THE INFLUENCE OF COLD IN STIMULATING THE GROWTH OF PLANTS [1]

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In regions having a cold winter like ours, with prolonged or repeated freezing, the native trees and shrubs become dormant in autumn. According to the general belief this condition is brought about by the cold. It is also the general belief that warm weather is of itself the sufficient cause of the beginning of new growth in spring. Both these ideas are erroneous. It is the object of the present address to show: first, that in our native trees and shrubs dormancy sets in before cold weather, and that cold weather is not necessary for the establishment of complete dormancy; second, that after such dormancy has begun, the exposure of the plants to an ordinary growing temperature does not suffice to start them into growth; third, that these plants will not resume normal growth in the warm weather of spring unless they have been subjected previously to a period of chilling; and, finally, a theory will be advanced to explain this paradoxical effect of cold in stimulating growth instead of retarding it.

The subject will be presented in a series of numbered statements, each followed by supporting evidence.

1. Trees and shrubs of cold climates become dormant at the end of the growing season without the necessity of exposure to cold weather.

A little more than 10 years ago, while engaged in a series of greenhouse experiments, the speaker came upon a strange phenomenon which was wholly unexpected and which threatened to interfere seriously with the success of the experiments. Healthy blueberry plants, intended to be used during the winter for breeding purposes, were brought into the greenhouse at the end of summer and were kept at an ordinary growing temperature. They refused to continue their growth during the autumn, gradually dropped their leaves, and went into a condition of complete dormancy. They did this at a greenhouse temperature which in spring and summer would have kept the plants in a condition of luxuriant growth. The completeness of the condition of dormancy which such plants reach can be best appreciated from photographs (Pl. 20, A).

Since 1910 this experiment has been repeated many times and with many species of plants, and without exception those trees and shrubs

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native of our northern cold-winter region which were tested went dormant in fall or winter regardless of temperature. In comparing outdoor plants with indoor plants of the same species the most that can be said in favor of outdoor conditions is that dormancy progresses a little faster in outdoor plants, evidently because their foliage is injured by freezing weather, and they drop their leaves somewhat earlier than indoor plants.

2. Trees and shrubs that are kept continuously warm during the winter start into growth much later in spring than those that have been subjected to a period of chilling.

In the late winter and early spring of 1910 I waited patiently, and then impatiently, for my indoor plants to bloom, and at last I was forced to realize that they never would bloom. When compared with plants of the same kind that had been outdoors during the winter and had been brought into the greenhouse in early spring, the difference was astonishing. The outdoor plants burst into leaf and flower luxuriantly, while the indoor plants remained completely dormant and naked. The experiment was repeated many times and with various species of plants, some of which may be used in illustration. (See Pl. 20, B; 21; 22, A.)

At first it was supposed that the plants needed to be frozen to start them into growth, but a single freezing proved not to be effective. And then it was found that the dormant plants would start into growth without any freezing whatever. It was necessary only that they be subjected to a period of prolonged chilling, usually two or three months, at a temperature a few degrees above freezing.

If plants are kept continuously in a warm place without chilling, the dormant condition often continues for an extraordinary length of time. In some instances plants have remained dormant for a whole year under conditions of heat, light, and moisture that ordinarily would make the same plant grow with the greatest luxuriance.

3. The stimulating effect of cold is limited to such portions of the plant as are subjected to the chilling.

The conspicuous difference in spring growth between chilled plants and plants not chilled has already been shown. These differences, furthermore, can be produced experimentally upon different parts of the same plant. Plants thus treated present a very curious and remarkable appearance, as shown in Plate 22, B, and Plate 23.

On February 3, 1912, a blueberry plant (Pl. 22, B) 44 inches in height, which had shed its leaves and become dormant in a warm greenhouse maintained at a temperature of 60° to 70° F., was subjected to the following experiment: It was repotted in a 7-inch pot and set in the south end of a greenhouse at the temperature already mentioned. A small opening was made in the glass, and through this opening one of the two stems of the plant was pushed. The open space about the stem where it passed through the glass was carefully plugged with moss. During the rest of the winter the plant remained in the same position, the pot and the stem, shown at the left in the illustration, continuing in the warm temperature of the greenhouse, while the stem at the right, projecting through the glass, was exposed to the rigors of winter, with its alternate freezing and thawing. The illustration, from a photograph made April 18, shows that when spring came the outdoor branch started into normal growth while the indoor branch continued dormant.

A second illustration (Pl. 23) shows a modification of the first experiment. In this case the plant was set on a shelf outside the greenhouse, and a single branch was passed through the glass wall into the warm interior. When spring came it was this interior branch that remained dormant, all the outside branches putting out leaves promptly and normally.

From a comparison of the two experiments it is evident that the difference in behavior of the indoor and outdoor branches could not have been caused by any special action of the root system, for in one experiment the roots were inside, in the other outside. It is clear that the causes that stimulated growth in the exposed stems operated in the stem itself, not in the roots. This principle is still further exemplified and confirmed by the behavior of cuttings taken from blueberry plants in the first stages of their dormancy. Such cuttings if kept warm continue their dormancy into late spring or summer, but if chilled for two or three months they start into growth at the normal time in early spring.

It should be stated here that the difference in the amount of light inside and outside the greenhouse had nothing to do with the stimulation to growth, for chilled plants are ready to start into growth promptly whether the chilling is done in the full light of an outdoor situation, or in the partial light of a greenhouse, or in the complete darkness of an ordinary refrigerator.

4. The stimulating effect produced on dormant plants by cold is intimately associated with the transformation of stored starch into sugar.

In most of our wild species of trees and shrubs the reserve carbohydrate material is stored away during summer and autumn in the form of starch. At the beginning of dormancy the twigs and sapwood are gorged with this material, the starch grains being stored ordinarily in the cells of the medullary rays and sometimes in the pith. As the process of chilling goes on, this starch little by little is transformed into sugar. The presence of large quantities of starch in the fall and early winter may be observed by applying to freshly cut surfaces of the twigs the well-known starch test of a 2 per cent solution of iodin in a 1 per cent solution of iodid of potassium. With a strong hand lens the starch is readily observed, if present, by the deep blue color it assumes under this treatment. The intensity of the coloration gives roughly an idea of the number of starch grains present, and thus by this simple means anyone may observe in the twigs of trees and shrubs the gradual disappearance of their starch as spring approaches.

The measurement of the increasing amount of sugar is more difficult and must be done by chemical analysis. Through the courtesy of the Chief of the Bureau of Chemistry, exact data can be presented on this point from analyses by Mr. Lorin H. Bailey. In samples of dormant blueberry wood taken in early spring when growth was about to begin the ratio of sugar to starch proved to be seven times what it was in similar dormant wood taken in autumn.

I desire at this time to comment on the fact that one of my colleagues reading the manuscript outline of this address criticized the use of the word "stimulate" as applied to the effect which chilling produces on these dormant plants. His idea was that the chilling induced certain physiological changes in the cell contents but that the actual stimulation to growth came from the temperatures that followed the chilling. I defend, however, the propriety of the language I have used, for although the later stages of growth admittedly can not take place without warm temperatures, not only does the transformation from starch to sugar take place at the chilling temperature but the buds actually swell and push if the chilling temperature is continued for several months. In illustration I may cite the following experiments.

On March 3, 1915, 286 cuttings were made from dormant outdoor blueberry plants. They were stored in bundles, some in moist sphagnum moss, others in moist birch sawdust, at a contemplated temperature of 31° F., just below freezing. The cuttings remained in cold storage until December 6, a little more than nine months. An examination of the cuttings on that date showed that one or more buds had begun to swell on every cutting with the exception of a small number which were mildewed and dead. In other words, growth had already begun to take place at the cold-storage temperature. The thermograph record for the 278 days was as follows:

	Hours.
29° to 32° F.	5, 591
32° to 33° F.	990
33° to 34° F.	91

The temperature record did not go above 34° F. It is an astonishing fact that temperatures so very near freezing will start dormant plants into growth.

On March 3, 1915, 58 cuttings from dormant, outdoor blueberry plants were placed in moist birch sawdust in commercial cold storage at 33° to 36° F. On December 4, nine months later, buds on every cutting had begun to grow. Not one of these cuttings gave a starch reaction when tested with iodin. The transformation of their stored starch into sugar was complete. (See Pl. 24.)

