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Connecticut Hybrid Chestnuts and Their Culture

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The cover photograph by B. W. McFarland shows a selected hybrid (C6) 22 years old, 41 feet high, and 8.3 inches in diameter breast high. Mr. McFarland also took many of the other photographs in this Bulletin.

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INTRODUCTION

Who remembers the American chestnut? Unless you are over 50 the chances are you have only read about this famous tree. Few people today realize that 60 years ago the American chestnut, *Castanea dentata* Borkh., was the most valuable single species in the mixed hardwood forests of the eastern United States. Then, in the relatively short time of 40-odd years, almost all of the large chestnut trees were completely destroyed by a fungal disease.

When it seemed probable that the American chestnut was doomed, geneticists and plant breeders set out to fashion a new chestnut, resistant or immune to the blight, retaining as many as possible of the desirable traits of the old. In Connecticut, this work has now been underway for more than 30 years. We have not created a new chestnut with all of the good qualities of the old. But we have fashioned blight-resistant chestnut hybrids that seem promising, some perhaps as forest trees, others tailored to specific uses such as production of nuts for market, and planting as ornamentals. We describe nine of these hybrid chestnuts in this Bulletin, and explain the principles of hybridization and propagation that have been used in their production. We welcome inquiries from persons interested in commercial propagation of these hybrids.

American chestnut trees indeed had many admirable traits. They were fast growing and tall, often attaining heights of 100 feet. The decay-resistant wood found many uses in construction work and was almost the exclusive source for utility poles and railroad ties. Deer, squirrels, chipmunks, pheasants, grouse, and many other animals feasted on the nuts each fall.

The blight fungus, *Endothia parasitica* (Murr.) And., which destroyed all the native chestnut trees, apparently came into this country on Asiatic nursery stock about 1890 (Figure 1). It was not discovered until 1904, in the Zoological Garden of New York City. This bark disease spread rapidly through the Appalachian Mountains, traveling about 20 miles a year until the early forties, when it reached the last stronghold of healthy trees in the Great Smoky Mountains. Even today some of the decay-resistant timber from these dead trees in the southern Appalachians is being harvested for fence posts, tannin extraction, and other uses.

In New England, only the persistent sprouts from the old stumps remain. The sprouts occasionally reach a diameter of 6 inches at shoulder height and

* Arthur H. Graves died December 31, 1962, at the age of 83.

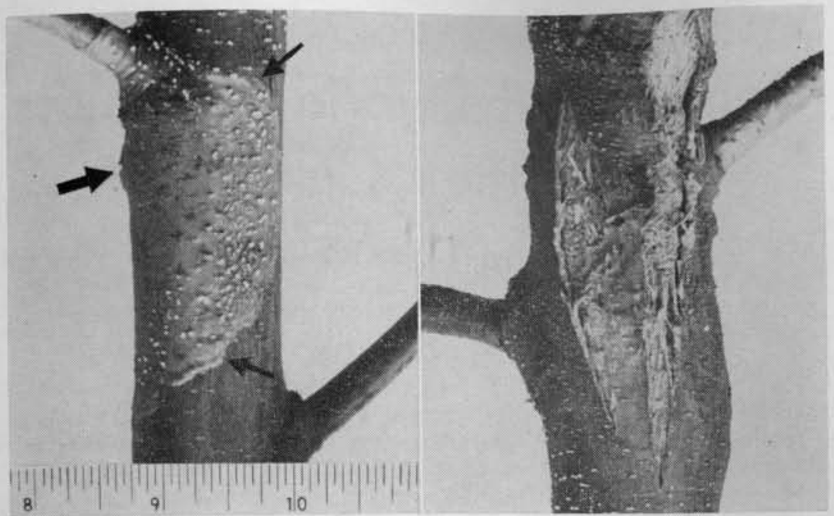

Figure 1. Two stages of the chestnut bark disease on sprouts of the American chestnut. Left, 2 or 3 months after infection and, right, an advanced infection causing death to upper portion of sprout. The chestnut blight, a wound parasite, attacks through an injury or break in the bark (large arrow, left). And on susceptible trees it forms a characteristic orange-colored mycelial fan which spreads in a semi-circle (small arrows) until it encircles the host. Spore producing bodies or pustules maintain the characteristic orange coloration of the young mycelial fan even in advanced infections. Scale is in inches.

produce a few nuts, but these larger sprouts invariably are killed back to the ground by the bark disease.[1]

There are 13 different species of chestnut, all included in the genus *Castanea;* of these, the only large tree native to the United States was the American chestnut. Several shrubby species called chinkapins grow in the southeastern states. These chinkapins have one nut per bur, most of the larger-growing species have three.

Chestnuts bought in the market are commonly those of the European chestnut, *C. sativa* Mill., sometimes called Italian chestnuts. However, some Chinese, *C. mollissima* Bl., nuts from orchards in the southeastern United States are beginning to enter the market. Trees grown from European chestnuts in the United States have so far been susceptible to the blight fungus. The bark disease was introduced in Europe more recently than in the United States and many chestnut trees in Italy have been infected and killed. Some of the European trees may be disease resistant (Kurth et al. 1957, Borelli and Pettina 1958, Bazzigher and Schmid 1962).

Most of the chestnut trees of appreciable size now growing in the eastern United States are either Japanese, *C. crenata,* Sieb. and Zucc., or Chinese chestnuts. Trees of these two Oriental species are usually blight resistant; a trait that

[1] We are interested in learning of healthy *American* chestnut trees growing in the eastern United States and 8 inches or more in diameter 4½ feet above the ground. If you know of such a tree write to the Genetics Department, The Connecticut Agricultural Experiment Station, Box 1106, New Haven 4, Connecticut.

sets them apart from other chestnut species. They have a spreading growth habit like that of an apple tree, and they produce edible nuts. Seed and seedlings of the Chinese chestnut can be obtained from several nurseries.

Two lesser known species from the Orient have been used in breeding work: *C. seguinii,* a shrub species bearing three nuts per bur, and *C. henryi,* a forest tree bearing only one nut per bur. Trees of these two species are generally susceptible to the chestnut blight fungus.

USES FOR CHESTNUT TREES

Those who knew the American chestnut share nostalgic memories of the harvest. The towering trees, the carpet of yellowing leaves, the brown beauty of the chestnuts and their delicate and distinctive flavor, left memories that time has not effaced. We do not know whether these aesthetic values may one day be renewed, but note that there are other reasons why chestnut trees may be planted today. Chestnut may have a place 1) as a forest tree, primarily for lumber and tannin; 2) to produce food for squirrels, deer, pheasant, and other animals; 3) as an orchard tree for commercial nut production; and 4) as an ornamental and landscape plant.

As a Forest Tree

In breeding for a forest tree it is logical to work towards a type similar to that of the old American chestnut, i.e. straight bole, fast growth, high tannin content, and decay resistance. The breeding of chestnuts in Connecticut was started with this aim. Superficially there appears to be no reason why resistance to the blight fungus found in Chinese and Japanese species cannot be transferred into a prototype of the American chestnut. Indeed, as can be seen from the photographs of C3, C6, C7, and C9 on pages 16 and 17, progress has been made in obtaining good form and blight resistance. What makes the task formidable, though, is the synthesis of a tree fully competitive with the native vegetation and also capable of satisfactorily reproducing itself under natural conditions. If a cross between two trees is found which will produce a high percentage of superior offspring then seed orchards (see page 11) can be set up to reproduce the hybrid nuts in large quantity. This problem of selecting for a high percentage of trees with upright growth is indicated in the information presented in Table 1. Using the ratio of stem height to crown diameter to indicate columnar growth, we find that only one hybrid seed lot (ratio of 2.1) compares favorably with the American seedlings (ratio of 2.0). All the other lots have indices of 1.7 or less.

