stoolbeds and propagation blocks. Accordingly, the station embarked upon propagating standard American varieties upon the Malling rootstocks and distributed them widely in the country.

In 1937 the catalogue of the Maloney Brothers Nursery Company of Dansville, New York listed for the first time in America the availability of trees on Malling rootstocks (44), principally Malling I and IX. Kelly Brothers Nursery Company, also of Dansville, New York, and Jackson and Perkins of Newark, New York, followed shortly. In 1939, 44 shipments of material comprising 28,716 rootstocks and 927 trees were made from the New York State Agricultural Experiment Station in Geneva to researchers, orchardists, and nurserymen in 11 states and the province of Alberta in Canada. At that time there were 11 cooperative test orchards in New York State (46). By 1940 the number was increased to 28 (48) and in 1942 there were 50 tests under way in New York and several other states, all of which were supplied stions or rootstocks from Geneva (52). In the latter year, the Geneva Station produced and introduced as many as 40,000 rootstocks and 2,000 two-year-old orchard trees. The New York State Rootstock Cooperative, Inc. was formed in 1940 to produce clonal dwarfing rootstocks in some quantity (52). From 1935 to 1945 the Geneva Station propagated and distributed 191,669 rootstocks and 15,820 fruit trees worked on these stocks to 238 individuals and Experiment Stations in 36 states and in Canada. Much of the information available on the performance of dwarfing rootstocks and dwarfed trees in the United States is based upon these widely disseminated materials.

Tests of propagation

The Paradise and Doucin stocks which preceded the classified Mallings in America were propagated by the same variety of methods, apparently, that have been utilized with the latter. Coxe, in 1817, (70) spoke of propagation by suckers as being the usual method,

while reproduction of the plant by cuttings was publicized in the *New England Farmer* in 1852 (93). Patrick Barry, in his lengthy and detailed discussion of the Paradise and Doucin stocks in "The Fruit Garden", published in 1857, states that both kinds were propagated almost exclusively by mound layering (57). Under conditions of a scarcity of stocks, trench layering was also employed (57). In 1862, Thomas Meehan informed an inquirer from Provo, Utah, that dwarf stocks were reproduced by making cuttings from the roots of old plants. (11). Lodeman's bulletin, published by the Experiment Station at Cornell in 1896, described mound layering as the principal method of propagating dwarf stocks, but suggested that the use of suckers from stock plants was a good accessory method (103).

Propagation studies constituted some of the earliest research work in this country with Malling rootstocks. Apparently Massachusetts experienced difficulty in finding a suitable commercial method for reproducing the Mallings. They reported in 1929 that "mound layering gave rather poor results, and attempts to propagate several of the stocks from cuttings planted in the field resulted in complete failure". However, they found that "when cuttings were grafted on nurse roots from ordinary apple seedlings, good success was achieved and practically all the trees rooted from the scion and are now on their own roots" (34). Two years later, they again reported good results with nurse root grafts and also with layers. Cuttings of roots of five-year-old stocks gave indifferent results (35). In spite of reports of satisfaction with nurse-root grafting, study along this line and with mound layering continued. A report in 1935 differentiated between the Malling rootstocks with regard to survival after nurse-root grafting. None of EM VI, VIII, or IX survived. The best performance was with EM I, IV, X, and XVI, in which approximately 80 percent rooted. (42). In 1944, Shaw, in what apparently is a summary of his experience with and knowledge of Malling stocks, speaks of root cuttings, stem cuttings, nurse-root grafts and layers as means of propagation. No preferential method is distinguished (134). With respect to mound layering, it was stated that EM IV, VII, XIII, and XVI were the most productive types (134).

The Experiment Station at Geneva concentrated its attention immediately on layering as a commercial means of propagation and on means to improve rooting under this system. It also adapted devices such as shovel plows, potato hillers, etc. to propagation practice to reduce labor costs (44). In several reports (163) (44) it is asserted

that the more vigorous stocks, such as I, XII, XIII, and XVI propagated best by trench layering, while the weaker growing sorts such as II and IX did best with mound layering. Though layering, by all indications, was the more commonly used type of propagation for Malling rootstocks, it apparently was not fully satisfactory. Tukey and Brase used granulated German peat moss between the rows prior to mounding to try to improve rooting. The mixing of this material with the soil not only increased the relative numbers of well-rooted layers, but improved their quality. It was especially beneficial on those types which root with difficulty (161). They also reported good success from root cuttings as an emergency method of propagation.

Tukey and Brase at Geneva (165) and Anthony and Clarke (54) have characterized the ease of rooting of Malling layers. In general, the two reports are in agreement. EM I, V, VII, IX, and XIII are stated to root easily, whereas XII roots with difficulty. EM II was found to root with difficulty at Geneva (165), but moderately well in Pennsylvania (54). Under optimum cultural conditions it was found at Geneva, New York that up to 25,000 salable rootstocks might be produced per acre in mature beds. This was considered satisfactory for commercial production (163). It was found also that the amount of rooted material available could be increased by taking hardwood cuttings from layers which were longer than necessary or which were poorly rooted (163). While ease of rooting is important so far as the usefulness of a rootstock is concerned, root quality and shoot size are important as contributing to survival as lining-out stock and salability, respectively. These factors were also studied by Tukey and Brase. In general, those types which rooted most readily in the stoolbeds gave the best stands of lining-out stock. The stands of all Malling types were always as good or better than those of French Crab seedlings (167) (171). Carlson and Tukey have also described and pictured cultural methods for Malling rootstocks (68).

In 1952, O'Rourke and Tukey reported on further work with the nurse-root technique of propagation which had given good results earlier in Massachusetts. They employed piece-roots and a thin copper wire at the graft union so as to pinch off the nurse root in time. EM VII performed best with this method, while IX had the lowest survival rate and poorest growth. EM I, II, IV, VII, IX, and XVI were tested. A method wherein the polarity of the piece-root was reversed was also checked, but found to have no usefulness in reproducing rooted Malling clones (110).

As a rule, the technique employed in producing the stion does not appear to have created any problems with Malling stocks worthy of more than incidental study. Budding or grafting are used depending upon local practice and the preference of the propagator (26). The point at which to insert the bud on dwarf trees excited more discussion. A writer in *The Horticulturist* in 1848 said that it was not necessary to bud them close to the ground, but that they probably should not be budded more than 4 to 5 inches above it (5). Patrick Barry, on the other hand, asserted that the bud should be inserted as close to the ground as possible. It was deemed even better if some soil was removed, the bud placed, and the soil returned to its former position, so that the stock would be entirely below-ground (57).

Observation on compatibilities

The manifestations of stock-scion incompatibility include the definitive as well as the vague. Hence, it may be expected that where incompatibilities are not generally severe, as in the Malling stocks, some discrepancies may occur in reports.

Early reports of good or poor performance of varieties on Paradise and Doucin stocks were not labelled as cases of incompatibility. The instances of specific recommendations of varieties for dwarfing suggest that such a condition was found to exist (6) (20) (77) (185). Hedrick, reporting in 1915 on the results of an extensive experiment with dwarfing stocks, made a stronger implication of a general incompatibility in Paradise stocks. This was of the type associated with graft union breakage (86). Beach, however, in 1902, stated, "So far as I can learn, all of our cultivated apples form a good union with this stock (French Paradise) and are as productive in proportion to their size, as healthy, as vigorous and as long lived as the same varieties are when grown as standards." (58).

The first reports in North America relating to the compatibilities of the Malling stocks suggested the possibility of certain incompatibilities and uncongenialities. Tukey and Brase stated in 1938 that EM I showed uncongenialities and that EM XII and XIII would not take as wide a variety of buds as would EM II and XVI (165). Research from Massachusetts published in the same year showed that Wealthy/EM I was an uncongenial combination there. Such trees were extremely dwarfed and showed swelling at the graft union (143). A report from Pennsylvania concerning EM I states that it was compatible in the nursery with a number of scion varieties tested. Failures

of Starking and Golden Delicious trees on EM I over a 10-year period in an orchard were found to be due to death of tissues in the crown (54). This may or may not have been due to an incompatibility. EM I may be prone to winter injury at the crown (176). Both Upshall and Sudds have also reported irregularities with EM I. In the former case, Rhode Island Greening/EM I showed evidence of incompatibility in that two trees out of 14 were fractured at the graft union by severe winds (181). Sudds characterized as "a high degree of uncongeniality" the production of miniature-sized and very low-yielding trees by the combination York Imperial/EM I (150).

Instances of incompatibility or uncongeniality of other than ornamental apple varieties with other Malling stocks have been reported, but not so generally as with EM I. Sudds noted irregular size and poor yields in York Imperial/EM II and stated "some possible evidence of uncongeniality has been observed'. Jonathan, Staymared, Starking, and Golden Delicious on the same stock produced dwarf trees bearing good crops (149). Certain inconsistencies in performance wherein some trees were appreciably smaller and had foliage which developed autumn coloration and fell early, were observed by Shaw and Southwick in Massachusetts. This occurred with Starking on EM XII, XIII, XV, and XVI. All abnormal trees on EM XVI survived and after eight years began to perform in a more normal manner, though they remained dwarfed (138). Enlargement at the graft union and tipping and breakage of trunks at or near the union of stock and scion in the hurricane of September, 1944, were studied by Shaw. He concluded that the severity of the irregularity at the graft union increased with an increase in the tendency of the stock to dwarf the tree. EM IV trees exhibited an enlargement disproportionately large for the stock's moderate dwarfing tendency. Trees on EM IV showed a greater amount of breakage in the hurricane than those of any other stock represented. Melba and Red Spy were the only varieties which did not sustain damage on this stock (135). Several other investigators have recorded instances of aberrant performance or structures involving Malling stocks, but did not refer to such as evidence of incompatibility or uncongeniality (54) (125).

Probably the most sharply defined incompatibility and that involving the Malling rootstocks and scions more generally is the incompatibility with the ornamental crabapples. Both Shaw and Upshall reported this phenomenon in 1941. The former budded 10 kinds of flowering crab on nine Malling stocks. Failure of buds to start growth,

or weak unions if growth did start, was general on the more dwarfing rootstocks (131). Shaw did not label these instances as incompatibilities because of the small numbers of each combination involved. However, later studies confirmed the nature of the phenomenon. Also in 1941, Upshall obtained results similar to those of Shaw with seven Malling rootstocks and Bechtel's Crab. In contrast to the results in Massachusetts, the incompatibility in Upshall's experiment extended to the more invigorating rootstocks, EM XII, XIII, and XVI. Two other ornamental crabs which were not tested by Shaw showed no incompatibility with the Mallings (180). In 1944, Shaw and Southwick budded 31 ornamental crabapples on EM III, IV, and XII. Results in this instance confirmed his earlier report that incompatibilities were associated mostly with the more dwarfing types of Malling rootstocks (138). Sax found that seedlings of an ornamental hybrid apple (20139) were incompatible with EM IX. He reasoned that the insertion of a variety compatible with both other components might cause the EM IX scion to unite and grow better on the seedling ornamental apple stock. The insertion of the compatible Ottawa 524 did not alter the incompatibility (124).