5. THE THEORY ADVANCED IN EXPLANATION OF THE FORMATION OF SUGAR DURING THE PROCESS OF CHILLING IS THAT THE STARCH GRAINS STORED IN THE CELLS OF THE PLANT ARE AT FIRST SEPARATED BY THE LIVING AND ACTIVE CELL MEMBRANES FROM THE ENZYM THAT WOULD TRANSFORM THE STARCH INTO SUGAR, BUT WHEN THE PLANT IS CHILLED THE VITAL ACTIVITY OF THE CELL MEMBRANE IS WEAKENED SO THAT THE ENZYM "LEAKS" THROUGH IT, COMES IN CONTACT WITH THE STARCH, AND TURNS IT INTO SUGAR.

I have stated the theory in these words out of regard for simplicity and general understanding, but if anyone should require that it be presented in orthodox technical language it might be restated as follows: The reserve amylum carbohydrate bodies are isolated from the amylolytic enzym by semipermeable protoplasmic living membranes of high osmotic efficiency, but under the influence of low temperatures the protoplasmic membranes are proximately devitalized, they become permeable to the amylolytic enzym, and amylolysis ensues. I may add, however, that the use of such terminology seems to me to involve a certain degree of unnecessary cruelty.

From the evidence already presented, no one, presumably, will question that the chilling of dormant trees and shrubs is followed by growth and that the growth is associated with the transformation of starch into sugar. But the hypothesis that this transformation is brought about by the weakening of the cell membrane and the consequent leakage of starch-transforming enzyms into the starch chambers may very properly be challenged. In the Tropics there is no chilling weather, yet trees and shrubs spring into growth after the dormant period of the dry season just as they do in temperate climates after the dormant period of winter. The critical scientific man will therefore ask, "Are there not other agencies than chilling which will start dormant trees and shrubs into growth even in our latitude?" It must be said in reply that there are. And it will be worth while to consider some of these causes, for not only are they of interest in themselves but also, instead of weakening the hypothesis here presented, they serve to strengthen and confirm it.

The data may best be presented through a series of illustrations.

The pruning of a long-dormant plant will often start it into growth (Pl. 25, A). Girdling produces a similar result (Pl. 25, B, at left). Notching the stem does the same (Pl. 25, B, at right). Rubbing the stem also starts the plant into growth (Pl. 26).

In all these examples of the stimulation of growth by injury it is conceived that the enzym is brought into contact with the starch as a direct result of the breaking and straining of the cells. Sugar is then formed and growth begins.

It should be observed that when a normal chilled plant starts growing it grows from many buds (Pl. 27, A), for the effect of the chilling on sugar formation is general. When a dormant plant starts growing as the result of injury, however, it usually starts, as shown in several illustrations already presented, from a single bud, the one nearest the point of injury. The injury is local, and both the sugar formation and the growth that follows it are local.

We are now brought to the consideration of a phenomenon which I take to be of special significance—namely, the procedure by which the dormant plant starts itself into growth in the absence of chilling. After a blueberry plant has remained dormant at a warm temperature for a very long period, sometimes a whole year, the tips of the naked branches begin to lose their vitality. Just before or just after the death of the tip a single bud, or sometimes two buds, situated next below the dead or dying part starts growing (see Pl. 27, B; 31, A). The new growth of the stem is confined to the one or two buds, just as it was in the case of growth induced by injury. My interpretation of the phenomenon is that, as death approaches, the cell membranes become weakened in much the same way as when chilled, the enzym passes through into the starch storage cells, sugar is formed, and the adjacent bud begins to grow. The process going forward here in a restricted portion of the stem, and due to a local cause, is essentially the same as that taking place generally over the plant, from a general cause, when the plant is chilled.

In the Tropics some plants are able to grow continuously; others become dormant in the dry season and start into growth again at the coming of the rainy season. Tropical plants probably have various methods of coming out of their dormancy, and there is every reason to expect that some of them will be found to accomplish this act in the same way as our long dormant greenhouse plants, by the weakening of their cell membranes. This, I have endeavored to show, is in its effect substantially identical with chilling.

6. THE TWIGS OF TREES AND SHRUBS AFTER THEIR WINTER CHILLING AND THE TRANSFORMATION OF THEIR STARCH INTO SUGAR MAY BE REGARDED AS MECHANISMS FOR THE DEVELOPMENT OF HIGH OSMOTIC PRESSURES WHICH START THE PLANT INTO GROWTH.

Food in the form of starch can not be utilized by a plant directly. The starch must be changed into sugar before it can be used in making new growth. But this transformation does more than make the starch available as food for the growing plant. It serves also to increase the tendency of the cells to swell and enlarge. In the form of starch the material is inert in the creation of osmotic pressures, but when transformed into sugar it becomes exceedingly active. According to the rigid experimental tests of H. N. Morse and his associates, a normal solution of cane sugar at 32° F. has an osmotic power of 25 atmospheres of pressure. It has been demonstrated that there sometimes occur in the cells of plants osmotic pressures as high as 30 atmospheres, or 450 pounds to the square inch, a pressure sufficient to blow the cylinder head off an ordinary steam engine. It can hardly be questioned that these or even much lower osmotic pressures take an important part in forcing open the buds of once dormant plants.

We have evidence that there sometimes arise within the plant osmotic pressures of such intensity as to threaten the rupture of the cells. Consider the case of the exudation of drops of sugar solution from certain specialized glands. When this exudate of sugar occurs in flowers it is known as nectar, and it serves a useful purpose to the plant by attracting sugar-loving insects which unconsciously carry pollen from flower to flower and accomplish the beneficial act of cross-pollination. But sugar solution is often exuded outside the flower, in positions, or at times, that preclude any relation to cross-pollination. For example, a blueberry plant during its spring growth, when a leaf has reached nearly full size, is sometimes observed to exude drops of sugar solution from certain glands on the margins of the leaf and on the back of the midrib (Pl. 28). It is physically impossible for the sugar to have left the cells by osmosis. The sugar serves no useful purpose to the plant through the attraction of insects. The exudate certainly can not represent the elimination of a waste product, for sugar is one of the substances most used by plants in forming new tissues. I can conceive of no reason why the plant should exude sugar except to relieve a dangerous physiological condition—namely, the development of excessive osmotic pressures which would burst the cells of the plant or in some other way derange its physiological activities. I look upon such sugar glands as safety valves for the relief of excessive osmotic pressures that are dangerous to the internal economy of the plant. And not only is this conception applicable to extra-floral nectaries in general, but it may serve also, in the case of floral nectaries, to explain their origin. Having once arisen as osmotic safety valves, the usefulness of the floral nectaries as an aid to cross-pollination would then tend strongly to bring about their natural selection and perpetuation.

7. THE ESTABLISHMENT OF A DORMANT CONDITION BEFORE THE ADVENT OF FREEZING WEATHER AND THE CONTINUATION OF THIS DORMANCY THROUGH WARM PERIODS IN LATE FALL AND EARLY WINTER ARE PROTECTIVE ADAPTATIONS OF VITAL NECESSITY TO THE NATIVE TREES AND SHRUBS.

A little consideration will show how important the principle of chilling is to those species of trees and shrubs which are subjected each year to several months of freezing weather. If they were so constituted as to start into growth as easily in the warm days of late fall as they do in the warm days of early spring many species would come into flower and leaf in those warm autumn spells that we call Indian summer, and the stored food that the plant required for its normal vigorous growth in the following spring would be wasted in a burst of new autumn growth, which would be killed by the first heavy freezes and would be followed by a winter of weakness and probable death. But when two or three months of chilling are necessary before a newly dormant plant will respond to the usual effect of warmth, such plants are protected against the dangers of growth in Indian summer. It is probable that all our native trees and shrubs are thus protected.

Any member of this audience may make a simple and instructive experiment next fall and winter with such early spring blooming plants as alder, hazelnut, pussy willow, yellow bush jasmine, forsythia, Japanese quince, peach, and plum. In mid-autumn bring into your living room and set in water freshly cut, dormant, leafless branches of these plants. They will not bloom. At intervals of a few weeks during late autumn and winter try the same experiment again. You will find that the branches cut at later dates will come into bloom under this treatment. They will not do so, however, until the expiration of the period of chilling appropriate to the various kinds of plants included in the experiment. The required period of chilling varies greatly. For some of the cultivated shrubs about Washington, especially the yellow bush jasmine (*Jasminum nudiflorum*), so brief a period of chilling is required that an extraordinarily cold period in late October or early November may chill them sufficiently to induce them to bloom if a period of warm weather follows in late November. The period of chilling required for the peach is so short that in Georgia unusually warm weather in December sometimes brings the trees into flower, and their crop of fruit is destroyed by the freezes that follow.