As a Source of Food for Wildlife

Most important in considering the chestnut tree as a source of food for wildlife would be the annual yield by weight of nut meat, and consistent productivity from year to year. Chestnut trees are unique among the native nut trees in that fruit production is not strongly cyclical. Chestnut would be valuable when planted with oak, walnut, beech, and hickory to tide over the lean food years of these companion species. Some selections of the Chinese chestnut yield dependably, but by crossing these selections with a native species, particularly one of the chinkapins, greater adaptability to local environment and possibly higher fruit production would be expected. Tree form need not be of primary concern unless the trees are eventually to be cut for timber but, as with a timber tree, the ability to compete favorably with native vegetation is desirable.

As an Orchard Tree

For orchard nut production, ability to compete with other trees is unimportant. Important factors here are fruiting at a young age; nut size, uniformity, and quality; and maximum production year after year. It has been only within the last 15 years that these traits have been sought in the Northeast. Several years ago, the USDA at Beltsville, Maryland, released the Chinese varieties Meiling, Kuling, and Nanking. In New England, however, the performance of these varieties is unsatisfactory (Yeager and Meader 1958, and personal observations), presumably because of the relatively cold winters and short growing seasons. Yet thousands of Chinese and hybrid chestnut seedlings are being privately grown in the Northeast. Through efforts of members of organizations like the Northern Nut Growers Association and the Connecticut Nut Growers Association, better orchard-type trees will continue to be selected. (The Orrin and Crane varieties of Chinese chestnut released by the USDA in 1963 have not yet been evaluated in the Northeast.)

Davidson and Reed (1954) discuss the possible income from chestnut orchards. Their estimates of gross income based on plantings in Maryland and Georgia range from $440 to $950 per acre annually for an orchard in full production.

As an Ornamental and Landscape Plant

Trees tailored for ornamental and landscape planting should first of all have a good branching habit and generally attractive form; production of high quality nuts may also be desired. On present-day small lots, a tall tree, but one with not too great a spread, may have a place. Several of the trees described in this Bulletin meet these qualifications. Within a few years quite different trees of slow growth and dwarf stature may also be available.

HYBRIDIZATION

After several methods (chemical, fire, quarantine, etc.) were found to be unsuccessful in control of the blight fungus, breeding was begun between the American chestnut and the blight-resistant Oriental species, with the aim of combining the form and vigor of the American with the disease resistance of the Oriental (Van Fleet 1914, 1920; Graves 1930; Clapper 1954).

Under the sponsorship of the Brooklyn Botanic Garden, the first hybrid nuts were produced in 1931 on Japanese trees on Long Island, N. Y. The pollen for these hybrids came from a large American chestnut near Washington, D. C., and was furnished by the United States Department of Agriculture. The seedlings produced from these hybrid nuts harvested in 1931 were set out on the Sleeping Giant Plantation at Hamden, Connecticut, which since 1947 has been under the management of this Station. Experiment Station staff members who have for varying periods of time been instrumental in continuing the Connecticut chestnut investigations include, in addition to the authors, Donald F. Jones, Hans Nienstaedt, and Harry T. Stinson, Jr.

The geneticist working with chestnuts is fortunate in that he has almost unlimited variability to work with among the 13 chestnut species, and these

species can, for the most part, be crossed with one another (Clapper 1954; Jaynes 1961a). Among the traits available in the genus are these: nut weight ranging from 1 to 30 grams (500 to 15 nuts to the pound); early or late fruiting; prolificness; growth habit; slow growers (dwarfs) or rapid growers; and varying degrees of blight resistance, plus adaptability to a wide range of habitats. In fact, virtually all the traits of chestnut trees show wide variation, and these traits are presumably under genetic control. With patience the geneticist can hope to synthesize trees combining the characteristics he desires.

Perhaps the biggest problem in hybridizing chestnut trees is that of determining the degree of blight resistance in the hybrid. By artificial inoculation of seedlings we can eliminate highly susceptible trees within a few years, but we often have to wait 15 years or more to determine just how disease resistant a tree will be. Young sprouts and seedlings have juvenile resistance: they are partially or completely resistant to the blight fungus. Trees approaching flowering and fruiting maturity become highly susceptible to the blight fungus, and it is only at this stage that valid classification of resistance can be made.

Inheritance of Blight Resistance

Blight resistance (or susceptibility) is apparently controlled by two or more primary genes (Clapper 1952; Solignat 1962). In the production of timber-type trees a further complication is the apparent linkage of high resistance with poor form. All first generation hybrids between blight-resistant trees and the American or the European chestnut have been found susceptible to the blight fungus. Resistance therefore behaves as a recessive character, and selection of blight-resistant individuals is possible only in the second or later generations.

Tree Farming with Chestnut

In the past it was common practice in chestnut breeding to transfer hybrid seedlings, after 1 or 2 years in a nursery bed, to permanent sites with trees spaced 15 to 25 feet apart. This procedure requires much land with consequent high costs of maintenance, site conditions are not uniform, and it is difficult to control rabbits, mice, and deer. As a means of eliminating these difficulties, we are now "tree farming" on a more conventional agricultural basis. By planting germinating nuts at 3 × 3 foot spacings, comparisons of growth rate, habit, flowering, and blight resistance can be made under relatively uniform field conditions during the first 4 years of growth. At the end of 4 years, only the most promising trees are outplanted to other sites and allowed to develop for several years. This planting program is the most efficient we have devised for screening large numbers of hybrids.

In Table 1 are growth measurements of some hybrid families produced from pollinations made in 1958. These seedlings were transplanted from a nursery bed to field spacings of 3 × 3 feet after 1 year, a transplanting operation we have since eliminated by direct field sowing of germinating nuts. (Stratified nuts are now placed, one per container, in 20-ounce paper cups containing a light sandy loam, and these cups are sunk in the ground at the 3 × 3 foot spacing.) At the time the trees were field planted, each family was divided into thirds and one-third of the trees placed, in a randomized pattern, within each of three replicate plots. The superior growth of seedlings from combinations of trees identified as 3A-24, 4-10, and H4-7 is apparent (Table 1). However, caution must be emphasized in attempting to predict the future growth of these trees.

Table 1. Growth comparisons of 3-year-old hybrid seedlings

Pedigree	Identification of parent trees	No. of trees	Average height (inches)	Ave. ratio height to crown diam.[4]	Ave. stem diameter at 4 in. (inches)
CJA × CJA[1]	57-15 × 59-39	20	34	1.5	.6
	57-15 OP[3]	26	29	1.5	.5
	59-39 OP	25	32	1.6	.6
CJA × A	14-3 × Rox	22	32	1.4	.7
	14-3 OP	29	32	1.3	.7
A × A[2]	Rox × OP	10	26	2.0	.4
CJA × CJA	5-13 × 14-3	27	34	1.5	.6
	5-13 OP	25	27	1.6	.5
	14-3 OP	29	32	1.3	.7
CJA × JA	3A-24* × 4-10*	3	52	1.6	.8
	3A-24 OP	27	32	1.6	.5
	4-10* OP	16	40	1.6	.6
JAC × JAJ	H4-7* × 2A-35	27	46	1.7	.8
	H4-7* OP	18	49	1.7	.8
	2A-35 OP	19	30	1.6	.5
JAC × CJA	H4-7* × 3A-24*	5	52	2.1	.8
	H4-7* OP	18	49	1.7	.8
	3A-24 OP	27	32	1.6	.5

1 C, Chinese, *C. mollissima;* J, Japanese, *C. crenata;* A, American, *C. dentata.*
2 Uncontrolled pollination, but only pollen from American trees was present in area to effect pollination.
3 OP, Open pollinated or uncontrolled pollination—pollen parent unknown.
4 Crown diameter taken as average of two measurements, parallel and at right angles to the row.
* Note superior growth of seedlings from combinations of trees marked with an asterisk.

Note that the American seedlings were the slowest growing of all. The branching habit of the American, which we expect to differ from Oriental trees, is approximated by only one of the hybrid families, H4-7 × 3A-24, as measured by the ratio of stem height to crown diameter.