In spite of the specific instances reported of incompatibility of Malling rootstocks and varieties grown for their fruit, and the somewhat more general incompatibility of the ornamental crabapples, this is not a problem in a broad sense. Tukey and Brase reported in 1941 on an experiment involving McIntosh, Cortland, Delicious, and Northern Spy budded on 10 of the Malling types. A few of the possible combinations were not represented. None of the combinations showed evidence of incompatibility in the nursery row (172). The same year they reported that 38 varieties of apples had shown no uncongenialities to the age of two years, though not all combinations produced strong-growing trees. EM I, II, IV, VII, IX, XII, XIII, and XVI were used in the tests, but each stock was not used with every scion variety (171). More extensive tests in both length of time and scope of material were reported later by Tukey and Brase. These embraced 40 scion varieties, and 14 rootstocks in a total of 210 combinations over a period of 14 years. At the time of the report no incompatibilities were evident (174). Shaw stated in 1944, "There are few, if any, varieties that will fail to grow and bear fruit when budded on any of the Malling rootstocks. However, not all combinations are equally satisfactory" (134).

Stock-scion interrelations and interactions

Numerous investigators have noted that the tree growth of two apple varieties will not be in the same relation to each other on two different types of the Malling stocks or on a Malling stock and seedling stocks. In most instances, the tree size relations were not reversed, but the differences were decreased or increased (134) (168). Shaw saw an increase in size difference for McIntosh and Wealthy on EM I as compared with own-rooted trees and those on other Malling stocks (35) (38) (42). In an experiment reported in 1935 and 1938 by Upshall, Malling I decreased the size of four varieties in comparison with the same varieties on Malling XVI, but not the size of Northern Spy. The same situation occurred with these varieties on Malling IX in comparison with EM XVI (178) (179). In 1943 Upshall made a further report on this experiment. At that time the greatest height reduction by the use of EM I and II in comparison with French Crab and EM XVI had been effected in Northern Spy (181). This shows a reversal, in the thirteenth year of the test, of a situation which had existed through the eighth year in the orchard.

A tendency toward more severe dwarfing of York and Gallia Beauty on EM I than of Starking and Staymared was noted by Yerkes and Sudds (187). Similar more severe dwarfing with one variety than with others used on the same stock have been observed on different varieties and on other stocks than those mentioned above (51) (54) (140) (186) (187) (148). Other instances of invigorating effects relative to another variety or group of other varieties on the same stock or stocks are also recorded (120) (154) (181) (186). Over a period of time with numerous tests a generalized size-inducing relation has been established between the Malling rootstocks.

In some tests the combination of several scions with a particular stock has resulted in departures of all stions from the expected size (148). An observation made in Wisconsin may account for some of the disparities observed. It was found that late-maturing apple varieties such as York and Winesap made better growth on EM IX than upon EM XII. This was believed to be due to the earlier seasonal accumulation of carbohydrate reserves on the EM IX rootstock (40) (40a). Roberts also reported this more vigorous growth of some varieties on EM IX than on EM XII. He attributed this to the bench grafting technique. Varieties tended to grow more nearly in accordance with the known dwarfing tendencies of the two rootstocks

when they were produced as double-worked trees (119). It cannot be expected that the effect of a stock in dwarfing or invigorating a variety relative to some standard will be uniform with all varieties. Some Malling rootstocks have been more variable in this respect than others. Sudds and Marth characterized this effect as "extreme" in EM I, even in comparison with open-pollinated seedling stocks of some apple varieties (153). Anthony and Clarke found the growth performance of Malling II to be quite variable (54).

As budlings in the nursery, however, variation with respect to a given variety on several Malling stocks and a number of varieties on a single Malling type has been slight (172). It might be supposed that the differential performances mentioned above were instances of mild degrees of uncongeniality. While this possibility cannot be ruled out, the experiences of Tukey and Brase indicate that within short distances and with scions and stocks from the same source, variation in relative performance of stock/scion combinations may still be expected (168).

Shaw has also mentioned the effect of environment on differential performance (134). The reaction between stocks and scions might produce relatively greater differences in growth patterns for one scion on two different Malling stocks than for another scion. But R. B. Tukey, Klackle and McClintock have reported that such variation for a variety on several rootstocks was less in their experience than the variation between varieties (177). The same authors have also recorded what appears to be a stock-scion interaction with respect to susceptibility to winter injury. During two winters, severe trunk and crotch injury occurred on trees on Malling stocks. On EM I, Golden Delicious and Gallia Beauty sustained the greatest percentage of deaths, while on EM XII the greatest relative number of deaths occurred in Turley. There were no dead Gallia Beauty trees on EM XII (177).

Roberts, in several papers, has reported producing the variable varietal response to Malling rootstocks mentioned above by the use of stem bark grafts using Malling bark (121) (122) (123). From the data presented, it appears that the operation of removing a ring of bark and regrafting it on the same whip produced a depression of growth relative to ungrafted whips. Hence, it is not possible to say exactly how much effect may be attributed to the nature of the bark, especially since there is a season-to-season variability, but it does

appear that the technique was responsible for the major part of the decrease in growth observed.

The root system configuration of stocks as they were influenced by the scions was also studied by Roberts. He found that such scions as Wealthy, Whitney and Fameuse each produced a different type of root system in EM XII, whereas the root system of EM IX was quite uniform on all of these scions. It was suggested that EM XII produced vigorous trees because they were permitted to grow as if on their own roots (118). In a subsequent study the same effect was noted for EM XII and IX interstocks (119). Observation of root anatomy showed uniformity in number of rays, number of parenchyma cells, ratio of parenchyma to fiber, ray, vessels and bast, and vessel diameter of EM IX tree roots under several scions and dissimilarity in these characteristics of EM XII roots under the same scions (119). EM I and II stocks worked to Delicious scions have demonstrated aberrant rooting in Canada. Such trees have not stood up well in high winds when McIntosh, Northern Spy, Rhode Island Greening, and Melba, on the same stocks were satisfactory (181).

In general, variations in tree size related to interactions between scion and stocks will also have a bearing on the precocity of the tree. There are exceptions, however, and, hence, the situations recounted in the preceding sections may not necessarily be inferred to relate also to earliness of bearing.

Bailey in 1926 described such an exception in a study of stock effects on the scion, though stock-scion interactions in the sense employed in this paper were not involved. This study was aimed at eliminating variability in orchard trees. It was found that while trees on Oldenburg stocks were smaller than those on English Paradise, fruiting was not as early (55). Starking trees on EM IX in West Virginia were found to be slow in beginning to bear, although they were much smaller than Starking/EM II (186).

In a summary of rootstock work in Canada, Blair remarked on the variation in tree size, precocity and productiveness of varieties on EM IX. The greatest effect was found to be "the hastening of early fruiting in the late-bearing varieties, Spy and Delicious" (61). Results in Wisconsin were, in a general sense, contrary to these. Roberts stated that the stock effect on blossom bud formation was associated with the effect on diameter of wood. He found that single and double-worked trees of Wealthy and EM IX blossomed plentifully the second year. More vigorous trees, such as Spy, Fameuse

and McIntosh did not bloom at that age (119). EM I, in West Virginia tests, produced early-bearing trees with Gallia Beauty, York Imperial and Staymared, but apparently not with Starking (187). In this instance, precociousness seemed directly related to relative tree size.

Upshall has recorded an instance of differences in delayed bearing on EM XVI relative to French Crab. Rhode Island Greening trees on EM XVI bore at about the same age as those on Crab, while Delicious, Northern Spy, McIntosh, and Melba on EM XVI were relatively later in beginning to produce fruit (179).

Some investigators have reported stock-scion interactions with respect to fruit production over a period of years. Since this is a function not only of earliness, but of heaviness of bearing, its relation to precocity will not be apparent.

Sudds found at the end of 12 years that York Imperial and Gallia Beauty on EM I had been low-producing trees and that Staymared and Starking on EM I would be classed as intermediate in their bearing with respect to those varieties on the 16 other stocks used (150). Upshall reported in April, 1935, on fruit production of trees on Malling stocks which were set in the fall of 1929. In this limited period, Rhode Island Greening/EM XVI had outborne Rhode Island Greening/French Crab, but the reverse situation occurred with Melba on the same stocks (178).

In Upshall's rootstock work, EM I and II trees always produced a slightly larger percentage of No. 1 fruits of Delicious, Northern Spy, Rhode Island Greening and Melba than did EM XVI trees. With McIntosh, however, EM XVI produced higher grade fruits in 5 out of 7 years (181).

American and Canadian investigators, in the tradition of confining experimentation largely to facets having a direct application, have probed the chemical aspects of stock-scion interrelations very little. An observation incidental to field tests has, however, been made. Upshall observed a leaf scorch characteristic of potassium deficiency in five varieties of apples growing on three Malling stocks and on French Crab. Of the five varieties, Rhode Island Greening exhibited the symptoms most pronouncedly. Yet, on the rootstock, Malling XVI, the same variety showed outstanding vigor (179).

Observations on hardiness, soil, and general climatic factors

The consensus of stated opinion and observation in the pre-Malling period was that the French Paradise stock was not hardy (86)

(97) (114). Hedrick's evaluation of the stock as being tender was based upon winter root injury under the very shallow rooting conditions of his experiment. Doucin was also rated as more tender than French Crab. The number of deaths due to winter injury to the roots was intermediate between those of Paradise and French Crab (86). Powell had evidently had a similar experience, for he advocated budding high on the stock and setting the union 4 inches below the soil surface (114). The statement of Jaques in "A Practical Treatise on the Management of Fruit Trees" inputes "a tender habit" to the Paradise stock, though he appears to have the French Paradise and Doucin reversed (97).

On the other hand, a survey in 1869 by the Fruit Growers' Association of Ontario evoked no reply that dwarf apple trees were any more tender than seedlings. One reply claimed that the hardiness of the scion was increased by dwarfing stocks (22). Unfortunately, specific stocks were not identified. Ellwanger considered French Paradise as "perfectly hardy". He had known it to survive air temperatures of 20 degrees below zero without consequential injury (77), although there is no record that the roots were subjected to this low temperature. It must be remembered, also, that the fruit regions of Western New York and of the Niagara Peninsula of Canada are among the more tempered and favored areas for fruit production in North America.

Many observations and formal experiments relating to the hardiness of the Malling series have been reported since their introduction in North America. In general, it has been found that Malling stocks are not hardy in the Great Plains area. In Kansas, all Malling rootstocks were killed to the ground the winter of 1947 (79). Maney stated that it was well-known that the Mallings were not reliably hardy under Midwest conditions. It appears that he felt Clark Dwarf might be better in this respect (106). However, Brase has observed EM VIII and Clark Dwarf to be identical in many morphological characters (63). Where tested, EM VIII has been no more hardy than the other Mallings or less hardy. Tukey and Brase reported that none of the plants of 15 Malling types were killed in the nursery by a temperature of —25°F. Some tender apple varieties were badly injured at that time (164). In a later report and after more extensive testing the same authors characterized EM VIII as "not hardy" (165). Schultz and Graves conducted tests calculated to increase the hardiness of Malling roots so as to adapt the stocks to

conditions in North Dakota. They reported in 1951 that where Dolgo, a hardy crabapple, was used as a scion and the crab/Malling combinations planted with the bud union below the ground line, they withstood five North Dakota winters without root injury. Adjacent trees on seedlings of hardy varieties showed a large amount of winter injury (125).