From these facts it appears that our native trees and shrubs are so intimately adjusted to the changes of the climate to which they have been long subjected that they are almost completely protected from injury by freezing, but some of the cultivated species brought from parts of the world having a climate different from ours are only imperfectly adapted to our climatic changes. They grow at times when our native species have learned to hold themselves dormant, and they often suffer severely in consequence.

Chilling, as a protective adaptation, has become a physiological necessity in the life history of cold-winter trees and shrubs. So fixed indeed, is the habit that it appears to be a critical factor in determining how far such plants may go in the extension of their geographic distribution toward the Tropics. In the Tropics our common northern fruit trees, apples, pears, peaches, cherries, grow well for a time and then become half dormant. In the absence of chilling they never fully recover from their dormancy; they grow with weakened vitality and finally die. If these fruits are to be grown successfully in the Tropics they must be given artificially the periodic chilling they require.

When it became evident from the earlier observations and experiments that chilling played so essential a part in the behavior of our trees and shrubs, it was clear that additional experiments ought to be conducted in which actively growing plants might be subjected to chilling temperatures without being put in a dark place like the ordinary refrigerator. To meet the requirement of both cold and light a glass-covered, outdoor, brick chamber was constructed in 1912. It was kept above freezing by heating with electric lights, which were turned on and off automatically by a simple thermostat. In summer the chamber was kept cool, though not really cold, by means of ice and electric fans. Although much was learned with this apparatus, it was crude and inadequate. To provide for more exact experiments a glass-covered compartment chilled by a refrigerating machine was constructed in one of the Department of Agriculture greenhouses. The refrigerating apparatus is a sulphur-dioxid machine having a refrigerating power equivalent to 1,000 pounds of ice a day. It is run by a 2-horsepower electric motor, and it furnishes ample refrigeration for the lighted compartment, which is a glass-covered frame 25 feet long, 3 feet wide, and 14 to 20 inches in depth. The first of these refrigerated frames was devised and constructed in 1916. In this enterprise I had the valued advice and assistance of Dr. Lyman J. Briggs. The usefulness of this refrigerated frame in experimental work with plants was so great that another similar equipment was installed in 1918.

With the aid of this apparatus many of the experiments described in this address have been carried on or verified, as well as other experiments of a related character. For example, at ordinary summer temperatures many kinds of seed will not germinate but remain dormant until death overtakes them. Under the influence of chilling, however, these seeds are stimulated to prompt germination. (See Pl. 29.)

The experiments thus far made indicate the importance of a much wider use of the principle of chilling in many lines of experimentation bearing on the improvement of horticultural and agricultural practices. I commend the subject of chilling to experimenters in these lines, and I wish to call especial attention to the desirability of determining proper temperatures for the storage of seeds, bulbs, cuttings, and grafting wood, proper temperatures for the treatment of plants which are to be forced from dormancy to growth at unusual seasons, and proper temperature for the storage of nursery stock so that the nurseryman may have plants in proper condition for shipment on any date he desires. (See Pl. 30; 31, B; 32.)

The whole question of the effect of chilling on herbaceous perennials is an open field.

An understanding of the process of chilling explains the reason of some of the practices of gardeners, which they as well as botanists have erroneously ascribed to the need of "resting." What a gardener calls "resting" is often in reality a period of chilling, characterized not by physiological rest but by pronounced internal activity. Rest alone would not, in the case of our cold-climate trees and shrubs, accomplish the purpose the gardener has in mind. It is chilling, not rest merely, that is required. The practice of gardeners and nurserymen known as the "stratification" of seeds is probably to be explained as in reality a process of chilling.

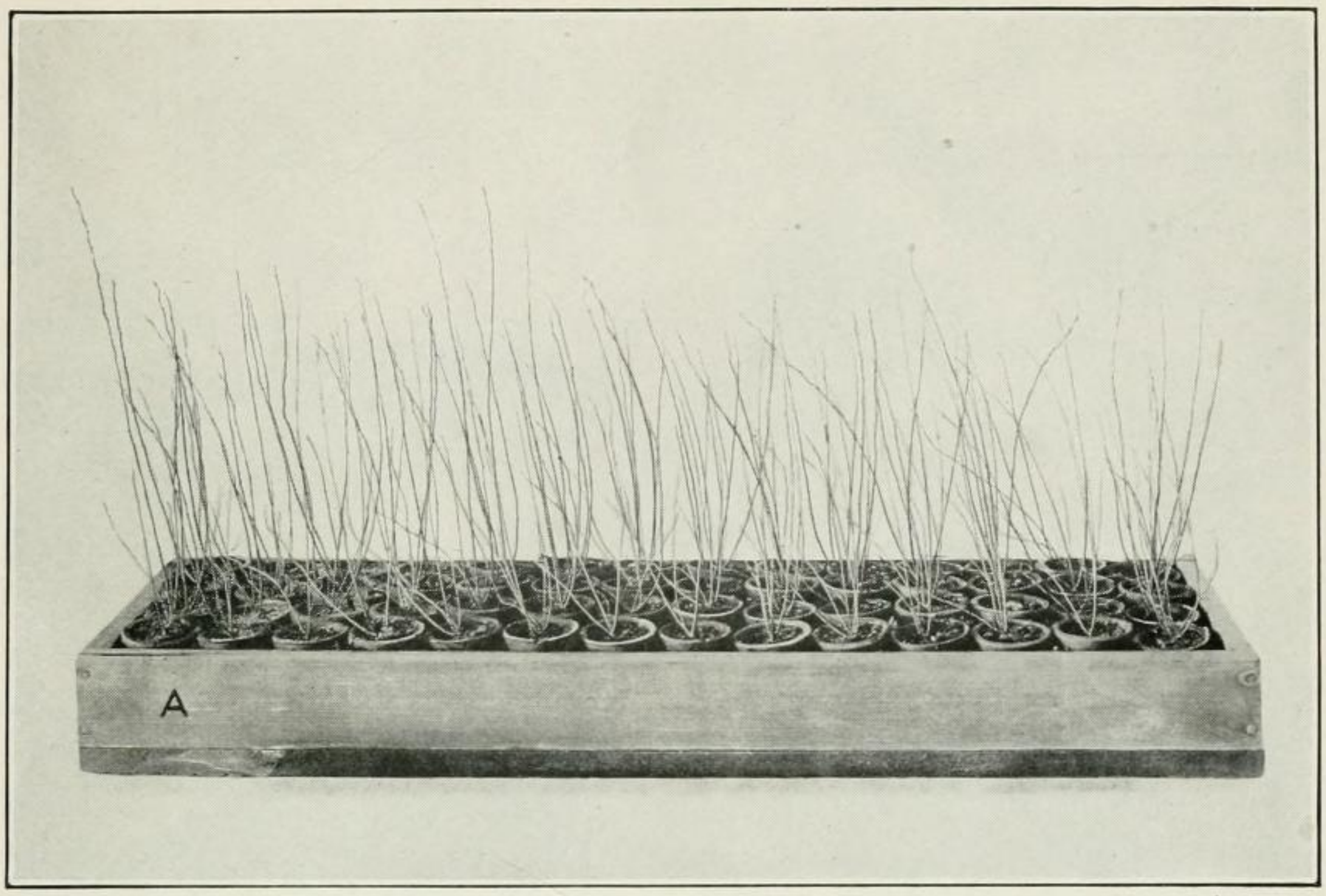
As a single example of the application of the principle of chilling let me cite the case of the blueberry. For several years we have been trying at the Department of Agriculture to domesticate this wild plant. We have raised many thousand hybrids and have set them out in waste sandy lands in the pine barrens of New Jersey (Pl. 33, A). We have grown the bushes to fruiting age and have brought them into highly productive bearing (Pl. 33, B). We have made them fruit so lusciously and so abundantly that they have brought returns to the grower at the rate of more than $1,000 an acre. In a word, we have changed the blueberry from a small wild fruit the size of a pea to a fruit the size of a Concord grape, and we have made its culture a profitable industry. (See Pl. 34, 35.) These things we should not have been able to do unless we had first worked out the principle of chilling, an understanding of which was essential to our work of breeding and propagation.