Crossing Technique

Chestnut trees are monecious; that is, the male and female flowers, borne on spikes called catkins, are separate but occur on the same tree (Figure 2). To make controlled pollinations the female (pistillate) flowers are isolated in waterproof paper bags before the stigmas become receptive to pollen. The male (staminate) catkins are removed and the male-bearing portion of the bisexual catkins pinched off. This eliminates the possibility of self pollination, which occurs only rarely with chestnut. The female flowers become receptive approximately a week after the male catkins on the same tree start to dehisce (shed) pollen. It is at this time that the pistillate flowers are pollinated. A male catkin, previously isolated in a paper bag and now shedding pollen, is obtained from the tree to be used as the male parent, and is drawn across the stigmas of the female flowers. After completing the controlled pollination the paper bag is left on the female flowers for almost 3 weeks to prevent introduction of unknown pollen, which may be carried by wind or insects. When the paper bags are finally removed, coarse-mesh cloth bags are placed over the developing burs. These bags serve to mark the location of pollinations, prevent the loss of identifying tags, and retain the hybrid nuts when they mature.

Figure 2. Chestnut flowers. The lower, unisexual catkins bearing only staminate (male) flowers are shedding pollen. The pistillate (female) flower, upper right, has just reached the receptive stage. Male flowers on this bisexual catkin are still closed.

Production of hybrid chestnuts is an arduous task. Over a period of 32 pollinating seasons, our average annual yield has been about 625 nuts. This total of approximately 20,000 hybrid nuts might be higher had we not been so interested in completing crosses with a number of trees which tend to drop their female flowers when bagged.

Seed Orchards

As already mentioned in discussing the development of forest trees, seed orchards might be established so that large quantities of hybrid seed could be produced. Since chestnuts are essentially self-sterile, virtually all the nuts collected from an isolated planting containing only two clones would be hybrids between those two clones. Thus, if we find from hand pollinations that a combination of two particular trees, such as H4-7 and 3A-24 (Table 1), yields desirable progeny which we wish to produce in quantity, then we can set up an isolated seed orchard containing propagations of the two desired parent trees. All the seed collected from such an orchard would be hybrid, having H4-7 as one parent and 3A-24 as the other.

NINE SELECTED HYBRIDS

The hybrids herein described are all over 20 years old and represent some of the best trees selected from several thousand seedlings. They were chosen

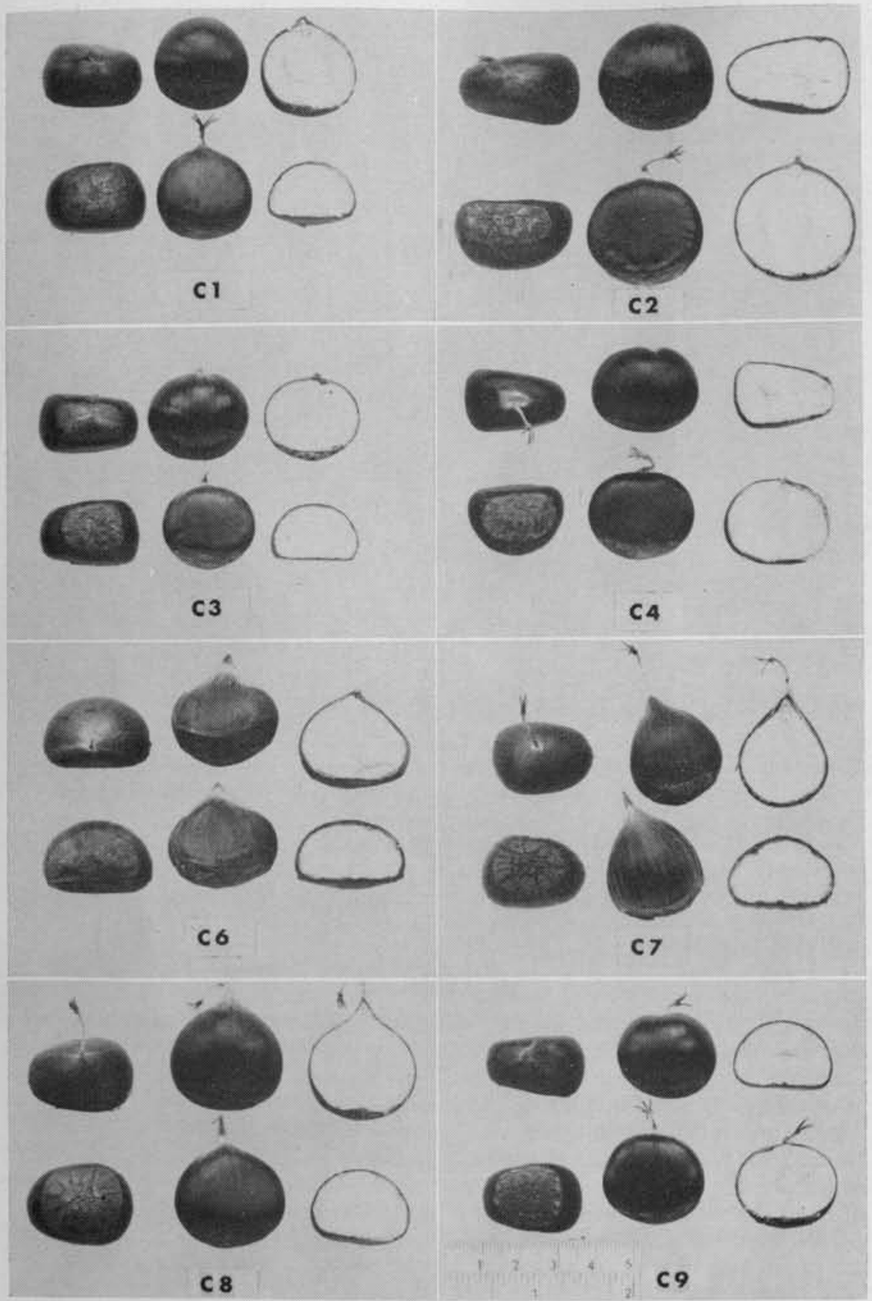

Figure 3. Nuts from selected hybrids. Note that nuts of C6, C7, and C8 are more tomentous (hairy) than the other selections, hence the shells appear less glossy. Nuts of C5 are not shown because they are so similar in appearance to those of C4. Upper scale is centimeters, lower inches.

primarily for form and blight resistance, but vary among themselves in these and other traits. Which tree is best depends on the primary use intended.

All of the trees are growing at the Sleeping Giant Chestnut Plantation in Hamden (Mount Carmel), Connecticut. The nearest U. S. Weather Recording Station is 2 miles away: the 1936-1959 average annual precipitation was 48.8 inches, annual mean temperature was 49.0 F, and the average freeze-free period was 158 days (Havens and McGuire 1961).

Three of the hybrids were given names by Graves (1960, 1962) and these names are included in single quotes. For ease of identification in this Bulletin, all of the trees are identified by numbers and the prefix "C" for Connecticut. Except for 'Essate-Jap' (C1), 'Sleeping Giant' (C2), and 'Toumey' (C5) propagations of these trees should always be identified by the C number. Thus C3, C4, etc., identify separate clones or cultivars.

Information on form, rate of growth, nut size, flowering and fruiting time, crossability, and grafting is given in the accompanying figures and charts.

C1 'Essate-Jap'

[(*C. crenata* × *C. pumila* Mill.?) *C. crenata*] *C. crenata*. Graves 1960. S8·J × J

The symbol "S8" refers to a hybrid developed by Van Fleet of the USDA at Bell, Maryland. It was apparently a cross of Japanese, *C. crenata*, with the Allegany chinkapin, *C. pumila*. This hybrid was then open-pollinated by *C. crenata*. A resulting seedling was used by Graves in 1934 as the female parent in a controlled cross with another Japanese. C1 was grown from one of the nuts obtained. As would be expected from backcrossing twice to the Japanese parental species, this tree has morphological characteristics predominantly like those of *C. crenata*. However, it is superior to the usual Japanese tree in growth habit, rate of growth, and nut flavor. It flowers early and is usually the first of our trees with ripe nuts in the fall, ripening a full 2 weeks before most other trees (Figure 4). No winter damage has been observed in Mount Carmel; however, progeny from this tree has suffered winter dieback in Coventry, Connecticut. Lower limbs tend to be heavy but the tree has a handsome broad conical shape (Figure 5). C1 has been grafted onto Chinese stock but only with difficulty. Japanese stock appears to be more satisfactory.