In the principal apple-producing areas of the United States, the desirable Malling rootstocks have shown satisfactory hardiness; although several tests have indicated that there are differences among them.

Shaw pointed out that comparisons of budded or grafted stocks of the Mallings and seedlings may place the former at a disadvantage, since in that case, the necessity for keeping the union above the ground line exposes a portion of the stock to air temperatures. In spite of this handicap, the Malling stocks had been as hardy as or hardier than French Crab seedlings in Massachusetts (134). EM IV has attracted attention at several experiment stations because it produces semi-dwarf trees bearing large crops of fruit. One of its weaknesses, however, as determined in Massachusetts, was its lack of hardiness in the orchard (41), which was characterized as no better than and probably a little poorer than that of Baldwin (129). R. B. Tukey, Klackle and McClintock recorded observations on tree losses due to winter injury in the 10th and 11th year of a Malling orchard. These losses were attributed to cold injury to roots, which were somewhat exposed from hoeing around the trees for mouse control. Of the four types tested — EM I, XII, XIII, and XVI — EM I sustained the greatest tree loss (177).

In the nursery row, Tukey and Brase have made observations on the hardiness of extensive populations of the Malling types. During the winter of 1933-34 no plants of 15 types were directly killed when the temperature dropped to —25°F. Four types, EM I, II, III, and IX, were undamaged by the exposure (164). In a later and more detailed evaluation of the relative hardiness in the nursery of the Malling stocks, Tukey and Brase stated EM VI, VIII, X, and XV were lacking in hardiness, EM IX and XIII were moderately hardy and EM I, II, III, IV, V, VII, XII, and XVI were hardy (165). Such evaluation as Anthony and Clarke made of unworked specimens is not entirely in accord with the research in New York. Under the conditions in Pennsylvania, EM II was also rated as hardy, but Malling I was found to be subject to winter injury of the trunk and Malling

V was of doubtful hardiness. No specimens of Malling I remained uninjured for more than 12 years (54).

An artificial freezing technique was used by Stuart to evaluate Malling hardiness. With such a method, previous treatment, time of harvest of the sample, and conditions of freezing may produce different results with the same plant material. Hence, duplication of the generalized hardiness response of intact plants outdoors would not necessarily be expected.

Stuart tested stems, etiolated stem bases, and roots of Malling types by measuring the electrical conductivity of the exosmosed liquid from these parts previously frozen at —15 and —20°F. Excellent agreement was obtained in the results for the several parts, except with the roots. With these, injury was general because the treatment temperature was too low. On the basis of the several tests Stuart divided the 10 stocks into three groups between which differences were statistically significant. The first group contained only EM III, which produced the smallest increase in conductivity of the exosmosed liquid and would, therefore, be considered the hardiest. The second group contained EM IV, VII, XIII, and XVI and the third included EM I, II, V, IX, and XII (146).

Several investigators have employed Malling and other rootstocks in studies of the effect of the rootstock on the hardiness of the scion variety. Dorsey, in 1918, used as stocks Patten Greening and Hibernal budded or grafted high in comparison with root-grafted Paradise and *Malus baccata.* No detectable differences in low temperature injury to a given scion were found to result from the use of the different stocks (72). Blair reported on a similar experiment employing EM II, IX, and XVI and three seedling stocks. Scion injury was assessed on the basis of 100 points for maximum injury. The 100 points were subdivided into maxima for the various regions of the tree which might sustain injury. No differences in injury to the scions due to the rootstocks were statistically significant (59).

Information on the adaptation of Doucin and Paradise and of Malling rootstocks to other environmental factors than cold is generally rather vague. A few controlled experiments have been performed and, with one stock, a particular response has been so general as to leave little doubt of the adaptability of the stock.

Among nineteenth century writers, Jaques warned against growing trees on Paradise stocks in sod (97) and Barry stated that because of their shallower rooting Paradise and Doucin layers did not need

as deep a soil in the nursery as seedlings (57). It was observed by George Ellwanger that they needed a warm, dry soil in good condition (77). The writings of Hovey on dwarf trees, which were quite evidently promotional in nature, indicated that dwarf apples were "less particular as to soil than the pear", which was widely grown (96). Sixty years later, Powell, another vigorous proponent of dwarf apple trees, asserted that desirable varieties on Paradise and Doucin stocks could be grown on all limestone and on good clay soil over a wide area (115).

Probably the most definitive studies on environmental adaptation other than that to low temperatures have been those at Geneva, New York, by Tukey and Brase on adaptation to soil moisture conditions. In greenhouse studies, one-year-old Malling plants of eight types were grown under high, medium, and low soil moisture conditions. Results indicated that EM I, VII, and XIII grew satisfactorily under a wide range of soil moisture conditions, that EM I, VII, and XVI were tolerant of high moisture and that EM I, VII, and XIII tolerated low levels of soil moisture (169). Later the same authors observed that differences between the Malling types in the nursery are more evident in years of deficient rainfall than when moisture was adequate (171). Several field observations have indicated that EM XIII is not drought resistant (45) (51) (54) (186), but rather that it will tolerate wet, heavy soils (169).

A report from Pennsylvania suggests that this may be due more to a tendency to shallow rooting than to any anatomical or physiological characteristic of the stock (51). Results in West Virginia impute this characteristic more definitely to young trees than to older ones (186). EM IV has been shown in the field to be sensitive to soil moisture content and to general nutrient level. Smith has reported from New Hampshire that on poor soils subject to drought, trees on EM IV have performed badly, but on good soils have been superior to trees on seedling roots (141). Soil depth appears to be important with EM II. Sudds and Yerkes stated that EM II in West Virginia was "especially adapted for use on deep fertile soils" (154).

In some instances the factors contributing to adaptation or lack of it are obscure or made up of a complex of factors. Such is the poor root development of EM IX in the Annapolis and Cornwallis Valleys of Nova Scotia reported by Blair. Apparently it was more satisfactory at other stations and areas in eastern Canada (61). Shaw noted differences in growth of a given stion in different Massachusetts

orchards. These different responses he attributed to soil variations and to cultural practices (136).

The only report from the northern part of the Western Hemisphere on adaptation to soil chemical status seems to be that by Upshall in 1938. Of the three Malling stocks, I, II, and XVI and French Crab seedlings, growing on a soil low in potassium or low in potassium availability, trees on EM I more generally showed symptoms of potassium deficiency. EM XVI trees were, in general, more free of symptoms of the deficiency (179).

Tree size relationships of various stock-scion combinations

Top growth is naturally the aspect of Malling rootstock performance which has been the subject of the greatest amount of research work. The measurement of such growth has been done in several ways. One of the difficulties in comparing tree growth in various widespread locations is often the absence of a comparison base or the use of an uncommon or of several uncommon bases.

One is immediately impressed in reading some accounts of dwarf trees on Paradise and Doucin, by the large trunk diameters relative to tree height or the stockiness of the trees. Such a relationship undoubtedly exists in trees on Malling rootstocks today, but apparently not to the degree that it occurred in the older combinations. For instance, Ellwanger gave the dimensions of 30-year-old trees on French Paradise stock as follows: "Stem from 6 to 8 inches in diameter, height 6 to 8 feet, and branches about the same in diameter" (77). Waugh presented data which characterized this stockiness. It was shown that several varieties on Doucin were stockier than the same varieties on seedling and that Paradise trees were stockier than those on Doucin. For two-year-old Baldwin trees, the ratios of tree height to trunk diameter for seedling, Doucin and Paradise were, respectively, 103.8, 82.9, and 70.0 (184).

Apparently during that period pruning was a much more important adjunct to producing a dwarf tree than it is today. The general use of the European system of pruning, irrespective of the amount of wood removed, would suggest that this was so. Hedrick, in speaking of tree size in the tests conducted in New York State with Paradise, Doucin, and seedling stocks, said, "There is not nearly the difference in size that we had expected between trees on the three different roots". He attributed this partially to "the failure to find a workable method of summer pruning". He further said, "It is cer-

tain that man must aid the stock very materially in dwarfing trees by severe pruning and training in both winter and summer". He admitted, however, that scion rooting might also have been involved in the lack of difference in size of his trees (86).

The commercial grower, George Powell, did not agree with the practice of severe pruning. The result is evident in the dimensions of his 15-year-old trees on Doucin stocks. The trunks were about 10 inches in diameter with heights and spreads averaging 20 and 18 feet, respectively (114). These trees, obviously, were not much dwarfed by the stock. Ten-year-old trees on Doucin stocks at the then Massachusetts Agricultural College were 12 feet tall, according to Sears (126).

Malling I has been mentioned with respect to size relations in more scientific reports than any other Malling stocks. Many of these, of course, are reports on the same experimental plantings at different ages. Shaw presented a grouping of the various Malling stocks based upon their size relations with several scion varieties. In this grouping no distinction was made between EM I, and IV, V, VI, VII. The entire classification was as follows: (a) VIII, IX, (b) III, (c) I, IV, V, VI, VII, (d) XIII, (e) X, XV and (f) XVI, XII. No distinction was made between those types within the groups (136). Several reports have characterized EM I as semi-dwarfing in comparison with seedling stocks or have implied that such trees were semi-dwarf or of intermediate size with respect to seedling trees (61) (168) (44) (83) (186).

Others have stated merely that such trees were smaller than those on seedling roots (47). Gourley and Howlett found in Ohio that EM I at the end of six years, produced smaller trees than either seedling or EM IV stocks (82). On the other hand, Smith stated that results in New Hampshire showed Malling I trees to be larger in terms of height and spread and in trunk circumference than trees on EM IV or on EM III, V, X, or XVI (140). In Upshall's trials in Ontario, five-year-old trees on EM I were as large as those on EM XVI where Northern Spy was the scion variety. With all other varieties, such trees were smaller than EM XVI, French Crab, and EM II trees (179). At the end of the thirteenth year, the Spy/EM I trees in this orchard were also smaller in height than the Spy/EM XVI combination (181). Results reported by R. B. Tukey, Klackle and McClintock indicated that in Indiana, grafted Malling I was as vigorous as or more vigorous than EM XIII and of about the same vigor as EM XII (177).

General results have shown Malling II also to be a semi-dwarfing rootstock or to produce a tree smaller than seedling stocks (186) (47) (83) (61). A review of work in Canada by Blair shows that trees on EM II were larger than on EM I at Vineland, whereas the reverse condition apparently existed in Nova Scotia (61). As indicative of the extent to which the size of trees on a particular rootstock may vary with localities and scion varieties, Sudds and Yerkes have recorded very little difference in the size of six-year-old Jonathan trees on EM II and IX (154). On the other hand in another study, Melba/ EM II was as large as Melba/EM XVI at 13 years of age, as measured by trunk cross sectional area. In terms of height, also, Melba/ EM II was more nearly the same size as its counterpart on EM XVI than was any other variety on EM II to its duplicate on EM XVI (181).

Malling IV generally would be classified as a semi-dwarfing rootstock. Gourley and Howlett found it to be intermediate in size between domestic seedlings and Malling I when grafted to Staymen (82). Tabular information from Michigan indicates that EM IV was larger than EM I in the fifth season in the orchard in the single instance in which they were tested with the same scion variety (175).

EM VII produced smaller trees than EM I, II, IV, V, XII, and XIII with several scions in Michigan (175). This was often the case in New York State, also, though in a single instance and with different scion varieties EM XIII or II or I might produce smaller trees. EM IX trees were always smaller (168).