In conclusion, I wish to express the opinion that the chilling of dormant trees and shrubs of temperate climates as a prerequisite to their resumption of normal growth in the spring ought to be recognized in books on plant physiology as one of the normal processes in plant life. These works should contain chapters on chilling, just as they now contain chapters on other fundamental factors and principles relating to the life history of plants. And especially in books on plant physiology in relation to agriculture should the subject of chilling be dealt with in detail, for when in the pursuit of agriculture we take plants from one part of the world to another, or undertake to grow them out of season, or attempt to propagate them in quantity by grafting or by other processes unknown in nature, we are greatly handicapped and limited in our operations if we do not understand the principles of a process so widely existent in nature and so indispensable to a large proportion of the plants of temperate agriculture as the process of chilling.

PLATE 20

A.—Blueberry plants, *Vaccinium corymbosum*, made dormant without cold. These blueberry seedlings, in 2-inch pots, were kept during the fall and winter in a greenhouse at a temperature of 55° to 70° F. Although this is a very favorable temperature for the growth of the blueberry, these plants shed their leaves and became completely dormant, just as they ordinarily do when exposed to the frost and cold of an outdoor fall and winter. The photograph was taken on January 25.

B.—Chilled and unchilled blueberry plants. The six blueberry plants at the left, after an outdoor winter chilling, were brought indoors on March 25, into a greenhouse having a temperature of 55° to 70° F., and were repotted. On April 20, when the photograph was taken, they had developed both leaves and flowers, while the six plants at the right, which had been in the same greenhouse at the same temperature all the fall and winter and were repotted on the same date as the others, were still completely dormant.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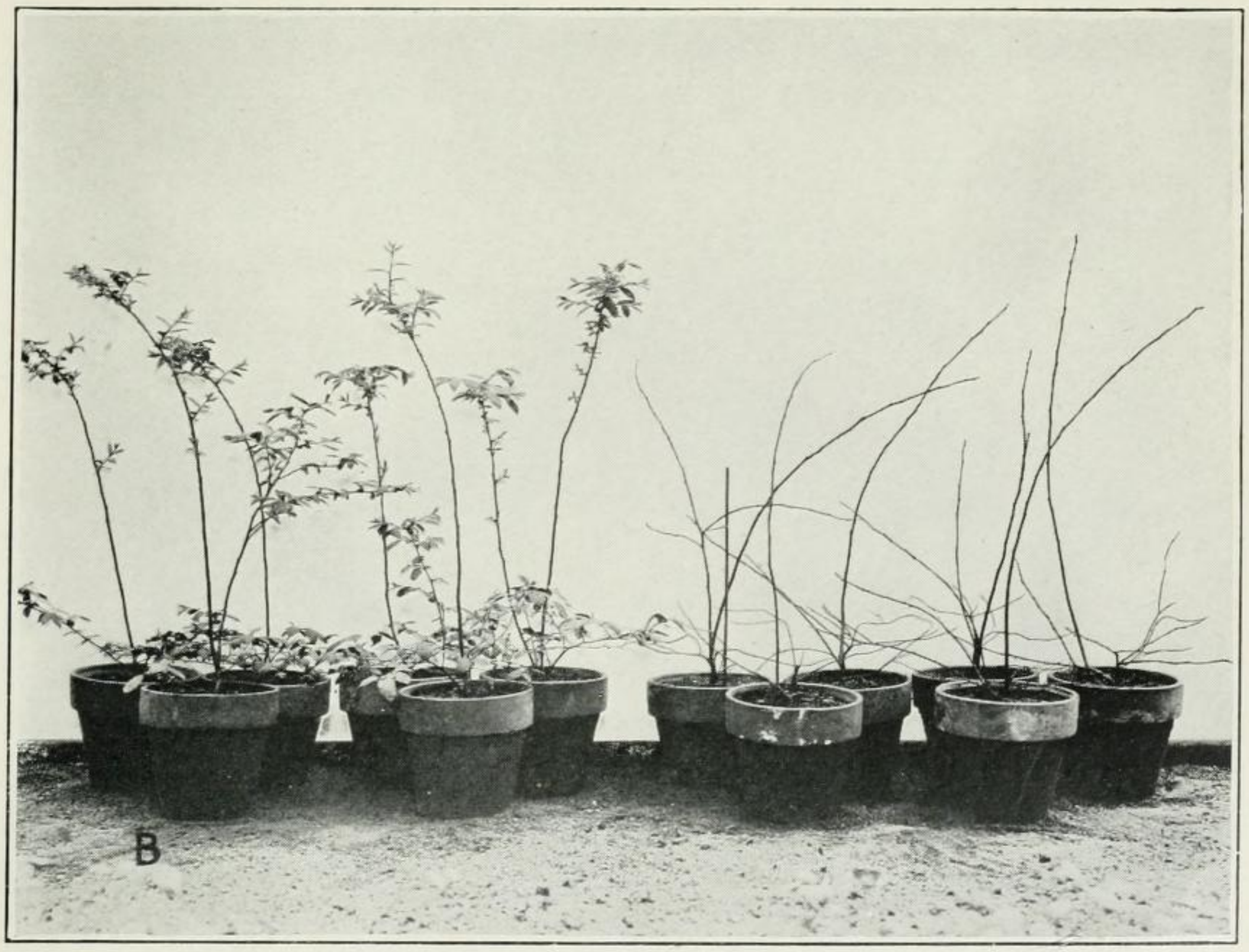
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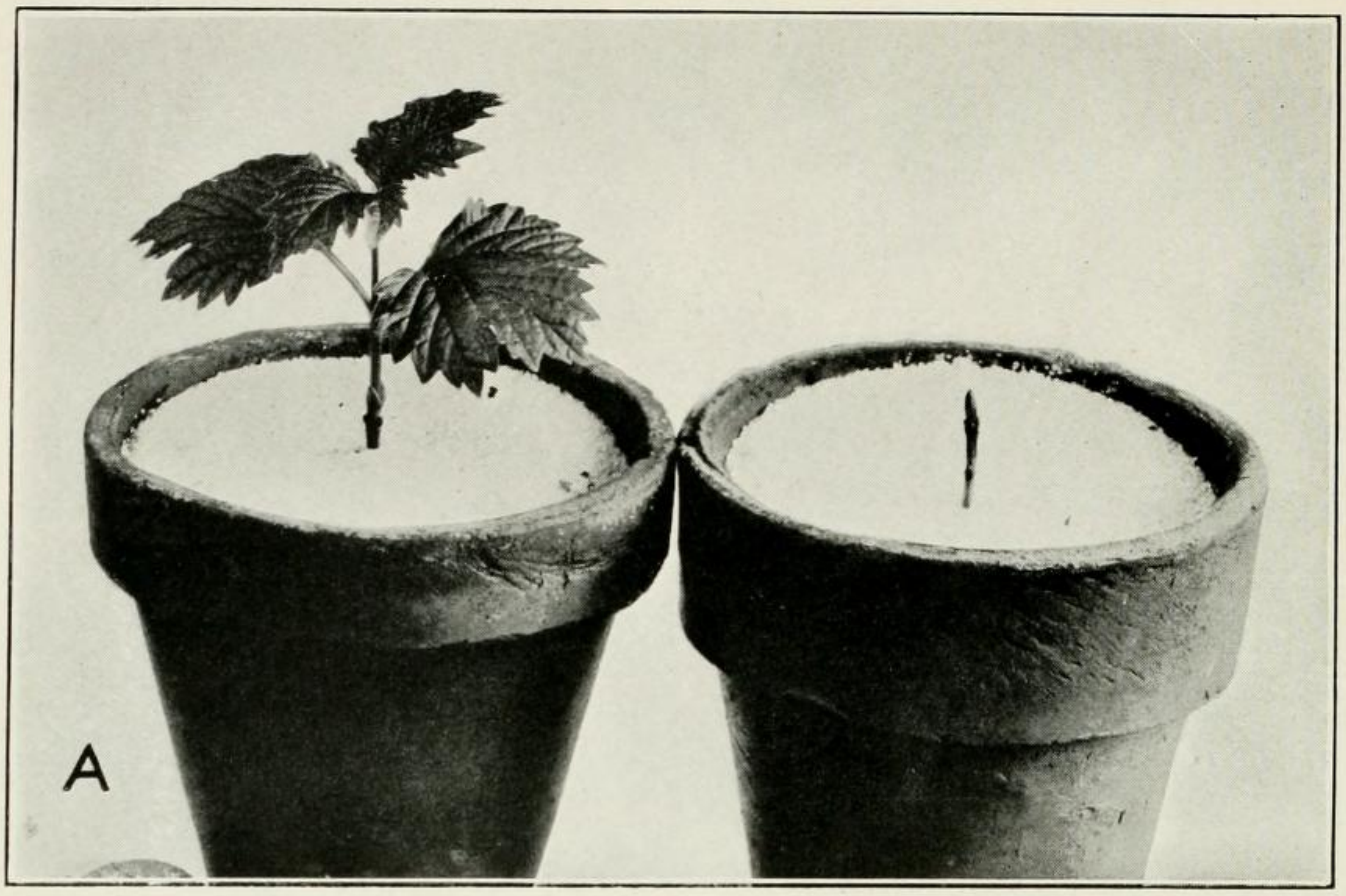