C2 'Sleeping Giant'

C. mollissima (*C. crenata* × *C. dentata*). Graves 1960. C × JA

The result of a cross performed in 1937 of a Chinese (C) tree with pollen of a Japanese-American (JA) hybrid. C2 is a consistent producer of large handsome nuts (Figure 3 and Table 3). It is potentially a large tree. Lateral limbs tend to be heavy but can be reduced by pruning or shading. In addition to use in yard plantings this tree might be considered for orchard use.

C3

[(*C. crenata* × *C. pumila*?) *C. crenata*] *C. mollissima*. S8·J × C

The female parent, S8·J, is the same as for C1. In this case the S8·J was crossed in 1938 with pollen of a Chinese tree instead of backcrossing to Japanese. Lateral branches of C3 are much smaller and form a more acute angle with the main stem than the primary laterals of most Asiatic chestnuts. The resulting

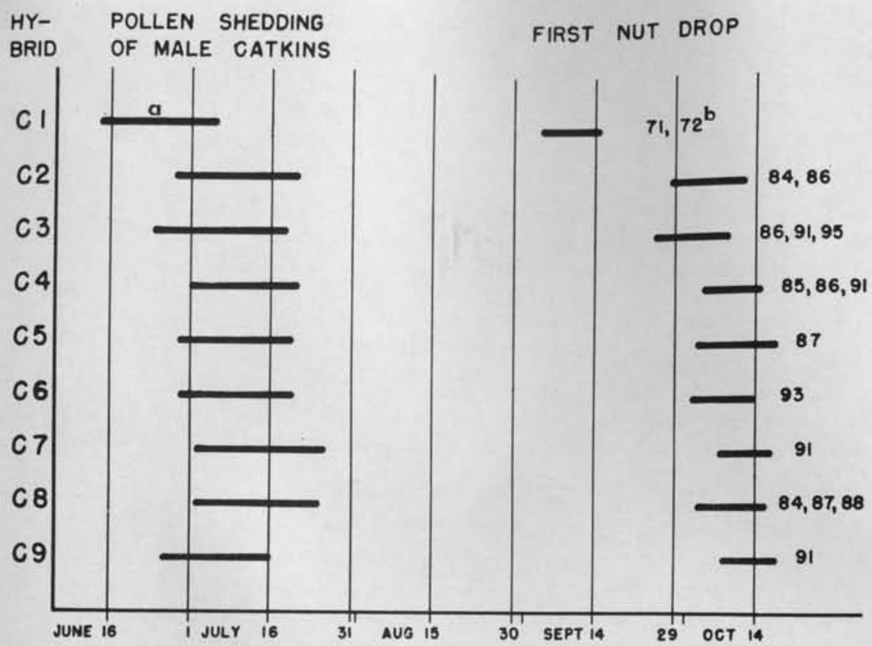

Figure 4. Relative pollen shedding and nut ripening dates of hybrids. a, Female flowers become receptive 6 to 12 days after start of pollen shedding and may remain receptive a week or more. b, Actual number of days between pollination and harvest of some controlled pollinations.

form of the tree is columnar. Grafts of C3 maintain the upright growth pattern (Figure 6B). This tree should be very useful where a tall tree is desired with limited lateral spread. Catkins are shorter (10 cm.) than on most trees, abundant, but relatively light in pollen production. Leaves remain green in the fall a week or two longer than those of most other chestnut trees.

C4

C. mollissima (*C. crenata* × *C. dentata*). C × JA

The Japanese-American pollen parent was the same for this selection as for C2 and C5. However, different Chinese trees were used for the female parents of all three. The cross was made in 1937, hence the first growing season was 1938. C4 is potentially a large tree (Figures 5 and 6C). It is a reliable producer of medium-large chestnuts but probably not prolific enough to be considered for commercial orchard use. Some of our oldest grafted trees include propagations of this selection and C5 (Figures 6A, 6C). The grafts grow essentially like the original hybrid seedling and will also develop into large trees. There is a tendency for the main stem of these trees (C4 and C5) to be somewhat crooked and for the lower primary branches to be large. Foliage of C4 remains green longer in the fall and nut production appears to be somewhat more abundant than for the similar C5 selection.

C5 'Toumey'

C. mollissima (*C. crenata* × *C. dentata*). Graves 1962. C × JA

A companion tree to C4. The two are very similar to one another as indicated in the description of C4. C5 has one difference which is important to plant breeders. The female flowers when isolated in paper bags, in preparation for controlled pollinations, very often drop off, whereas those of C4 do not. This is presumably due to the sensitivity of the female flowers to the increased humidity and temperature, or decrease in light, received in the bags.

C6

(*C. crenata* × *C. dentata*) OP. JA × OP

This tree was raised from a nut borne on a Japanese-American hybrid in 1940. The nut resulted from an uncontrolled or open-pollination; hence we know only the female parent. But because of various morphological characters of the twig and leaf we believe the male parent was Chinese or a Chinese hybrid. C6, of all the hybrids here described, is the one which most closely resembles the American chestnut in overall tree form and fruiting characters. It is a light nut producer, but this situation may be improved in grafted trees, particularly if they are grown in full sun. Natural infection by the blight fungus has caused some extra proliferation of cork cells in the lower portion of the trunk, but growth of the tree does not appear to be affected.

C7

C. mollissima (*C. crenata* × *C. dentata*). C × JA

The Chinese and Japanese-American parents used in this cross in 1939 were not used in the other CJA's described. Like C6 this selection has very good form, is a light nut producer, and a rapid grower. Of the trees we have of similar size, C7 probably equals or exceeds all the others in current rate (last 4 years) of height growth. It may not be as resistant to the blight fungus as hybrids C1 through C6, but to date inoculations and natural infections have caused only small cankers and extra proliferation of cork cells on the main trunk near the base of the tree. Rate of growth has not been noticeably affected. Nuts of C7 are attenuated or pointed toward the stylar end (extreme expression of a Japanese and American character) and are often angular when viewed in cross section (Figure 3). Occasionally burs contain up to seven nuts instead of the usual three. Catkins are very long (25-30 cm.) but flowering is generally not heavy. Foliage remains green longer in the fall than on most other chestnut trees.

C8

C. mollissima (*C. crenata* × *C. dentata*)? CJA

The original pedigree record of this tree was lost. Based on its location and morphological characters it probably is a CJA. C8 is not as blight resistant as we would like. The bark on the lower portion of the trunk is swollen from infections and a few sprouts have recently been initiated from near the root collar. The tree is mentioned here because it has traits which others might like to use in breeding work. It is a very vigorous grower (Table 2), and produces a heavy crop of nuts each year. It breaks dormancy late in the spring—a trait which is correlated to reduced cankerworm damage of the leaves.