EM IX has almost without exception produced dwarf trees when used as a rootstock (44) (45) (154). In an instance, previously cited, it produced trees of about the same size as EM II with a single scion variety (154).

Shaw classifies EM XII in the category of largest trees on Malling rootstocks (136). Information from elsewhere is in conformity with this classification (44) (47) (175) (177). With respect to stocks in the same general size category it has, however, produced trees larger than EM XIII (175) or of about the same size as EM XIII (44) (177) and smaller than EM XVI (177).

EM XIII might be classified as producing a semi-standard tree. It has variously been reported from several localities as "producing strong, vigorous trees" (44), as slightly smaller than EM XII (175) and as being as vigorous as or less vigorous than EM I (177).

EM XVI appears to have been as variable in response within a narrow range of size as have many of the other Malling rootstocks.

In New York State trees of such size as would appear to be classified as of standard size were produced (44). Such also was the case in Ontario with 13-year-old trees (181). However, in Pennsylvania it was found to have a tendency toward dwarfing in some instances (54).

Size relations have been reported in terms of tree height or height and spread or on the basis of trunk circumference or diameter. Sudds reported his results both in terms of trunk circumference and tree weight. Indications were that with respect to variability within a stion and comparisons between stions having a common scion, trunk circumference alone was not a sound basis of comparison (147) (148).

Observations on the use of interstocks

Apparently to attempt to circumvent the poor anchorage of some of the more dwarfing Malling rootstocks which produce trees of desirable size, studies have been made by American investigators of the performance of trees with Malling stem interpieces. Most such studies have involved an interpiece of EM IX. Blair reported in 1938 on such a study made in Canada. A Bramley Seedling scion and French Crab roots were common to all combinations. Uniform 9-inch pieces of EM IX, II, and XIII were used as interstocks. The report is not explicit as to the duration of the experiment, but it appears that it was two seasons. At the termination, trees containing components of EM II and XIII were of the same size and weight. Trees having stempieces of EM IX were half the size of the other two kinds of trees. Cross-sectional area of the EM II stempieces were, however, less than that of the EM IX inserts (60). Hewetson also double-worked EM II, IX, and XII as interpieces in an experiment which included interstocks of a Malus species and Malus varieties. McIntosh was the scion variety. Only EM IX as an interpiece produced a significantly smaller tree than the control (90). Trees with 3-inch interpieces of EM IX were compared by Tukey and Brase with trees (a) single worked on EM IX rootstocks, (b) with McIntosh interpieces and (c) single worked on French Crab roots. The cross-sectional area of the trunks of trees with interstocks of Malling IX ranged from 54 to 91 percent of the area of those with interpieces of McIntosh. In size and performance such trees more nearly approach the characteristics of the trees with French Crab rootstocks than those on EM IX rootstocks (173). A report was also made by Blair on the growth of a variety double-worked on trees having a 4-inch interstock of EM IX. Such trees grew significantly less than

trees on seedling roots without an intermediate stempiece (61). Apparently no comparison was made with trees on EM IX as a rootstock.

Persistence of relative tree size

Several investigators have shown that the early performance of trees on Malling stocks is not a reliable index of the relative size later. The data of Gourley and Howlett show that trees of a particular variety planted to a similar series of Malling rootstocks both in the spring of 1940 and 1941 did not exhibit the same size relations in terms of trunk circumference at the beginning of 1946 (82). At that age, the inherent size-influencing factors were evidently not sufficiently strong to overcome ecological factors associated with time in the same location. Shaw and Southwick stated, "Usually trees on semi-dwarfing stocks grow about as rapidly as those on standard stocks but begin to bear earlier, and this checks growth. Trees on very dwarfing stocks may grow less rapidly from the start" (137). It was found by Tukey and Brase that a number of varieties on Malling IX produced as much or more growth the first year as the same varieties on seedling rootstocks. Strong terminal growth also developed the second year. In the third year the trees began to show divergent characteristics (170).

If the graft union of dwarfing stocks obstructs the movement of organic materials downward and this has some influence on the dwarfing process through reducing the supply of metabolites to the roots, it might be expected that the swell at the graft union would be inversely related to the size of the tree. Shaw found that no such correlation existed, though there did appear to be such a relationship between tree size and stock diameter (132).

It has often been stated that the pruning required on dwarf trees is less than on trees of standard size, but little evidence has been presented to support this. It is possible that less pruning might be required on a tree and yet such pruning would bear the same relation to the size of a dwarf tree as to a standard sized tree. Such is indicated by the research of Upshall. Working with French Crab seedlings and Malling I, II, and XVI stocks, he found that "there is, in a general way, a positive correlation between size of tree of a certain variety and the weight of prunings taken from those trees" (179). A similar statement was made by Upshall in a later paper wherein he pointed out that pruning would tend to reduce size differences between combinations of different possibilities (181).

Uniformity of trees on Malling rootstocks

One of the common objectives in North American rootstock work has been the elimination of variability in performance of individual trees of a stock-scion combination. Where tree size is not an important factor, variability might determine the acceptability of a stock. Such was the case in Canada, where Blair indicated that EM XVI seemed to have no usefulness in the Niagara Fruit Belt because there was no reduction in tree size variability with respect to seedling stocks (61). Southwick and Shaw also found that the Malling stocks which they tested, EM I, X, XII, XIII, XV, and XVI, had done nothing to improve the uniformity in size of orchard trees (143). Size variability, as measured by trunk cross-sectional area, was found to decrease from the fifth to the eighth year of age of a Malling planting, according to Upshall. However, concomitantly, the coefficient of variability of seedling trees decreased to the same extent (179).

In particular instances, less variability in Malling stocks than in seedlings or of differences in variability of Malling stocks have been reported. EM I and II are particularly noteworthy in this respect. Sudds records "very irregular size" in EM II, but only where York Imperial is the scion (149). It was found by Upshall that EM I and II were less uniform in trunk cross-sectional area at the end of the thirteenth year than were trees on the other two stocks in the experiment, French Crab and EM XVI (181). In a previous report, however, at the termination of the same orchard's eighth season, EM I had been even more variable than EM II. This, Upshall thought, might be due to a variable potassium supply in the soil and an apparent sensitivity of EM I to this condition (179). A lack of uniformity in tree size of EM I has also been noted in West Virginia in instances where the red sports of Rome Beauty, Red Rome and Gallia Beauty, were used. Sudds emphasized that the size discrepancies were not due to scion rooting or large differences in trunk circumference at planting time (147).

In contrast to the above reports of variability in EM I, Smith reported trees on EM I in New Hampshire as more uniform in size and behavior than trees on EM III, IV, V, X, and XVI (140). Among the other Malling rootstocks, EM XVI as a stock for McIntosh, has been mentioned as being "outstanding in uniformity of trunk size" in comparison with EM I and II and French Crab seedlings (181). Statements above have indicated that a scion can influence uniformity of size with specific stocks. Results of work by Shaw indicate that

this can also be true with a particular scion and a number of Malling types. He says, "while the Wealthy trees are more variable on seedling stocks than on any clonal stocks, the McIntosh trees are less variable only on XVI" (129).

Observations in tree shape associated with various Malling rootstocks

Tree shape may be altered by the rootstock. This has been shown by several investigators. R. B. Tukey, Klackle and McClintock stated that varieties on EM I and XII resulted in lower and wider trees than on EM XIII (177). Shaw, remarking on the difficulty in distinguishing dwarfing stocks from those producing standard trees, stated that EM IV produced trees with as great a branch spread as 12 other types, and next to largest in trunk diameter, but not as great a height (129). The effect of the scion in this respect is evident from Upshall's work. McIntosh on EM I and II produced dwarfed trees of about the same width as McIntosh on seedling stocks, whereas Rhode Island Greening was reduced in both height and width (181). The reports by Tukey and Carlson (175, 68a) depict both of these points with sketches of the shapes of McIntosh and Cortland on six stocks common to both scions (175). Ritter and Tukey have also discussed tree shape as affected by rootstock (117a).

Relation between tree size and fruiting

The mechanism or mechanisms of dwarfing have not been definitely established. Among other possibilities as suggested by conjecture and experimentation, the possible role of early bearing as a direct factor in dwarfing rather than as a concomitant result of some mechanism would be likely to suggest itself to researchers. At the end of the third bearing year, Yerkes and Sudds found that growth had been affected little by the fruit crop, except in Gallia Beauty. They considered, however, that future bearing might affect the growth rate of the various combinations unequally (187).

Dwarf tree size and heavy fruit bearing are commonly considered as being linked. Sudds found that some 12-year-old combinations, as Gallia Beauty/EM XV, had small trunk circumferences and high yields, whereas others, such as Gallia Beauty/EM I and York Imperial/EM I had both small trunk girths and low yields (150). It was also reported that after 16 years the trunk circumferences of the trees in this same test orchard were less variable than the yields (151).

Comparing size at any particular time may not be an entirely satisfactory means of assessing the performance of Malling stocks. Upshall found that five-year-old Delicious, Spy and McIntosh on French Crab were larger than those varieties on EM XVI. However, the French Crab trees had been larger at planting time. Applying Moffat's Geometric Mean formula, Upshall found that the growth rate of the trees on Malling XVI was greater for the five-year period (178).

Seasonal growth, wood brittleness, and leaf size

Colby has studied the seasonal growth pattern of varieties on EM IX and XII. Shoots of Whitney on EM IX and on XII grew at about the same rate from the initiation of growth to May 26 in Wisconsin. After that date, Whitney/EM XII grew rapidly, while growth almost ceased in Whitney/EM IX. McIntosh/EM IX grew faster than McIntosh/EM XII in early summer, but ceased growth earlier than the latter combination (69).

Various other miscellaneous observations regarding the performance or characteristics of the tops of unworked Malling stocks or of stions involving Malling stocks have also been made. Anthony and Clarke (54) and Shaw (134) have reported that the wood of EM IX is very brittle. Anthony and Clarke have further stated that such wood is soft (54). A practical implication of the wood softness of EM IX is found in the statement by Tukey and Brase that "rubber and other tying materials girdle the stem easily" (165). Colby noted that the bark on the stem of EM IX was much thicker than that on EM XII. It was also observed that shoot leaves of Whitney on EM IX and on EM XII were of approximately the same size, but that spur leaves of the former were 0.6 the size of shoot leaves, and spur leaves of Whitney/EM XII were only 0.3 the size of shoot leaves (69). Work on the ratio of internally exposed surface to external surface of leaves or R-value by Pickett revealed significantly greater R-values for Winesap when Virginia Crab, EM XVI or EM XIII were the rootstock than when French Crab or Clark Dwarf was the stock. These latter two also produced significantly greater values than EM IX or Hibernal. Results were different where Blaxtayman or Jonathan was used as the scion (112).