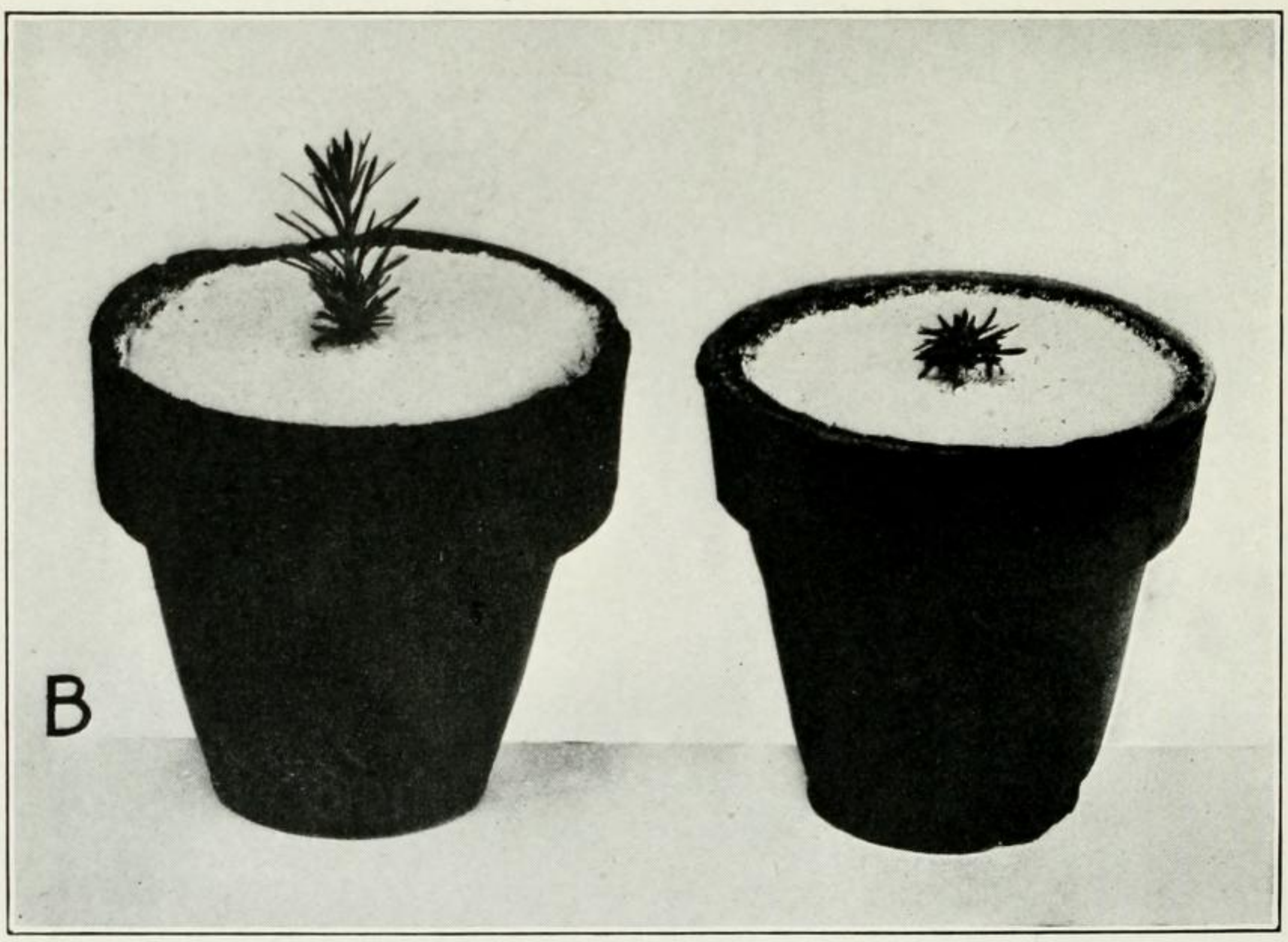


PLATE 21

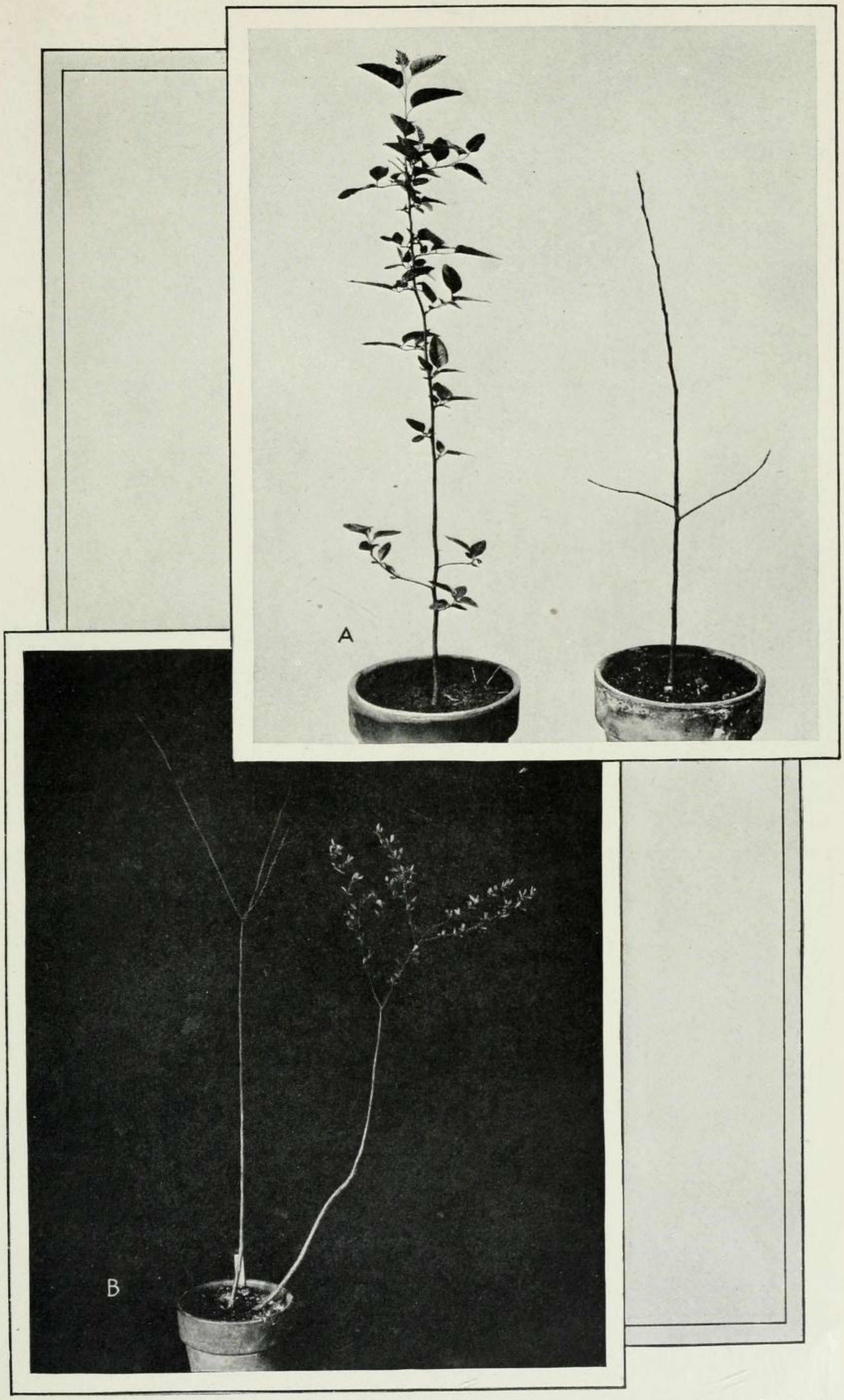
A.—Chilled and unchilled plants of grouseberry, *Viburnum americanum*. The illustration shows two 1-year-old seedlings with the same history, except that the one at the right was kept during the winter in a warm greenhouse at a temperature of 55° to 70° F., while the one at the left was wintered in a cold greenhouse at a temperature of 32° to 40°. When spring temperatures warmed up this coldhouse, the plants in it began to grow, and on April 7, 1914, when the photograph was taken, they had reached the stage shown in the left-hand figure, while the plants in the warmhouse, as illustrated by the right-hand figure, were still completely dormant.