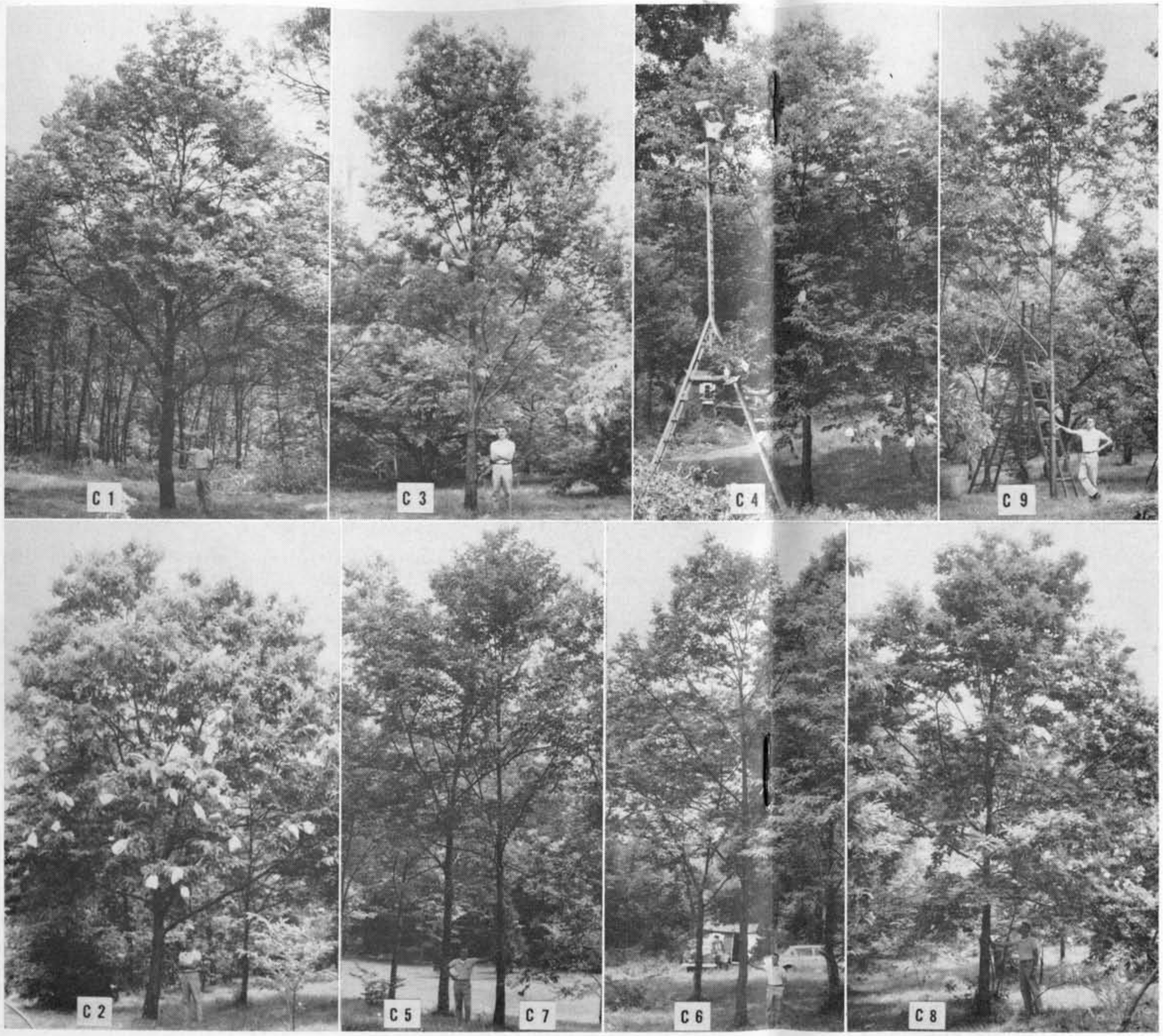

Figure 5. Nine hybrid chestnut trees, photographed July 5, 1962.

C9

C. mollissima (*C. crenata* × *C. dentata*). C × JA

From a 1938 cross pollination. Neither parent was used in the other CJA's described. The twigs, leaves, and nuts of this tree are very much like those of the pure Chinese species, but the upright bole sets it apart (Figure 5). The lack of lower limbs on C9 resulted from self-pruning because it was crowded as a sapling. The competing trees were removed several years ago; yet it has maintained good form even in its recent crown growth. So far C9 has not been seriously affected by the bark disease but, because of more bark proliferation than usual among resistant trees to an artificial inoculation, we presently regard it as having questionable resistance. C7 and C8 also are of questionable blight resistance. We can speak with assurance only of the performance of the trees to date, but on this basis we can make what we believe are intelligent estimates of their future performance. The photographs are the best illustration of the blight resistance of these trees after artificial and natural inoculations.

Table 2. Comparative size and growth rates of hybrids

Hybrid	Height	DBH	Age at 4.5 ft.*	Height yr. above 4.5 ft.	Diameter per year at 4.5 ft.	Relative expression of vigor Ht/yr. x Diam/yr.
	Feet	*Inches*	*Year*	*Feet*	*Inches*	
C1	40	13.0	23	1.54	.565	.87
C2	34	8.8	20	1.48	.440	.65
C3	34	8.0	18	1.64	.444	.73
C4	42	9.3	22	1.70	.423	.72
C5	43	9.4	22	1.75	.427	.75
C6	41	8.3	18	2.03	.461	.94
C7	38	7.8	18	1.75	.433	.76
C8	32	7.6	14	1.96	.543	1.06
C9	34	5.3	16	1.84	.331	.61

DBH Diameter breast high (4.5 feet).

* Rather than use the age as computed from time of seed germination, the number of annual rings at 4.5 feet was determined with an increment borer. This figure was used in determining the height per year above 4.5 feet. In so doing many artificial discrepancies in growth rate that appear in the first few years of field-grown trees was eliminated; i.e. transplanting shock, rabbit and mouse damage, and mechanical injury from machinery.

Cross Compatibility Among Hybrids

In setting out grafted chestnut trees, it will be necessary to have more than one clone represented to obtain cross fertilization and nuts. The crossing chart depicts crosses attempted between trees of the nine described hybrids (Figure 7). When nuts are obtained from a single controlled cross between two trees, this indicates the trees are capable of intercrossing when planted together. However, when no nuts are obtained we cannot conclude that the two trees are incompatible with one another until several crosses are attempted. The lack of fruit set may only reflect faults, such as timing, in the controlled pollination technique. The results, so far, from comparative pollinations (that is, several male parents crossed to the same female parent on the same date) indicate that C3 and C9 may not function effectively as male parents in certain crosses: namely, C9 on C1 and C8 females, and C3 on C1 females. Interestingly, the reciprocal cross of C1 on C3 is highly fertile. Trees which tend to drop the female flowers when enclosed in paper bags are difficult to evaluate by using

controlled crosses. Also, trees such as C1, which flower early in the season, will not make good companions with late-flowering types. The relative pollen shedding and nut ripening dates of C1 and the eight other hybrids are given in Figure 4.

Grafting of the Hybrids

We have successfully grafted the selections described and all, with the possible exception of C1, can be grafted on Chinese stock. We have not made enough grafts, however, to draw specific conclusions as to the occurrence or degree of incompatibility. (For more on grafting and incompatibility see page 24.)

Nut Quality of Hybrids

Two panels evaluated the nuts of the hybrids for appearance, peeling ability of pellicle (fuzzy layer over kernel), kernel texture, and kernel sweetness and flavor (not cooked), plus an overall rating. Each trait was evaluated as excellent, good, average, fair, or poor. Participants in the second trial were members of the Connecticut Nut Growers Association.

Opinions varied but, in general, the ratings given the nuts by members of the two panels agreed with opinions formed by the authors over the past several years: C2 and C5 receive the highest in overall rating; C2 is particularly nice in appearance and is also large; C1, along with C5, scores high for flavor and texture of the nut kernel; the kernel flavor of C7 is comparatively bland; the pellicle of C6 peels off the kernel most readily and in that respect closely resembles the American chestnut as contrasted to the European and Asiatic chestnuts; and the pellicle of C1 does not readily peel free.

No storage or keeping problem peculiar to any one hybrid has arisen. However, in 1962 about 10 per cent of the nuts of C7 had brown kernels at harvest time. This apparently was due to a physiological breakdown, believed to have been caused by environmental conditions. It is not a regular characteristic of this tree. The trait has been observed sporadically in other chestnut trees.

The male or pollen parent can have considerable influence on nut characters. The time of fruit maturation, nut size, and embryo dormancy can be altered, depending on the male parent (McKay 1960; Jaynes 1963). As a practical matter, however, the source of pollen is probably not a major consideration.