Pest and rodent resistance

Observations by Anthony and Clarke indicate that Malling V may be more subject to borer injury than other Malling stocks and

that unworked EM I, IX and X were susceptible and III especially susceptible to fire blight. Malling types II, XII, and XIII were resistant (54). Anthony and Clarke also stated the EM IX wood was especially attractive to rabbits and mice. Small, unworked EM IX bushes were often eaten back to the ground line (54). Tukey and Brase (168), Shaw (134), and Yerkes and Sudds (186) have made parallel observations, noting that the cortex of this rootstock is thick and relatively soft. These latter authors also attributed this apparent attractiveness of EM IX to mice partly to its tendency to "keyhole" in the soil due to a lack of firm anchorage. Such a structure provided ready protection for rodents. They found no mouse damage on the trees on EM II in the same orchard. The leaves of unworked EM I, VII, and XIII have shown susceptibility to aphids in comparison with II, IV, IX, XII, and XVI, according to Tukey and Brase. EM VII was especially susceptible (169).

Some observations have also been made on the susceptibility of Malling roots to the depredations of insects and diseases. Anthony and Clarke reported that the roots of EM IX seemed inordinately susceptible to attack by woolly-aphis (54). EM I, IV, VII, and IX have been reported by Carlson and Tukey as showing more woolly aphid injury than II, XII, XIII, and XVI (68). Fromme and Schneiderhan attempted to find a rootstock more resistant to black root rot. Ungrafted two-year-old whips of EM I, II, III, XIII, and XV were planted in infested soils in two orchards in West Virginia. None of these clonal stocks appeared to have any particular resistance to the disease (80).

Root systems and anchorage, including intermediate stem-piece effects

Many observations have been made on the root systems of Malling stocks. This is probably largely to be attributed to the greater difficulty generally encountered in keeping the more dwarfing types erect. Shaw has remarked on "poor anchorage as one possible weakness of dwarfing rootstocks". He found them to be especially susceptible to being blown over in high winds when cropping heavily. Semi-dwarfing stocks, however, were found to withstand winds of hurricane force nearly as well as standard trees (134). Sudds and Marth had under test a series of clonal rootstock, which included EM I, XIII, and XV, and a series of seedling rootstocks, at the time a severe summer storm occurred in 1940. They observed that, in general, the clonal stocks sustained more injury in terms of root breakage and blowing over of trees than did the seedling stocks (152).

Certain of the Mallings have been singled out for particular attention because of poor anchorage as manifested in several ways. EM IV is a very desirable semi-dwarfing rootstock with respect to its ability to produce heavy-bearing trees. However, in numerous instances its roots have been found to provide poor anchorage (41) (42) (129) due largely to the high top/root ratio that is characteristic of this rootstock. In Tukey and Carlson's report this may be inferred from statements that EM IV trees tended to blow over and required staking (175). Contrary to other reports, Smith stated that in his test plantings, Macoun and McIntosh on EM IV had not been staked and though a little wobbly were standing upright. One had been broken off at the graft union by wind (140). EM IX has also attracted particular attention in this respect (134). Poor anchorage of Malling IX in Canada may again be deduced from Blair's review (61).

EM I has, in several instances, been stated to have produced trees which were poorly anchored or leaned. In these cases, such a situation occurred only in certain scion/EM I combinations or in trees within a scion/EM I combination which exhibited certain other characteristics. Upshall found EM I trees to be well anchored and to withstand high winds very well except with Delicious as the scion (181). With R. B. Tukey, Klackle and McClintock, Turley on EM I was a poor combination. Fifty percent of such stions were insecurely anchored (177). In several reports, Sudds mentions a peculiarity in the performance of Red Rome/EM I. Slightly more than half of such trees in a test block were much smaller than the remainder and precocious. These early-bearing trees leaned badly and had to be staked (147) (149).

EM II has not often been reported as insecurely rooted nor has this been implied. However, Upshall observed that, as with EM I, trees on EM II when planted with Delicious as the scion, did not exhibit secure anchorage (181). Shaw devoted an entire report to the anchorage of 10 Malling clones. Leaning and breakage at or below the graft union were associated in a general way. EM IV exhibited these characteristics to the greatest degree and EM IX and VIII almost as seriously. EM I and II showed leaning or breakage in a small number of combinations and in a small number of instances. Trees on EM V, X, XII, XIII, XV and XVI neither broke off nor leaned in any instance (135). Lincoln compiled observations on damage to trees on Malling, other clonal, and seedling rootstocks in New England after the 1938 hurricane. His report shows differing results, depending

upon location, exposure to wind and other factors. He concludes that with McIntosh the clonal stocks stood up about as well as the seedling (101). Severe winds in September of 1947 in Michigan caused no breakage or leaning of several varieties on EM I, II, V, VII, XII, and XIII (175). Blair reports breakage below the graft as occurring on EM IX in Canada (61).

"Poor anchorage" may imply several characteristics, one of which may be shallow rooting. One report has mentioned Malling rooting in this more refined term. Shaw found that the roots of trees in their seventh year on Malling stocks penetrated only 2 to 3 feet into the soil (42). The stocks checked for rooting depth were not identified, but the planting distance stated suggests that they were semi-dwarf trees. EM IX as an interpiece also has induced shallow rooting. Tukey and Brase reported that such trees had roots which spread outward and downward less than trees with intermediate stempieces of McIntosh (173). Gourley and Howlett pointed out that mature trees on seedlings growing in the same soil as their Malling planting possessed roots extending ten feet deep. Yet, trees on Malling stocks on this site showed appreciable leaning and heaving (82). Frost heaving of Malling rootstocks has also occurred in Massachusetts. Shaw identified EM II, III, VIII, and IX as being subject to it under their conditions (129).

Sparse or shallow rooting would be likely to be more serious with respect to the leaning or blowing over of a tree as the top increased in size with respect to size of the root system. Sudds and Marth stated that in their study there was no consistent influence of the size of the top of a tree on its tendency to lean or blow over. However, no studies of the root system were attempted (152). Apparently, no thorough studies of top/root ratio with respect to wind damaged trees have been made. Blair, however, has determined the top/root ratio on a weight basis for what were apparently two-year-old trees. Malling interpieces of II, IX and XIII were used rather than rootstocks. Ratios of top to roots were, respectively, 3:5, 5:2, and 3:9 (60). Young Stayman trees on EM XIII were observed by Anthony and Clarke to have a less spreading root system than Stayman/EM XII. The root mass also penetrated less deeply. A large proportion of the roots were in the upper 2 feet of soil (54).

Several papers have presented information on the general extent of the root system as influenced by the use of Malling interpieces. In two distinct experiments involving EM IX interstocks, Tukey and

Brase observed that the size of the root system of several stock materials was reduced (162) (173). In the one experiment it was noted that EM IX as a scion also dwarfed the root system (162). Blair determined that the French Crab root system of trees having 9-inch interstocks of EM IX weighed half as much as those from similar trees having interpieces of EM XIII (60).

In studies of the characteristics of individual roots, in New York State, it was found with unworked Malling stocks in greenhouse studies, that EM I, VII, and IX had long roots, EM IV, XIII, and EM XVI had roots of medium length and that EM II and XII had short roots. With respect to root diameter, those having large diameter occurred on EM II, IV, VII, XII, and XVI, those having medium diameter on EM I and XIII and those of small diameter on EM IX (169). Blair recorded that although 9-inch intermediate stempieces of EM IX and XIII produced differences in the amount of stock roots, there was no difference in the proportion of coarse to fibrous roots (60). The bark thickness of roots of EM IX has been observed to be much greater than that of roots of EM XII. Suberization of rootlets of EM IX occurs rapidly as the soil dries and as later flushes of root growth occur with periodic rains (69).

Scion rooting

Because of the dwarfing nature of many of the Malling series, scion-rooting is of particular concern. Differences in amount between stocks and between scions on a given stock have been noted. In a test of six apples varieties on EM II and IX, Sudds and Yerkes found that, under similar and favorable conditions, scion-rooting of trees on EM II was of no moment but that it occurred more frequently on trees on EM IX (154). Upshall observed that in Canada, trees on EM I scion-rooted more freely than those on French Crab, EM II and EM XVI (179). Studies of the relative freedom of scion-rooting of shoots from low-vigor, fruiting trees and of shoots from vigorous, vegetative trees were made in Maryland by Lincoln. Stocks used were seedling, EM XIII, and EM XVI. Considerably less scion-rooting occurred in scions from vigorous, vegetative trees, regardless of the stock. About 12 percent less rooting occurred where Malling stocks were used rather than seedlings (102). Golden Delicious/EM IX was more prone to scion-rooting than were York Imperial, Gallia Beauty, Jonathan, Staymared and Starking on the same stock, according to Yerkes and Sudds (186).

Suckering

A tendency to sucker has been especially noticeable in some of the Malling stocks. Shaw has stated that semi-dwarfing stocks have shown this tendency less and dwarfing stocks more than seedling stocks in a test in Massachusetts. All Mallings except VII, XI and XIV were used in this experiment with worked trees (129). Observations on EM I, II, III, IV, V, VI, VII, VIII, IX, X, XII, XIII, XV, and XVI in Pennsylvania elicited the statement from Anthony and Clarke that unworked specimens of EM IV and V sucker badly from the crown. Both grew as bushes (54). Research workers testing Paradise and Doucin stocks in the early part of the twentieth century also noted this objectionable feature (33) (86). Powell observed no such difficulty with his trees on Doucin and Paradise, but he planted his trees deep, practiced "deep plowing" for the first six years and plowing to a depth of 5 inches thereafter (114).

Precocity in fruiting and fruit yields of various stock-scion combinations

Those who wrote about and tested Paradise and Doucin stocks often mentioned the yielding capacity of trees on these stocks (33) (57) (77) (86) (96) (97) (103) (114) (115) (126) (185). Results were contradictory as were many other aspects of dwarf trees at that time. Barry warned that varieties on Paradise tended to fruit excessively. He stated, "unless the fruit branches be occasionally thinned and shortened, in order to reduce the number of bearing buds, and to produce new wood, the trees become enfeebled." (57, p. 220). Ellwanger mentioned 3- to 4-bushel yields in favorable seasons on 30-year-old trees on French Paradise stocks. Such trees were 6 to 8 feet tall (77). Powell obtained yields of 9 bushels on 15-year-old trees having Doucin roots (114). Hedrick, on the other hand, obtained production in the tenth year of only slightly more than a bushel and a half from trees on Doucin stocks. He admitted, however, that excessive pruning might have kept yields low (86).

In speaking of dwarfing stocks, it is common to hear that they outbear standard-sized trees. It is often not clear whether the speaker believes that this will be true at any given age of the two trees, or whether he refers to the early bearing years, to acre yields when the dwarfs are planted closer together or to yield in relation to tree size. Blair, in a review of rootstock work in eastern Canada, states that work

at Vineland showed that trees on Malling IX produced "much heavier crops in the earlier years in the orchard" taking into account their smaller bearing area (61).

Results in Michigan by Tukey and Carlson showed that, in the fifth year, yields of trees of several varieties on EM I, II, IV, V, VII, XII, and XIII were inversely related to tree size (175). Sudds found that in general, size of top was directly related to yield with 10-year-old Gallia Beauty, on EM I, XIII, and XV (148). Sudds has documented the changing relations in the yield of a variety on several Malling stocks. Through the eighth year, Red Rome/EM I was superior in cumulative yield to Red Rome/EM XIII. At the end of 12 years there was no significant difference, but a year later the Red Rome/EM XIII stions had taken the lead (149).