B.—Chilled and unchilled plants of tamarack, *Larix laricina*. These two seedlings, grown from seed procured in Alaska, have had the same history except that the one at the left was wintered in a cold greenhouse at a temperature of 32° to 40° F., the one at the right in a warm greenhouse at a temperature of 55° to 70°. When the photograph was taken, on April 10, 1914, the chilled plant had put out new growth in the warm spring weather, while the unchilled plant still showed only its leaves of the year before.

PLATE 22

A.—Chilled and unchilled plants of wild crab, *Malus coronaria*. The plant at the left had been outdoors during the fall and winter, leafless and dormant, exposed to the frost and cold. The plant at the right had been in the warm greenhouse during the fall and winter at a temperature of 55° to 70° F. When the outdoor, chilled plant was brought into the greenhouse in early spring, it promptly began to put out new leaves and twigs, but the indoor, unchilled plant continued its dormancy. The photograph was taken April 24, 1917.

B.—Blueberry plant with one branch stimulated to growth by cold. The right-hand branch has been stimulated to growth by chilling; the left-hand branch has been kept dormant by heat. For a detailed description of this experiment see p. 152–153.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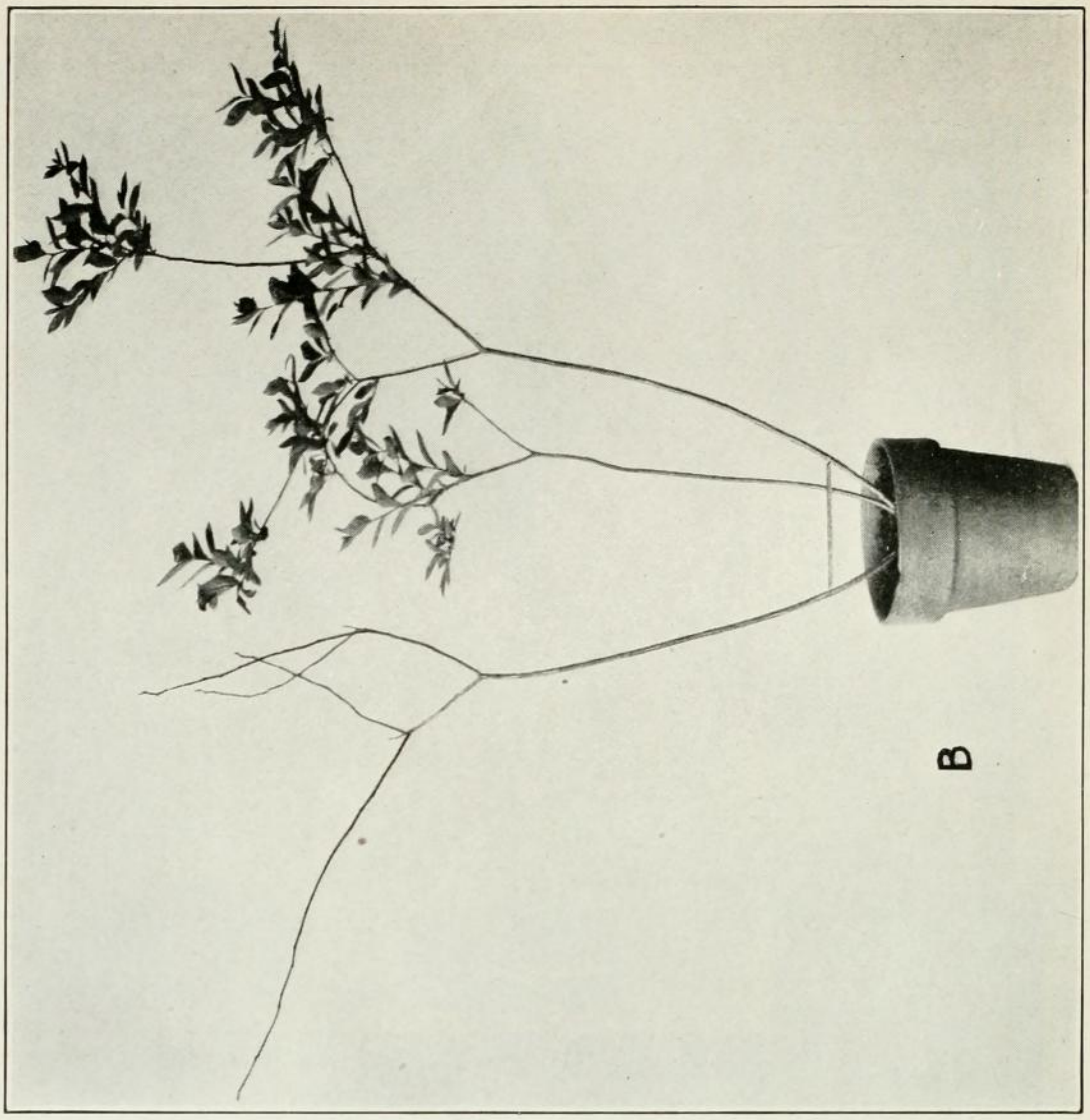
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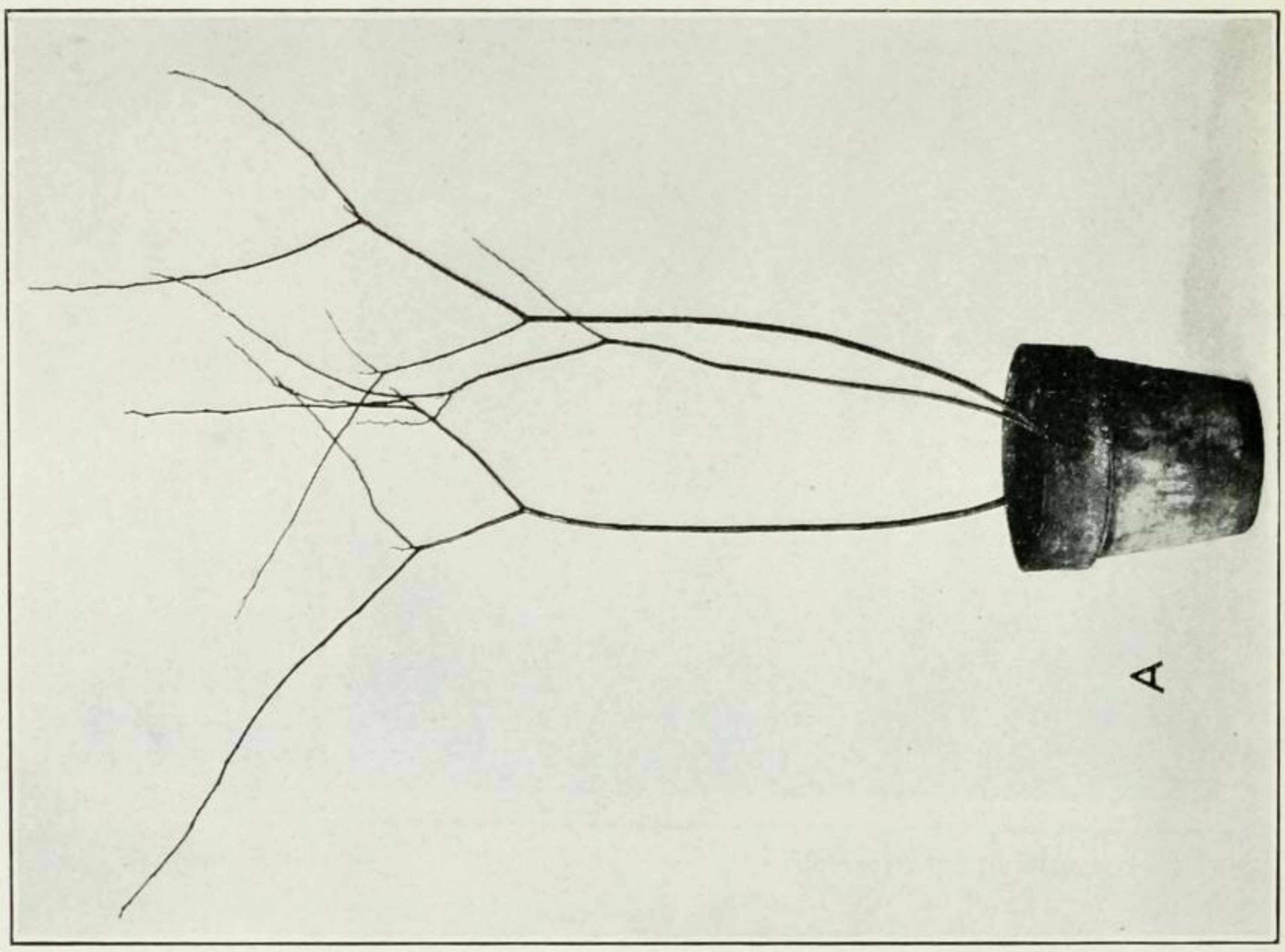
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PLATE 23