Table 3. Weight of nuts from hybrid trees (range of fresh weight averages for 2 or more years)

Hybrid	Grams/nut	Nuts/pound	Relative size*
C1	5.6— 6.0	76— 81	Medium
C2	9.3—13.7	33— 49	Large
C3	4.5— 6.1	74—101	Medium to Small-medium
C4	6.4— 9.4	48— 71	Large to Medium
C5	5.2—10.4	44— 87	Large to Medium
C6	5.5— 9.3	49— 82	Large to Medium
C7	4.6— 6.0	76— 99	Medium to Small-medium
C8	5.4— 6.8	67— 84	Medium
C9	4.8— 5.7	80— 94	Medium to Small-medium

* Number of nuts in 1 pound: Large, 44; medium, 66; small, 144.
Classification from New Jersey Agricultural Experiment Station Bulletin 717, April 1945.

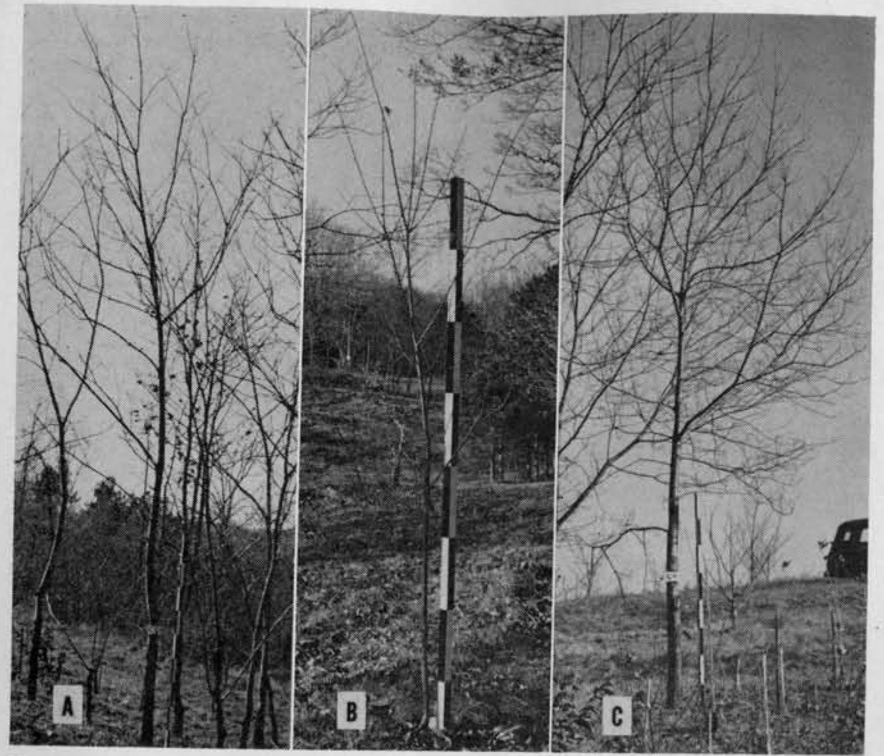

Figure 6. Grafted hybrids. (A) Graft of C5, 14 years old, 32 ft. high, 5.0 in DBH (Diameter Breast High). Shade from a taller tree on the right has caused some lean. (B) Graft of C3, 3 years old, 10 ft high. (C) Graft of C4, 14 years old, 29 ft high, 5.1 in DBH. Stake is marked in 1 ft sections.

FUTURE DEVELOPMENT AND SELECTION OF BLIGHT RESISTANT CHESTNUTS

Chestnut trees are not normally self fertile; hence it has been impossible to develop true breeding types (inbreds) through inbreeding. We cannot reproduce selected trees in exact kind from their own nuts. Superior trees, at the present time, must be propagated vegetatively. Yet there are two ways in which desirable trees might be reproduced from nuts.

One way is to find a cross between two individual trees, such as a Chinese and a Japanese-American, which will yield a high percentage of desirable trees among the progeny. Some of our best trees are derived from the CJA cross, but we have not yet found a pair of trees of this or any other combination which consistently produces a high percentage of superior, blight-resistant offspring. (Note that five and possibly seven of the trees described are CJA's.) We are attempting to find such a combination by repeating combinations that have yielded our best trees and also by intercrossing the superior trees. We have two hybrid trees which impart good form and vigor to many of their seedling pro-

♀ \ ♂	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9
C 1	○	●	○		●				○
C 2	●	○	●	●	●	●	●	●	●
C 3	●	●	○	●	●	●	●		●
C 4		●	●	○	●	●	●	●	●
C 5		●	○	●	○	●	●		
C 6									
C 7						⊙		●	○
C 8		●	●	●	●	●	●		⊙
C 9		●	⊙	⊙		○			

Figure 7. Crossing chart. Fruit set from intercrosses of hybrids. • nuts formed. ⊙ one nut formed. o no nuts formed. Note that of the five trees self pollinated none has set fruit. There is no evidence for apomictic fruit set. Bagged female flowers of C1, C2, C3, and C4, emasculated and not pollinated, produced no nuts.

geny, but the degree of blight resistance among the seedlings is still undetermined (see Table 1 and discussion under Tree Farming). Once the right two-tree combination is found it will be possible to establish seed orchards to produce large quantities of seed.

The second possibility for producing good trees from seed is to cross sibling (sister) trees for several generations, selecting as parents in each generation those trees showing the desired characteristics. In this way it should be possible to fix the genotype determining the character of a true-breeding variety. Some attempts have been made along this line by a few nurseries working with the Chinese chestnut in the United States. However, the degree of uniformity is still in doubt, and the selection made has been towards the spreading form of the Chinese chestnut. To fix the genotype of hybrids using this method of crossing siblings would involve several generations and a great deal of time.

Presently then, when one does not wish to chance the outcome of a seedling tree, vegetative propagation (grafting) is the answer. This method has long been used to produce most other fruit and nut trees.

Our work with chestnuts is continuing. Some of the trees described and released in years to come will replace those described here; others may satisfy different needs. For instance, we have some promising hybrid seedlings of second-generation crosses of the Chinese chestnut with *C. seguinii,* a dwarf, prolific species. Some of these seedlings are slow growers (dwarf), have large nuts, are early and heavy bearing, and appear to be blight resistant.

Other selected individual trees may well be forthcoming from the Co-operative Hybrid Chestnut Plots established through the cooperation of the USDA and this Station. Since 1947, a total of 15 experimental hybrid field plots have been established in 10 eastern states. The plots have equal numbers of Connecticut and USDA hybrid seedlings, as well as a special introduction of Chinese chestnut. Many of these trees are now beginning to reach the age where they can be reliably evaluated for blight resistance, form, vigor, and other traits. Jesse D. Diller of the Forest Service, and the many people locally in charge of the 15 plots, deserve credit for establishing and maintaining these plantings.

CHESTNUT CULTURE

Propagation of Trees from Nuts

Harvesting Nuts drop from a chestnut tree over a period of about 2 weeks. In Connecticut the nuts of the Japanese chestnut start to drop soon after the first of September, with the Chinese trees starting to drop later the same month and continuing until about the middle of October. Chestnuts are perishable; hence it is advisable to collect nuts every 2 or 3 days. If squirrels are a pest, the nearly ripened burs can be picked and cracked open by hand, but heavy leather gloves are a must.

After collection, the nuts are cured (allowed to lose excess water); this can be done by placing them in trays in a cool room (50-65 F) for about a week. It is of utmost importance that nuts to be planted do not undergo extensive drying out which will kill the embryo. The nuts should remain nearly as plump as at harvest time.

General Rules However the nuts are handled after curing, a few basic principles should be kept in mind. *First,* the nuts need a cold treatment (stratification) of approximately 2 months in order to germinate; *second,* temperatures much below freezing or above 45 F should be avoided; *third,* whether planted or stored, the nuts need to be protected from rodents, squirrels, and birds; and *last,* if the nuts are kept too moist they will rot and if too dry they will not germinate. Planting should always be done in a light, well drained soil. A mixture of one-half sand and one-half peat can be used.