It is commonly thought that the effects of various Malling rootstocks on yield are considerable. It was found in Canada, however, that 13-year yields of a variety on EM I, II, XVI, and French Crab seedlings varied less between the stocks than did the yields between varieties without reference to stocks (181). Both Sudds and Southwick and Shaw remarked on yield variability within a scion/EM stion. The latter noted that the variability in a variety had not been reduced by the use of the clonal stocks (143). Sudds found such a condition to exist particularly in red sports of Rome Beauty when grown on EM I (147).

It is difficult to generalize on the yield tendencies of specific Malling stocks and many investigators have not attempted to do so. Upshall, however, determined that on the basis of trunk cross-sectional area or unit area of branch spread, EM I was most productive and EM II second most productive in his 13-year tests. EM XVI and French Crab seedlings were the other stocks tested (181). EM I was also productive of the highest yielding trees at 12 years in Indiana, where it was tested with EM XII and XVI (177). While EM I was represented in tests in West Virginia, yield performance relative to other stocks was not consistent with several varieties of apples. Sudds (150) (151) and Sudds and Marth (153) do not make any generalized statement regarding a particular level of productivity with the stock.

EM II was characterized by Sudds in 1945 as being "very satisfactory for producing trees with good yields". At that time he considered it as the most promising rootstock under test in West Virginia (149). Trees on EM II in Canada were performing as well as trees on EM I at the end of the eighth year when yield was calculated with

regard to tree size. However, the yield was highest on a per tree basis for EM II in four of five varieties and outyielded trees of all varieties on EM XVI and French Crab (179).

At about the fifth year, Yerkes and Sudds found Jonathan/EM IX to be outbearing Jonathan/EM II. The same situation existed with York Imperial as the scion variety. However, in the latter variety the trees were so small that the authors expected that trees on EM II would surpass those on EM IX at the first fair crop (186). A report from New York State in 1941 by Tukey and Brase stated that individual trees on EM IX bore as much as 16 pounds of fruit in their second year (50). Where EM IX as a 3-inch intermediate stempiece was used, six-year-old trees of several scion varieties did not bear a materially larger amount of fruit than trees with an intermediate stempiece of McIntosh. In comparison with trees on EM IX rootstocks, yield performance was poorer in those having EM IX interstocks (173).

In a rather fundamental study with 9-inch interpieces of EM II, IX and XIII, Blair found trees double-worked with EM IX to be very precocious. In the second year such trees averaged 2.6 blossom trusses per meter of shoot growth to 0.4 trusses per meter of shoot growth for trees with intermediates of EM II and XIII (60).

Tukey and Brase determined that although three-year-old trees of 16 varieties on EM IX rootstocks were thinned, in general, somewhat less than half the fruits which remained after thinning were retained to maturity. In general, the proportion of fruit retained was directly related to the vigor of the tree (170). Upshall found that trees on Malling IX outbore their counterparts on French Crab until the following ages for the indicated scion: McIntosh, 7th; Melba, 8th; R. I. Greening, 10th; and Delicious, 11th. At the end of the eleventh year, Northern Spy/EM IX was still outproducing Northern Spy/French Crab (181).

EM XIII has been reported as producing low-yielding trees in several instances. Twelve-year-old trees of EM XIII were reported as producing less fruit than several varieties on EM I, XII, and XVI in Indiana (177). This rootstock has also been stated to be conducive to light yielding with the scion varieties Starking, York Imperial, and Staymared in West Virginia (150) (151). Also, reports have been made on the bearing of other Malling types (41) (42) (90) (139) (140) (143) (150) (151) (153) (177) (181) (186). A more detailed presentation is omitted because the performance of the stocks was generally lacking

in sufficient distinction to warrant discussion by the authors or because the terminology does not permit satisfactory comparison.

Considerable difference exists in statements relative to the earliness of bearing of trees on Paradise and Doucin stocks. Beach pointed this out in inviting the members of the Western New York Horticultural Society to appoint a committee to help select sites for testing of dwarf and semi-dwarf trees (58). Undoubtedly, some of the differences resulted from a definition of early bearing. It was pointed out that dwarfs came into bearing earlier, but that the early yield difference was not appreciable or of commercial proportions (85) (86) (186). Some stated that they bore earlier, but without defining the proportions of the crop (55) (103) (126).

These apparent discrepancies resulted in some instances also from the type of culture which the author had in mind. Specific ages of bearing for combinations were presented by some authors (126) (33) (77) (127). These indicated that the scion variety was a considerable factor in determining the earliness of bearing (33) (77) (127). Hedrick admitted that excessive pruning might have contributed to the poor tree performance, which impelled him to consider trees on Paradise and Doucin stocks as not producing commercial crops appreciably earlier than standard trees (86).

Shaw stated in 1944, "Dwarf trees commence production and mature earlier than trees on 'standard' or 'free' stocks" (134). However satisfactory this may be as a generalized statement, research has indicated that in specific instances or where one makes a distinction between dwarf and semi-dwarf trees, there may be some variation from this statement. The *Massachusetts Annual Report* for 1934 recorded that with the varieties McIntosh and Wealthy "the dwarfing stocks, types 1 to 9, inclusive, do not seem to have hastened production, except in the case of type 4". The first "real crop" of this orchard was borne in 1934, which was the seventh year in the orchard for the trees (42). EM I was added as inducing early bearing in a later report, but only for McIntosh as the scion variety (129). It is not clear, however, whether this delay in coming into bearing was a direct effect of the stocks or not, for the 1931 Annual Report states, "The orchard of McIntosh and Wealthy on Malling stocks made a satisfactory growth during the season and showed considerable bloom and some fruit." (38). This was the fourth year in the orchard for the trees. Yerkes and Sudds appear to be making the same distinction between early blooming and early bearing. They found that Malling I induced early

flowering in Gallia Beauty, Staymared and York Imperial (186). Yet for three years little fruit was borne (187).

Blair and Upshall (178), in a review of rootstock work in Eastern Canada (61), stated that EM IX induced earlier fruiting in five varieties which were tested on it. A report from New York State in 1940 stated that 15 varieties on EM IX were very precocious. In their second year, a full crop of fruit was produced (48). Tukey and Brase (170) described the performance of 16 varieties of apples on EM IX rootstocks planted in the orchard as two-year-old trees; namely, Baldwin, Cox Orange, Early McIntosh, Gallia, Grimes, Jonathan, McIntosh, Northern Spy, Red Spy, R. I. Greening, Stark, Tompkins King, Turley, Wagener, Winesap, and Wolf River. All but Northern Spy and Red Spy carried some blossoms the first year set in the orchard, and Baldwin and Stark carried some fruit. The second year, all varieties carried blossoms, and all but Red Spy, Tompkins King, and Winesap carried fruit. The third year, all blossomed and all set fruit, which ranged from 16.7 and 13.6 pounds for Stark and Early McIntosh, respectively, to 0.8 and 1.2 pounds for Red Spy and Tompkins King, with an average of about 8 to 10 pounds per tree. At Ottawa, Blair observed that McIntosh/EM IX began bearing the third year after setting out. At this time McIntosh/Ames and on Antonovka had not blossomed (61). In contrast, Yerkes and Sudds reported that Starking/EM IX was tardy in beginning to bear, yet the trees were much smaller than those on EM II (186). As a 3-inch intermediate stempiece, EM IX did not induce earlier bearing in comparison with McIntosh as a stempiece where Baldwin, Delicious, and Early McIntosh constituted the scions. When McIntosh was the scion, fruiting occurred only a year earlier (173).

Gourley and Howlett placed EM VII in a group with two other Malling stocks which they rated as superior in inducing early bearing. Stocks which were inferior in this respect by implication, were EM II, V, VI, and XIII (82). EM VII was found, in general, to be a small, early-bearing tree by Tukey and Carlson. Even the normally late-bearing Northern Spy, produced fruit the fifth year when worked to EM VII (175).

EM IV was also included in the superior early-bearing group of Gourley and Howlett (82). However, in New Hampshire, McIntosh, Northern Spy, Red Spy and Cortland budded on EM IV were not as precocious as expected (141).

EM I was the third stock rated in Ohio as being outstanding in producing early bearing trees (82). Tukey and Carlson observed that McIntosh on EM I bore more heavily at an earlier date than McIntosh on six other Malling stocks that were tested (175). Upshall noted that Northern Spy trees on EM I began bearing earlier than those on French Crab (181). In Delaware, 50 percent of Gallia Beauty trees on EM I bore fruit the fifth season. Only 20 percent of such trees on seedling roots were fruitful. For trees with Blaxtaymen as the scion, 30 percent on seedling roots bore fruit the fifth year. A higher percentage fruited on EM I. An exact figure was not stated (47). Both Baldwin and Northern Spy on EM I fruited in their sixth growing season in New Hampshire. At that time the latter combination produced almost a peck of apples per tree (140). Sudds found Red Rome trees on EM I to be separated roughly into two groups with respect to the time they came into bearing. A group which he characterized as "true semi-dwarfs" fruited in their sixth year in the orchard, while a larger group did not fruit for the first time until two years later (147) (149).

EM II has been reported as producing precocious trees. A Delaware paper indicates that the relative time of bearing of Gallia Beauty and Blaxtayman were the same on EM II as on EM I, as mentioned in the previous paragraph (47). Upshall stated that Northern Spy/EM II stions came into bearing before Northern Spy/Seedling (181).

As pointed out earlier, EM XIII produces a tree of a size readily comparable to EM I. However, it does not appear to induce precociousness to the degree that EM I does. Sudds indicated that Red Rome/EM XIII bore very little fruit the sixth year after planting. At that time the larger part of the Red Rome/EM I bore a heavy crop (149). Tukey and Carlson have compared the earliness of bearing of Cortland/EM XIII in Michigan and New York and find it delayed in the former state with respect to its performance in the latter state (175).

Roberts (116) has calculated acre-yields in boxes as follows for the Golden Delicious variety of the first 10 years in the orchard in Oregon: EM IX (363 trees per A.) 5,082, EM VII (134 trees per A.) 3,752, EM II (70 trees per A.) 2,940, EM I (48 trees per A.) 2,112, Seedling (48 trees per A.) 1,488, and EM XVI (34 trees per A.) 1,802.

In New York State (64) the per-acre yield of 14-year-old McIntosh apple trees has been calculated as follows: EM VII (90 trees per A.) 404 bushels, EM II (68 trees per A.)—416 bushels, EM I (54 trees per A.)—352 bushels, EM XIII (46 trees per A.)—281 bushels, and Seedling (46 trees per A.)—440 bushels.

Finally, orchard records in pounds per tree have been reported from Michigan for the McIntosh variety (175, 68a) as follows:

Four years of age: EM I—79; II—28; IV—44; V—25; VII—60; XII—1; and XIII—4;

Seven years of age: EM I—121; II—144; IV—96; V—93; VII—198; XII—84; and XIII—198;

Thirteen years of age: EM I—859; II—531; IV—720; V—472; VII—490; XII—558; and XIII—895;

Grand Total in pounds per tree (one year frosted out): EM I—2727; II—1974; IV—2383; V—1973; VII—2007; XII—1519; and XIII—2283.

Observations on the relative time of bearing of trees on Mallings XII (47) (69), XV (47), and XVI (47) (179) have also been recorded.