Blueberry plant with one branch kept dormant by heat.

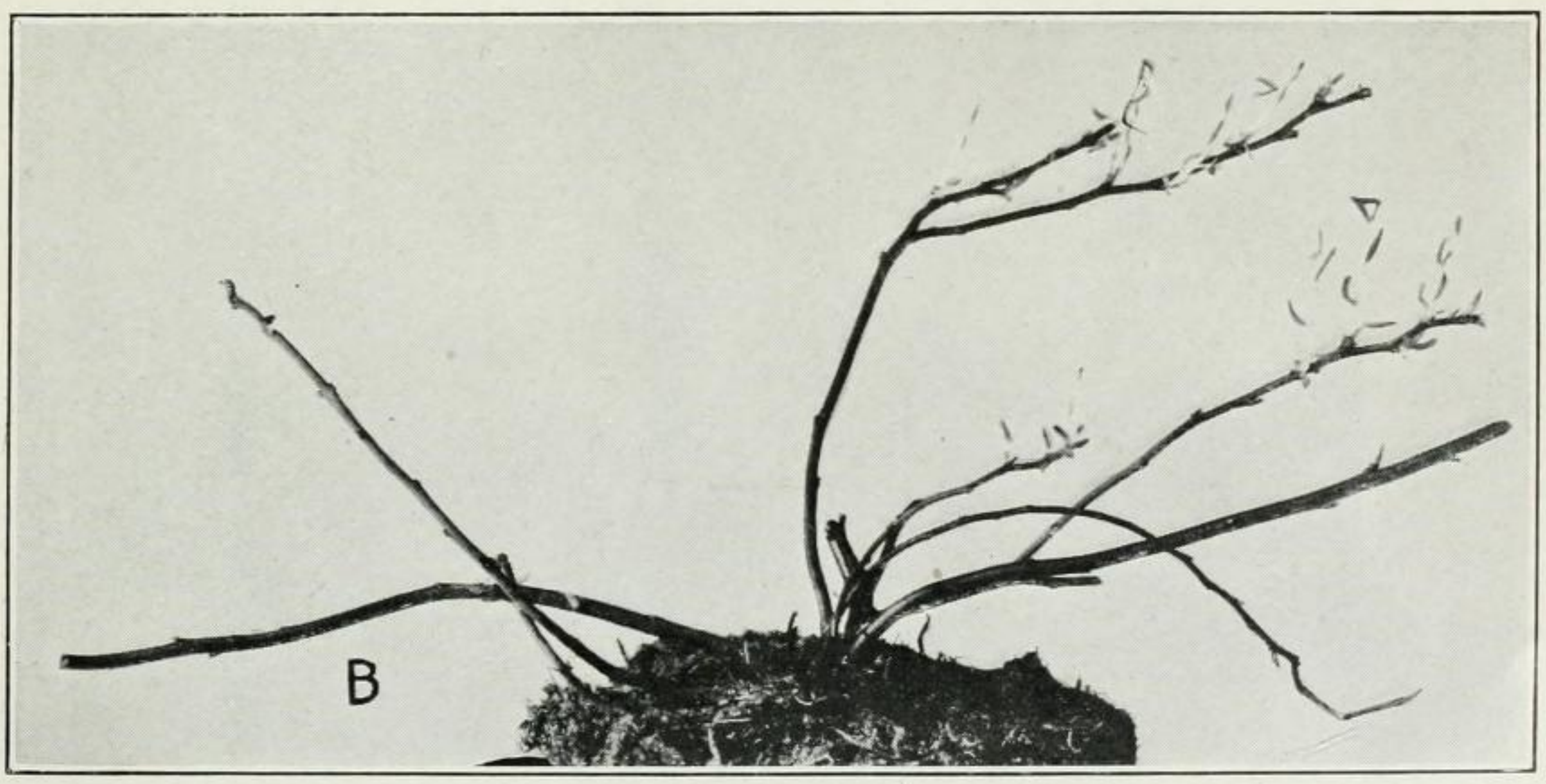
A.—Dormant indoor blueberry plant as it appeared on February 15, 1912. On that date the pot containing the plant was placed on a shelf outside a greenhouse, and a single branch was passed through the glass wall into the warm interior.

B.—Same plant photographed May 21. When spring came, all the outside branches, which had been chilled, burst into normal leaf, while the branch inside the greenhouse, which had been kept warm, still remained dormant.

PLATE 24

A.—Blueberry cuttings starting to grow at 36° F. These cuttings were placed in cold storage while still completely dormant. Although the temperature did not go above 36° F., buds on each of the cuttings finally began to grow. It is to be noted that although growth took place in the buds the other kind of growth which results in the formation of a callus, or healing-over tissue, at the severed base of the cutting is wholly lacking. Callusing can not take place at so low a temperature.

B.—Blueberry plant growing in the dark at 36° F. This plant was in cold storage in the dark in a commercial refrigerating establishment from March 30 to December 4, 1915. The temperature ranged from 33° to 36° F. Some of the plants in this experiment made new growth to the length of 32 mm.