Storage of nuts for more than 6 months is not normally advisable or necessary. Nuts kept in cold storage, however, may remain viable for more than 18 months.

Planting in the Fall John Olson, at the Pachaug State Nursery in Voluntown, Connecticut, has had success with direct sowing of nuts in the fall after harvest. He plants the nuts, after curing, about 1 inch deep in a light sandy loam. Before the ground freezes he covers the bed with a layer of salt marsh hay. Surprisingly, rodents and squirrels have not been a nuisance, though as a precaution poison bait is periodically set out for mice. Where squirrels and mice occur regularly, fine-mesh wire netting may be placed around the bed with the lower 5 inches of the wire in the soil. A layer of netting should also be placed over the bed and left until it starts to interfere with the germinating nuts.

A variation of fall planting has been used successfully by a Connecticut nurseryman. Instead of planting outside in a bed, the nuts are planted in No. 10 tin cans, one or two per can, and kept in an unheated garage until the beginning of February. No. 10 cans are 7 inches high and 6 inches across; they or similar containers can often be obtained from gas stations or restaurants.

Before filling the can with soil, the bottom is cut completely free except for about 1 inch, and on the edge of the can opposite this uncut section a slight fold or dent is made to hold the bottom in place. Starting in February some heat is used to keep the temperature above freezing. By the time the danger of frost has passed in the spring, the nuts already have started a good root system, as well as a shoot above the soil level. The cans are then placed outdoors. By the end of the summer the trees may be as much as 3 feet tall and are ready to be marketed. When moving the trees, no digging or transplanting is necessary. To plant in their permanent location, the bottom of the container can be torn off, the tree and can set in the ground, and the sides of the can lifted up over the tree. This procedure avoids root damage. The bottomless can may be left around the tree to prevent bark damage by mice during the winter months. If the trees grow well they will be of sufficient size at the end of the first year to use for grafting stock. One tree per can gives more erect and symmetrical growth.

Spring Planting After curing, the nuts may be stored in metal cans or plastic bags at a temperature of 32-36 F and a relative humidity of about 70 per cent. The container should have holes for ventilation; or, if mixed with damp sand or sawdust the nuts may be stored in open containers, then the top layer of nuts is covered with 2 to 3 inches of sand or sawdust. The nuts are planted in the nursery bed as soon as the soil can be worked in the spring.

If cold storage facilities are not available, the nuts may be buried in sand 6 to 12 inches below the surface of the ground in a well-drained location, protected by a small-mesh wire cage. Overwintered in this way, the nuts are taken out of the ground before germination is well started—about the last of March in Connecticut. If left longer the emerging radicles become tangled and break off when the nuts are removed. About the first of April the nuts can be planted in a nursery bed, but they still need to be protected from rodents.

Later Care of Seedlings After the seedlings have grown for a year they may be transplanted to a permanent location. They do best when planted at least 20 feet apart in a deep soil with a pH of 6.0 to 6.9 and where they will receive abundant sunlight. For good crops of nuts, plenty of light is a requisite. Transplanting shock is lessened by pruning. The top should be cut back and the lower unwanted branches removed. Seedlings benefit greatly if the ground around them is kept clear of grass and weeds within a radius of about 2 feet. Such growth competes with the seedlings for water and soil nutrients. Mulches of wood chips, sawdust, leaves, straw, or plastic can be used effectively in place of cultivation. Transplanting is best done while the tree is dormant, either in the fall after the leaves turn color or before the buds break in the spring. With fall planting, mulching is necessary to prevent frost heaving.

Normal Growth and Fruiting Time Trees may be expected to grow about $1\frac{1}{2}$ feet per year or, if of rapid growing stock, 2 feet or more. Chinese and Japanese seedlings usually begin to bear nuts after 5 or 6 years if grown in full sun. Grafted trees will usually bear after 3 years. Shaded trees are slower to flower. Chestnut, like other deciduous trees with a tap root system, may show little or no net growth in the year following transplanting.

Vegetative Propagation

Presently, grafting is the most feasible technique of vegetative propagation. Air layering, ground layering, greenwood cuttings, and hardwood cuttings all have proved unsatisfactory. Stooling, in which sprouts are girdled near ground level and then covered with a mound of earth, has been used with some success

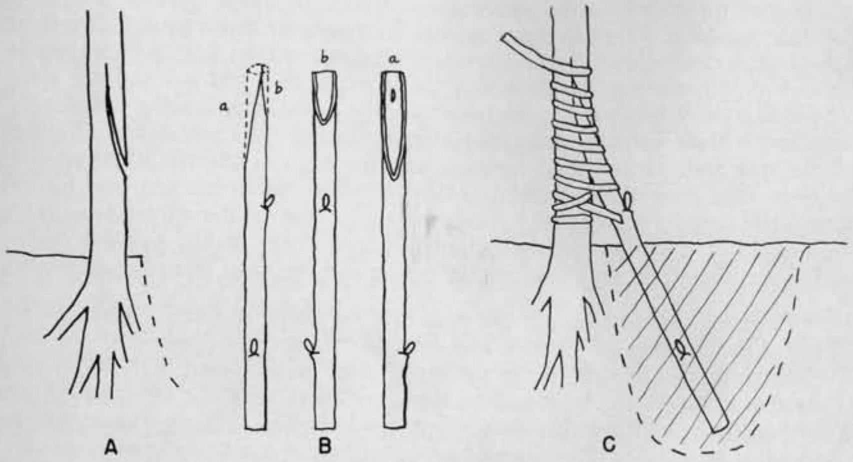

Figure 8. Buried-inarch. A grafting technique for obtaining rooted seedlings from scions of hard-to-root species. Root tips were of importance for chromosome counts. A and B, preparation of the stock and scion; C, graft completed, wrapped, and ready for waxing.

in Europe (Guerreiro 1956; Vieitez 1960), and we have developed a specialized technique called the buried-inarch method that can be used to root limited numbers of scions (Figure 8) (Jaynes 1961b).

Many grafting techniques have been used successfully with chestnuts. However, we will describe only two methods: the splice graft for small seedling stock and the bark slot graft for large seedlings or for topworking older trees.

Selection of material for grafting is important. Scions (the small budded twigs of the trees to be propagated) are best collected in late winter or early spring before growth starts. For scion wood the growth of the last growing season is desired with a bit of 2-year-old wood if the new growth is of small diameter. The larger the diameter of the scion, unless from a pithy sprout, the better the chances of a successful graft.

The following supplies are needed: a very sharp knife, grafting wax (various commercial types are available), and binding material, such as strong cotton twine. It is important that the cut surface of the stock and scion be smooth and fit together well. Spring grafting with dormant scion wood can be done from the time the buds of the stock start to break until the first leaves are almost completely unfolded.

Splice Graft Two-year-old seedlings make good stock, as do vigorous one-year-old seedlings. When the stock and scion are approximately the same size, the splice graft method can be used (Figure 9). The scion need only be long enough to contain one or two buds. For larger seedlings, and in topworking, the bark slot graft is a good method to use.

Bark Slot Graft The bark slot graft (also called the veneer crown graft) is used when the stock diameter is larger than the scion diameter. The stock should

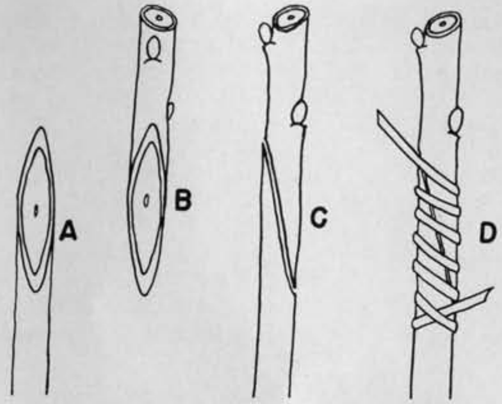

Figure 9. Details of the splice graft. The basal end of the scion (B) is cut obliquely with a smooth cut. The stock (A) is cut similarly, the cut surfaces fitted together (C) and tied with twine, raffia, or rubber grafting strips (D). The union and cut end of the scions are waxed with grafting wax.

be cut on a slant, up to 45°, and one scion placed at the upper edge of the cut between the bark and wood (Figure 10). The slanting cut heals over more rapidly than a right-angle cut. The placing of a second scion on the opposite side of the cut is often of little or no value. If the first scion takes, the second should be removed.