Size of fruit

While the relative ability of Paradise and Doucin stocks to induce precociousness was debatable, there was little dissent to statements that they produced larger-sized fruit. Some such statements appeared to be largely hearsay (7) (103), but there was much experience (57) (77) and some experimentation (33). Fruits from some such trees were of such outstanding size as to occasion special mention. *The Horticulturist* quoted an anonymous writer in the *Genesee Farmer* who mentioned Fall Pippin apples on dwarf trees 3 feet high which were up to 5 inches in diameter (7). Barry speaks of Red Astrachan apples which were 3 and a half inches in diameter growing on trees on Paradise stocks. There seems to have been little dissent to this point until the New York Experiment Station became interested in testing Paradise and Doucin stocks. Lodeman, whose bulletin was based to a great extent on the experience of backyard growers, stated the common view, but expressed some doubt regarding the extent to which this was true (103). Later, Hedrick, in several statements, maintained that there was no difference in fruit size (185) or in size from a "commercial standpoint" (86). He stated that any slight differences in size were due to differences in maturity (86). However, in evaluation of these statements, it must be kept in mind that Hedrick considered that the dwarf trees in this experiment may not have been handled to the greatest advantage (86).

Research with trees on Malling stocks has tended to disprove the concept that diminutive trees produce large fruit. An annual report

from New York State in 1941 speaks of large-sized fruit as being characteristic of dwarf trees, but does not use size in a comparative sense (50). A more technical paper the same year states that the fruit on dwarf trees was slightly above the size typical for the variety. Of more significance than size, however, was the uniformity of size of the fruit on such trees (170). Upshall found the differences in fruit size of five varieties on EM I, II, XVI and French Crab to be insignificant (179).

In a report five years later on the same trees, Upshall found that the size of fruit of trees on French Crab and EM XVI fell into one group and that of trees on EM I and II into a second group. The larger fruit occurred in the former group (181). Shaw stated that fruit from dwarf trees was often larger, but that, with aging of the trees, size tended to decrease unless tree vigor was maintained and fruit thinned (134).

Southwick made a specialty of fruit size and shape. He showed that, on a volume basis, McIntosh fruit from trees on the more dwarfing Malling stocks was smaller. Over a period of three years, fruit size generally decreased. Fruit shape was studied using a "form index", which was the ratio of the stem-calyx measurement to the cheek to cheek measurement. In general, form relations were maintained over a three-year period. The form index of McIntosh apples increased in the following order: EM XIII, VI, V, X, own-rooted, seedling root, EM XVI, I, XII, and XV (142). Hewetson worked with intermediate stempieces of Mallings II, IX and XII as well as stempieces of apple varieties and a Malus specie. He asserted that the interstock had little influence on fruit size. He thought that the apparent larger size of fruit of McIntosh/Malling IX/seedling was due to the relatively smaller amount of foliage on such trees, which tended to accentuate fruit size (90).

Color, maturity and quality of fruit

Observations and comments on quality of fruit from trees on Doucin and Paradise stock closely parallel those regarding fruit size (33) (57) (77) (86) (103) (186). Again, it was Hedrick (86) (186) and Lodeman (103) who first doubted or disputed that dwarf trees produced fruit of superior quality. Experimentation with Malling stocks has not tended to bear out the allegations of Hedrick regarding fruit quality. A report from New York State attributed "good color" to fruit from dwarf trees (50). Tukey and Brase noted that fruit of nor-

mally red-colored varieties developed especially high color on EM IX stocks (170).

Blair makes a similar statement concerning fruit from EM IX stions (61). Trees on EM IX interstocks produced fruit showing similar high color in comparison with fruit from trees on two other Malling and several other clonal stocks (90). Upshall graded the fruit of five varieties on several stocks according to commercial grades. Four varieties produced a slightly higher percentage of No. 1 grade fruit on EM I and II stocks than on EM XVI. McIntosh was variable, but produced higher grade fruit on EM XVI the majority of seven years (181). Shaw made the distinction that fruit from young trees on dwarfing stocks was more highly colored (134). Though all of the above reports attribute high color to fruit from dwarf trees on Malling stocks or interstocks, Hewetson (90) and Upshall (179) linked this to earlier maturity of fruit from trees on EM IX interstocks and stocks, respectively. One other author mentioned earlier maturity, but did not appear to attribute the better color to this factor (61).

The factor of earlier fruit maturity did not escape the attention of early horticulturists. Hedrick expressed a certainty that there were "slight differences in ripening dates" between fruit from trees on Doucin, Paradise and French Crab stocks. This he also related to slight color differences (86). In addition to the findings of Hewetson (90) and Upshall (179) relative to fruit maturity effects of EM IX, Tukey and Brase noted that "fruit matured from a week to 10 days earlier on the EM IX rootstock than on French Crab seedling rootstocks" (170). Earlier maturity of fruit on EM I, II, and XVI or a retardation of maturity in comparison with fruit from trees on French Crab could not be detected by Upshall. There was also no difference in results with storage tests (181).

It appears that advanced fruit maturity might be related to earlier blossoming. Tukey and Brase perceived that all 16 varieties tested on EM IX rootstock also blossomed a week to 10 days earlier than the same varieties on French Crab roots (170).

It appeared to Shaw that the Malling stocks exerted differential effects on the dropping of McIntosh fruits. The relative amount dropping from individual trees was not correlated with the load of fruit the tree was carrying (129). Upshall observed no such differential effect with McIntosh, Delicious, Northern Spy, Rhode Island Greening, and Melba on EM I, II, XVI, and French Crab seedlings (181).

Miscellaneous observations, including stock-scion chemistry, use of radioisotopes and root temperature studies

Little work has been done in North America on the chemistry of stock-scion relations. Colby conducted a rather comprehensive study of the nitrogen, phosphorus, fat, and carbohydrate relations. He found that the lower portions of unworked EM IX or EM IX worked to Whitney were high in nitrogen while shoots of EM IX were low in nitrogen. The same situation existed with phosphorus. Fat and starch were high in the lower portions (69).

Bukovac, Wittwer, and Tukey have studied the transport of P^{32} and Ca^{45} from roots to and through the bud union of McIntosh on EM VII, IX, and XVI and on Delicious seedlings. Differences in transport of both cations occurred between the several stocks. The least was translocated in the EM IX scions, while the greatest transport occurred in McIntosh on Malling XVI and on Delicious seedlings. Where P^{32} was applied to leaves, significantly different amounts were recovered in the roots of the different rootstocks. Greatest recovery occurred in the roots of Delicious seedlings and the least in EM IX and EM XVI roots (65).

Nelson and Tukey (108) found that root temperature greatly affects the growth of certain Malling rootstocks. They grew rootstocks of EM I, II, VII, IX, and XVI in nutrient solutions in controlled temperature tanks at 44, 55, 66, and 77 degrees F. For comparison, they included standard seedling rootstocks. They found that EM IX regenerated a few new roots even at 44 degrees F. but did not do well at the higher temperatures. Neither did EM II perform well at the high temperatures. On the other hand, seedling rootstocks failed to regenerate roots at the low temperatures but were prolific at the high temperatures. EM VII performed well over a wide range of temperatures. From this they suggested the hypothesis that several of the Malling apple rootstocks may be better adapted to cooler soils such as characterize England and the Continent than to some of the high soil temperatures that prevail in parts of the United States. In general, survival records show greater success with the Malling rootstocks in a belt from Massachusetts through western New York, southern Ontario, and Michigan than in areas south of the Mason-Dixon line. Further, the rather satisfactory performance of EM VII

over a wide area in the United States and Canada may be associated with its adaptability to wide range of soil temperatures as suggested by the studies.

In Conclusion

In the more than 150 years that dwarfing rootstocks and dwarfed fruit trees have been grown in America, much knowledge has been accumulated concerning them. From the often misnamed and mixed plant materials of early years have appeared rootstocks which have been standardized, named, catalogued and introduced. Methods of propagation have been studied, and the more successful commercial methods have been introduced. Many of the more important combinations between rootstocks and scion varieties have been evaluated. Winter hardiness and general adaptability have been examined. Suggestions on culture, fruit quality, and yields have been forthcoming. Much of the big hazard has been eliminated, and many of the serious questions have been resolved.

But there are still many questions to be answered. Are dwarfed trees more subject to spring frost than standard trees, due to low heading and the fact that the fruit is borne close to the ground? Are special frost-free sites essential? Does the fruit of different varieties ripen at different dates on different rootstocks? Does this affect marketability and storage life? How about finish and color? What about mulching, trellising, staking, depth of planting, irrigation, pruning, thinning, microclimate, insect and disease control, cost of production, and harvesting methods? These and many other questions are yet to be satisfactorily answered.

No single individual can provide all the answers, but the pooling of information and experiences from a number of individuals can be of great value. To assist in this process, a "Dwarf Fruit Tree Association" was formed in Michigan on March 4, 1958, and a "Northwest Dwarf Tree Association" was organized February 20, 1959, in the Pacific Northwest. The purpose of these associations is to hold meetings and tours, to observe dwarf tree plantings and performance, and to gather information concerning them. The formations of these associations could well prove an important step in the development of smaller than standard-size fruit trees in America, and could mark a significant period in the history of the Malling rootstocks in America. With awakening interest by growers as a spur, the future should make this field a fruitful one for study.

SUMMARY AND DIGEST

Dwarfing rootstocks under the names "Paradise", and "Doucin" or "Doucain" have been known in America for at least 150 years. Much confusion is found in the literature over these names, so that one is not always sure to what they applied. Generally speaking, however, "Paradise" referred to the very dwarfing "French Paradise" types of rootstocks in contrast to the semi-dwarfing "Doucin" or "Doucain" types which were also sometimes called "English Paradise".

The early records of dwarf fruit trees (early 19th century) and interest in dwarf trees showed dependence upon European practices and interests, running almost parallel with them.

The earliest book on pomology published by William Coxe in 1817 merely made mention of the Paradise apple. However, beginning about 1835 there arose great interest in dwarfed fruit trees in America which continued through 1855 to 1860. C. M. Hovey of Boston and Patrick Barry and George Ellwanger of Rochester, New York, were principal advocates of dwarf apple trees for both commercial and garden planting.

About 1860, there came a shift in interest in dwarf apples, which was supplemented by avid interest in dwarf pears grafted on the quince. Over half of the pears grown in the United States during this period were on quince roots. Seemingly, part of the shift in interest with dwarf apples was due to relatively heavy fruit production and low prices. It was easy enough to grow apples in a half neglected manner on seedling rootstocks without recourse to the greater attention required by dwarf trees. Further, new problems of summer pruning and training were seemingly introduced by the dwarf trees which were not present with standard trees on seedling roots.

It is interesting to note in this connection that the more enthusiastic advocates of dwarf apple trees were men who were themselves excellent plantsmen, such as Patrick Barry, George Ellwanger, and C. M. Hovey. Further, their orchards were located in some of the best horticultural areas of the country, which undoubtedly favored the performance of dwarf trees.

At all events, from 1860 to the early 1890's, in spite of much discussion and argument pro and con, there appears to have been no great interest in adapting dwarf apple trees to commercial fruit pro-

duction. They seem to have made no contribution to the solution of the problems of the fruit industry.

Then quite suddenly, in the 1890's, the menace of San Jose scale appeared. There was no known control except by covering a tree with a canvas or tarpaulin and fumigating with hydrogen cyanide gas. Small trees were required for such an operation, and again interest in the dwarf tree and dwarfing rootstocks appeared. State agricultural experiment stations now became involved with dwarf fruit trees, and more critical studies were begun.