Topworking should be standard practice in any orchard grown from seedling material: trees of low productivity and quality can be topworked to more desirable types. In topworking, the main branches of the trees are sawed off 6 to 12 inches from a crotch and where the stock is ¾ to 2 inches in diameter. When the stock diameter is more than 2 inches, complete healing of the union is greatly delayed.

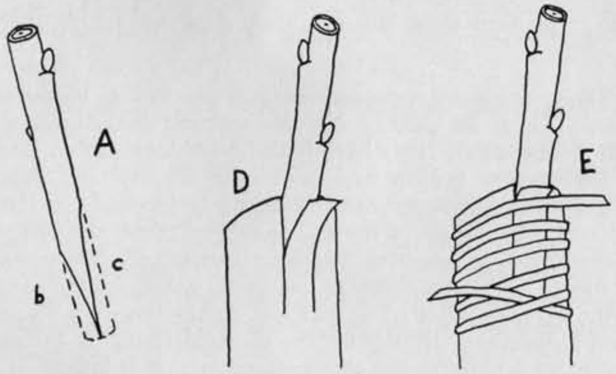

Figure 10. Details of the bark slot graft. Two oblique cuts of unequal length (b and c) are made on the scion (A). Two parallel cuts, the width of the scion apart, are cut into the bark of the stock and the scion inserted with the longer cut surface (c) against the wood of the stock (D). The graft is tied (E) and the union and all cut surfaces are waxed. Note that the stock should be cut on a slant and the scion placed on the upper edge of the cut.

The care given after grafting is important. After callus formation, the binding material should be cut before it girdles the graft union. Growth of the scions is often rapid and luxuriant, and staking may be needed to prevent wind breakage. Removal of sprouts and suckers which develop on the stock every week or two after grafting encourages growth of the scion.

Graft Failures Because of the many variables involved in grafting it is always difficult to assign specific causes to graft failures. Many so-called incompatible grafts are simply a result of using scions of insufficient diameter or are due to the susceptibility of the stock or scion to the blight fungus, with infection occurring at the graft union. The grafting of chestnuts will come into its own when we can specify which stocks are best for which clones or cultivars. Thus a record of the stock as well as the scion should be maintained.

Insect and Disease Control

Insect pests of chestnut foliage are about the same as those on oak trees, and control methods are the same. Cankerworms, whose numbers follow a cyclical pattern, sometimes cause serious damage to newly transplanted trees, and an application of insecticide such as DDT is often advisable about the time the buds open.

The most serious insect pests are chestnut weevils; there are two species and both attack the nuts. They seem to be prevalent mostly in large plantings. Where the weevils are a pest, the burs may be sprayed with DDT applied 40, 30, and 20 days before nut drop. Also effective are ground applications of aldrin, dieldrin, or endrin, which kill the weevil larvae before the adult egg-laying stage develops.

The damage wrought by mice, rabbits, and deer can hardly be over-emphasized: use of poison baits, repellents, and fencing may be indicated.

In the Northeast, chestnut blight is the one serious disease. Use of disease-resistant trees is the practical remedy. However, if partially resistant trees are grown, they can be kept alive and in bearing condition by using the inarching method.

Inarching When a large blight lesion develops on the trunk, suckers arise below the lesion or at the base of the tree. Because these sprouts are initially less prone to disease attack (they have juvenile resistance, as do seedlings) they can be grafted into the healthy bark above the diseased area. To do this the tip of a sucker is wedge-shaped, an inverted T-cut is made in the bark above the diseased area, and the tip of the sucker slipped under the bark, then the inarched sucker (scion) is bound in place and waxed. By this procedure, called inarching (Figure 11), translocation of food, water, and minerals between crown and root is maintained. The inarched sucker continues to grow through the years and may eventually replace the diseased trunk. If the scion itself is attacked, it too can be inarched in the same manner. It is important to note that in orchards of partially resistant trees, none need be lost if this inarching method is employed. Many of our blight susceptible Japanese-American hybrids which we used in C × JA crosses have been maintained in flowering condition for 25 years by inarching. Indeed, except in cases of C1, C3, and a few other hybrids with no American parentage, it is difficult to see how our breeding work could

Figure 11. Inarching. Blight infected Japanese-American hybrid inarched with four sprouts. Suckers not used for inarching were removed.

have succeeded without this inarching method. Unfortunately, the American chestnut itself is too susceptible to the bark disease for this technique to be successful.

PREPARATION AND STORAGE OF NUTS

Turkey Stuffing Add one to two cups of shelled chestnuts to a regular bread stuffing. To prepare nuts: place in boiling water for 3-4 minutes; remove, peel off shell and pellicle, break up meat of nuts and blend into stuffing. Discard nuts with obviously discolored meat.

Roasted or Boiled Chestnuts Place in boiling water, hot frying pan, or oven for 10-15 minutes; remove and peel nuts, salt and butter to taste, eat while still hot. Before roasting or frying chestnuts, the shells should be pierced so that they will not explode.

Storing Chestnuts Whole nuts can be stored for months in the hydrator of a refrigerator. Nuts should not be allowed to freeze or become too dry. Nut meats can be stored indefinitely if the fresh meats are dried in an oven and sealed in jars. To use these dried meats in cooking, one need only moisten them with water for about 15 minutes.

CONCLUSIONS AND SUMMARY

Chestnut blight, one of the most catastrophic plant diseases known, virtually eliminated a major forest tree in the eastern United States within half a century. The American chestnut tree has been lost as a timber producer and as a source of wildlife food. The development of blight-resistant hybrid chestnuts as a forest crop is still in the experimental stage. However, blight-resistant trees for orchards, as a source of food for wildlife, and for home or yard plantings can now be propagated.

Nine promising hybrids have been selected and described because of their blight resistance, superior form, and vigorous growth. Salient features of the nine hybrids:

C1 'Essate-Jap'—Morphological characters of buds and leaves are predominantly like those of the Japanese chestnut. However, it is a tall, conical shaped tree, bearing medium-size, sweet nuts that mature very early in the fall.

C2 'Sleeping Giant'—A cross of the Chinese and Japanese-American (C × JA), has a broad conical shape and is an abundant bearer of large, handsome nuts; useful as a shade and nut tree.

C3—A tree with upright growth and a relatively narrow crown, bearing medium-size nuts; useful as a yard tree.

C4—A C × JA hybrid which is potentially a large tree in height as well as in branch spread; a consistent but not heavy producer of large to medium-size sweet nuts. Fourteen-year-old grafts of this tree are about 30 feet high.

C5 'Toumey'—A C × JA very similar to C4, but possibly not as heavy a nut producer; presently 43 feet high.

C6—A columnar growing tree that in growth habit, and in nut characters, closely resembles the American chestnut; outstanding form, but a light nut producer.

C7—A C × JA which has an upright growth habit and relatively light lateral branches; the catkins, though not abundant, are very long; the handsome foliage remains green longer in the fall than on most chestnut trees.

C8—A vigorous grower, conical in shape, bears heavy crops of medium-size nuts; the buds are late to break dormancy in the spring and apparently for this reason the leaves are less damaged by cankerworms than are leaves on surrounding trees.

C9—An upright tree with a straight bole, having relatively light crops of medium-size nuts.

Presently these trees must be propagated vegetatively. Grafting has proved the most successful method to date, though efficient stooling techniques may be possible.

Inquiries on availability of scions of the nine hybrids discussed in this Bulletin should be addressed to the Genetics Department, The Connecticut Agricultural Experiment Station, Box 1106, New Haven 4, Connecticut. Grafted trees or seedlings are not available from this Station.

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