Unfortunately for the furtherance of studies with dwarf trees, lime sulfur and oil sprays, which were introduced between 1907 and 1910 for the control of San Jose scale, proved exceedingly effective and removed both the threat of the insect and the demand for small trees. Active interest in dwarf trees ceased almost as quickly as it had begun.

Nevertheless, some facts had been brought out regarding dwarfing rootstocks and dwarf trees. For example, the rootstock material was still loosely termed "Paradise" or "French Paradise", and "Doucin" or "English Paradise". The unreliability of rootstock material and the need for proper identification and certification was called to attention, and problems of scion rooting, anchorage, pruning, fertilizer treatment, winter hardiness, and stock and scion relation, came in for review. Finally some interest was shown in using dwarf trees as tools in studies of fruit bud differentiation and other fundamental research.

By 1920, the dwarf trees that had been planted due to the threat of the San Jose scale had been studied and exhausted, and dwarf fruit trees were virtually discredited for commercial fruit production. This was the era of large trees, tonnage productions, low costs of production, and little concern for consumer demand and quality control, to which dwarf trees were ill adapted.

A new wave of interest in rootstocks for fruit trees began in America in the late 1920's, brought about by steps which the United States Government was then taking to prohibit importation of the seedling rootstocks upon which American fruit trees were at that time almost exclusively worked. The net result was the requirement for a supply of domestically propagated rootstock material, in anticipation of the embargo which was to go into effect in 1930 against rootstocks from outside the United States.

At just this time, beginning in the late 1920's, the favorable results reported from England by the standardization of dwarfing rootstocks at the East Malling Research Station, was having its impact on America — especially in scientific circles. True-to-name standardized rootstocks known as the "Malling", "East Malling", or "EM" rootstocks were brought to America in limited number. It was natural that interest in these clonal rootstocks should be swept along with the general problems presented by the need for domestic rootstock materials for American orchards and nurseries.

Accordingly, experimental lots of the Malling rootstocks were brought to this country in the late 1920's, thus beginning the third period of interest in dwarfing rootstocks. Early acquisitions of these materials were made by Anthony in Pennsylvania in 1920 and 1922, by Shaw in Massachusetts in 1922, by Tukey in New York in 1928, and by the Ontario Agricultural Experiment Station in Canada some time prior to 1929.

Because of the enforcement of the Federal quarantine against foreign nursery stock in 1930, Malling rootstocks were in very short supply. Tukey and Brase at the New York State Agricultural Experiment Station at Geneva, New York, undertook to propagate and disseminate Malling rootstocks and budded trees to interested nurserymen, experiment stations, and growers throughout the county. Attempts were made also to induce nursery companies to propagate the Malling rootstock materials and to introduce dwarfed fruit trees under Malling number rather than as "dwarf trees" as had been the custom. In 1937, the nursery catalogue of the Maloney Brothers Nursery Company of Dansville, New York, listed for the first time in America the availability of trees on Malling rootstocks. Kelly Brothers, also of Dansville, and Jackson and Perkins of Newark, New York, followed shortly. From 1935 to 1945, the Geneva Station propagated and distributed 191,669 rootstocks and 15,822 fruit trees worked on these stocks, to 238 individuals and experiment stations in 36 states and in Canada. These distributions had much to do with furthering the development of dwarfed trees in the New World.

Early studies with the Malling rootstocks involved their propagation. Hardwood cuttings were not commercially satisfactory, only modest success resulted from nurse-root methods, and root cuttings although successful were not commercially feasible excepting for emergency measures. Propagation by layers became the accepted standard, as in Europe, although the short fall and spring season

afforded for getting the rooted shoots from the stoolbed were definitely limiting factors in Northeastern areas where much of the work was being done. This suggested the establishment of stool blocks in regions of more open winters, as the Pacific Northwest.

In general, it was found that EM I, III, IV, V, VI, VII, IX, XIII, and XVI rooted easily, EM II with less ease, and EM XII with difficulty. EM VII rooted especially well, with great uniformity in size and grade of the rooted shoots. EM I and XIII showed greater variability in these respects. Yields were found to be in the neighborhood of 25,000 rooted shoots per acre, which were deemed commercially practicable.

Although occasional instances were recorded of incompatibilities between the Malling rootstocks and the commercial cultivated varieties of apples, these were found to be the distinct exception and not the rule. EM I showed incompatibility with Wealthy, and there was some tendency towards incompatibility of this rootstock with other varieties; but it was not certain that this was not more a matter of crown injury to which EM I had been found susceptible than to any incompatibility as such. Incompatibilities with various ornamental crabs were much more common, especially with the more dwarfing Mallings, as EM IX.

The Malling rootstocks were shown to differ in their ability to dwarf the scion worked upon them, in approximately the following order: very dwarfing, IX; dwarfing, VII; semi-dwarfing, IV, V, I, and II; semi-standard XIII and XVI; and standard, XII.

Varieties worked upon these rootstocks bore the same general relationship to each other as they did on standard seedling rootstocks. Thus, the relatively small-growing Wealthy and Gallia, were small on all of the Mallings, as contrasted with the large-growing Northern Spy which was larger on all of the Mallings.

Small-growing scion varieties were found to be so small on very dwarfing rootstocks, as EM IX, that they approached incompatibilities; and strong-growing scion varieties were dwarfed little or none on vigorous Malling types, as EM XVI.

Budlings in the nursery did not show marked differences in the dwarfing ability of various Malling rootstocks. Only as the trees grew older did these differences appear.

Earliness in bearing was found to be associated in general with the degree of dwarfing, though some exceptions were reported, as EM XIII which was reported tardy in bearing with some varieties.

Although the various stock-scion, or "stion", combinations showed the general pattern enumerated above, nevertheless, each combination was seen to require individual, critical evaluation. Each combination acted as a new individual with definite characteristics of its own.

Considerable differences were reported as to winter hardiness of the different Malling rootstocks. In general, little injury was reported where there was sufficient snow coverage, or where winter temperatures seldom reached sub-zero temperatures Fahrenheit. On the other hand, Northern Canada and the Great Plains area where extreme low temperatures prevailed and where soil often froze to several feet, reported considerable injury and general lack of adaptability without artificial protection.

The more dwarfing rootstocks such as EM IX, were shown to have restricted root systems. EM IX required staking or other support, and EM V and VII were inclined to lean. EM IV developed a small root system in relations to the top and tended to blow over. EM I and II sometimes required support in early years. EM XIII and XVI appeared sturdy and well-anchored.

As regards soil temperatures, during the growing season, the Malling rootstocks in general seemed less tolerant of excessively high soil temperatures than standard seedling roots, and conversely more tolerant of low soil temperatures. EM VII, however, appeared to grow well over a wide range of soil temperatures. EM XIII and XVI seemed tolerant of wet soils.

Contradictions were reported over whether trees on Malling rootstocks were more uniform than trees on seedling rootstocks. The more complete and long-time tests of those reported, however, seemed to suggest greater uniformity on Malling rootstocks.

Suckering from the rootstock was found to be a characteristic of some rootstocks, with suckering being more prevalent with the more dwarfing rootstocks than the less dwarfing ones. EM III and VI were observed as suckering more than EM IX, VII, and II, and from this point of view less desirable.

Scion rooting was said to be not a serious problem if the union was placed at or slightly above the ground line. Budding at 2 inches above the ground level was reported as being satisfactory and not presenting any problem of scion rooting. Other reports were that better tree anchorage could be secured with less likelihood of scion rooting occurring if buds were placed 6 to 8 inches above the ground

and the resulting tree planted deeper than usual in the orchard, with the union an inch or two above the ground level.

Among the various Malling rootstocks, greatest interest seemed to center around EM IX as a very dwarf or garden plant, and EM VII and EM II as what might be called semi-dwarf.

Malling rootstock material tended to dwarf the scion when used as an intermediate stempiece. "Clark Dwarf", which was shown to be similar if not identical to EM VIII, proved useful as a dwarfing interstock, especially in regions where low winter temperatures were a limiting factor. Considerable variation of trees and unpredictability of performance were, however, reported.

Time of blossoming and of fruit maturity were found to be affected by the Malling rootstocks. With EM IX as a rootstock, blossoming of the scion variety was as much as four days to a week earlier than the same variety on seedling roots and fruit maturity was a week to 10 days earlier.

Fruit on young trees was reported to be of large size for the variety, but for mature bearing trees the size was typical of the variety. The fruit appeared more uniform and the color and quality as good as, or superior to, fruit produced by trees on standard seedling roots.

Yields of fruit from trees on Malling rootstocks were observed to vary widely with both the variety and the rootstock as well as with culture and location. On the tree basis, dwarfed trees generally yielded less than standard trees, but on the acre basis (considering the larger number of dwarf trees per acre) the yield of dwarf trees was as large as, or larger than, for standard trees.

The typical fruiting habit of a given variety was found to be, in general, accentuated by the more dwarfing rootstocks. Thus, an early-bearing variety like Wealthy, when worked onto the very dwarfing EM IX, might produce fruit even in the nursery row. On the other hand, the late bearing Northern Spy might not fruit even on EM IX until the third year in the orchard.

With 16 representative American varieties on EM IX, blossoming occurred either the first or second year in the orchard, and fruit was produced either the second or third year. Trees on EM IX were reported as yielding up to a quarter of a bushel of fruit to the tree at three years of age, one-half bushel at four years, and 1 to 3 bushels at an older age.

Yields for McIntosh in New York in pounds per tree at four years of age were: EM I—79, II—28, IV—44, V—25, VII—60, XII—1, XIII—4; at seven years of age, EM I—121, II—144, IV—96, V—93, VII—198, XII—84, and XIII—198; and at 13 years of age, EM I—859, II—531, IV—720, V—472, VII—490, XII—558, and XIII—895; for a grand total in pounds per tree (one year frosted out) of EM I—2727, II—1974, IV—2383, V—1973, VII—2007, XII—1519, and XIII—2283.

For comparison with standard trees at approximately 28 to 35 trees to the acre, suggested planting distances for the respective rootstocks represent the following number of trees per acre: EM I—48 to 108; II—70 to 108; IV—70 to 87; V—70 to 108; VII—72 to 145; IX—363 to 543; XII—28 to 36; XIII—36 to 72; and XVI—28 to 36.

Computed per-acre yields in boxes have been given for Golden Delicious in Oregon as follows for 10 years in the orchard: EM IX (363 trees per A.) 5,082, EM VII (134 trees per A.) 3,752, EM II (70 trees per A.) 2,940, EM I (48 trees per A.) 2,112, Seedling (48 trees per A.) 1,488, and EM XVI (34 trees per A.) 1,802.

In New York State, the calculated per-acre yield of 14-year-old McIntosh apple trees was: EM VII (90 trees per A.) 404 bushels, EM II (68 trees per A.) 416 bushels, EM I (54 trees per A.) 352 bushels, EM XIII (46 trees per A.) 281 bushels, and Seedling (46 trees per A.) 440 bushels.

As regards longevity, yields of 3 to 4 bushels per tree have been reported for 30-year-old trees on French Paradise (equivalent in size to EM IX) in western New York.

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