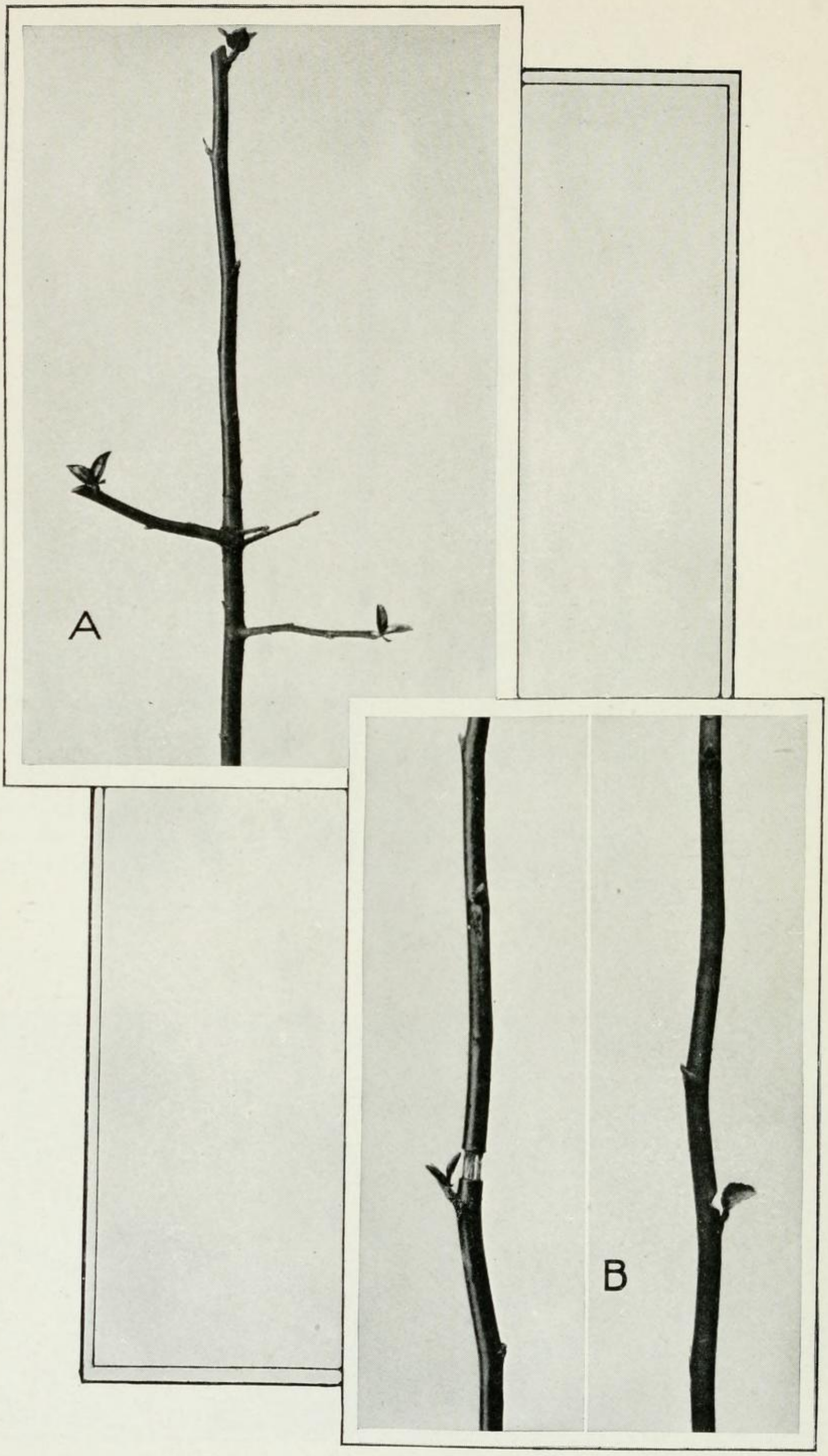

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PLATE 25

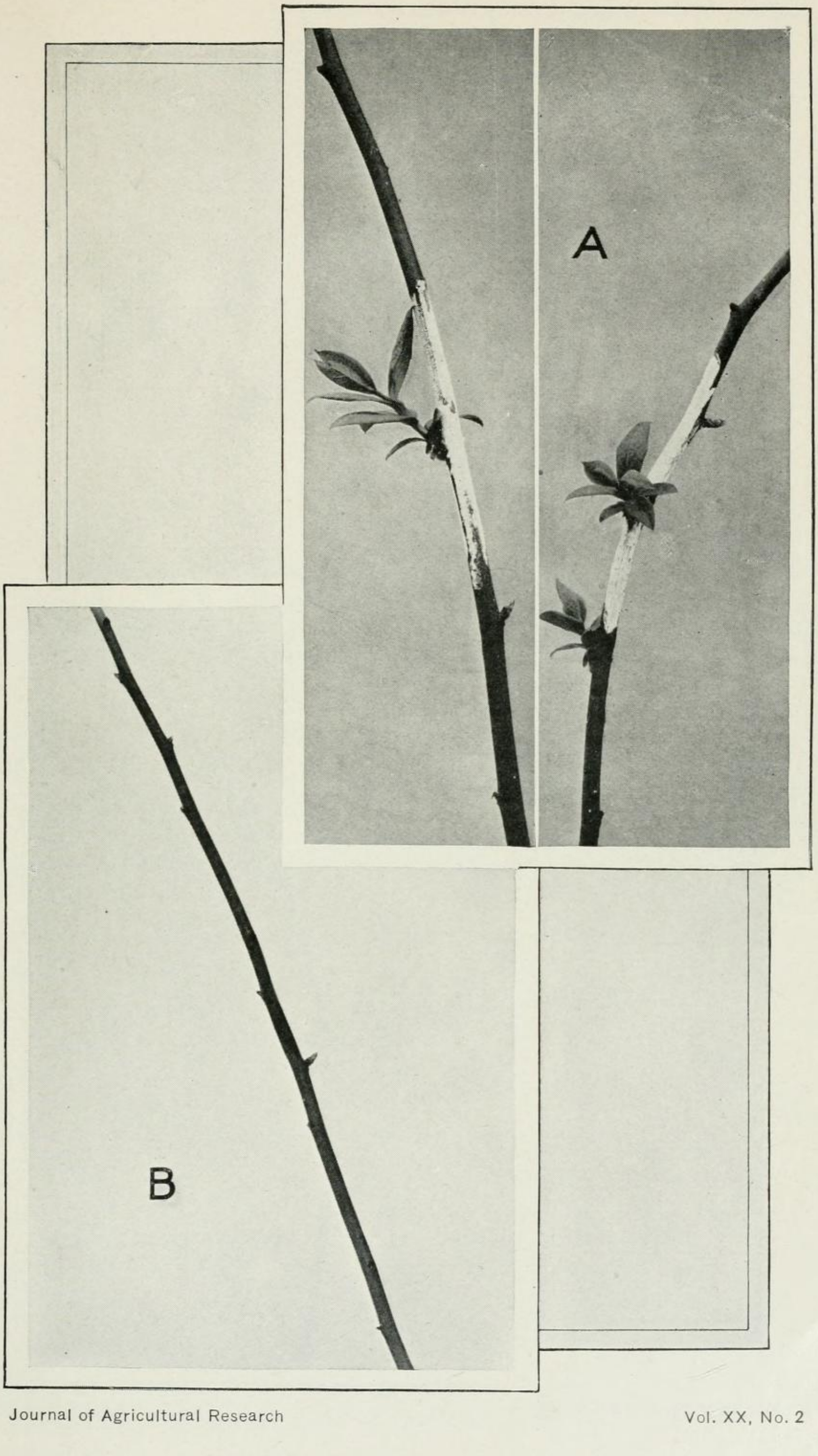
A.—Dormant wild crab stimulated to growth by pruning. This plant had remained dormant in the warm greenhouse during the fall and winter at a temperature of 55° to 70° F. On April 5 three branches were pruned, and on April 24, when the photograph was taken, the uppermost bud on each of the pruned branches had begun to grow. On other, unpruned plants no bud growth had taken place.

B.—Dormant wild crabs stimulated to growth by girdling and by notching the stem. These plants had had the same preliminary treatment as the one illustrated in A—that is, they had been kept in the warm greenhouse all winter, without chilling. On April 4 a ring of bark was removed from the plant shown in the left-hand figure, and the soft cambium was carefully scraped away, down to the hard wood. On April 24, when the photograph was made, the bud next below the girdle had begun to push. The stem of the right-hand plant was notched in early April. The bud next below the notch soon began to grow. The photograph was taken on May 2.

PLATE 26

A.—Dormant blueberry buds stimulated to growth by chalking the stem. This plant was brought into the greenhouse February 4, 1913, to be used in breeding experiments. It flowered, but since it had been insufficiently chilled only a few of the uppermost leaf buds on each stem grew. In order to keep small ants from crawling up the stems and interfering with the pollination experiments the stems were chalked near the middle. The dormant buds in and just below the chalked areas started growing. The photograph was taken April 5, the stems being rechalked over the same areas that were originally chalked. After numerous repetitions of the experiment it was found that if the chalking was done lightly the buds would not grow, but if the stems were rubbed hard in the process of chalking, as commonly happened in the case of very smooth stems, the buds grew. It was the hard rubbing, not the chalk, that stimulated the growth.

B.—Dormant blueberry bud stimulated to growth by rubbing the stem. The photograph, which was taken June 14, 1913, shows a single bud starting into growth on a dormant blueberry plant. The dark area just above the bud is a brown band on an otherwise green stem. It shows the position of a rubbing that was given the stem with a smooth knife handle a few weeks earlier. This bud afterwards grew into a long, vigorous branch, while all the other buds remained dormant.


A
B

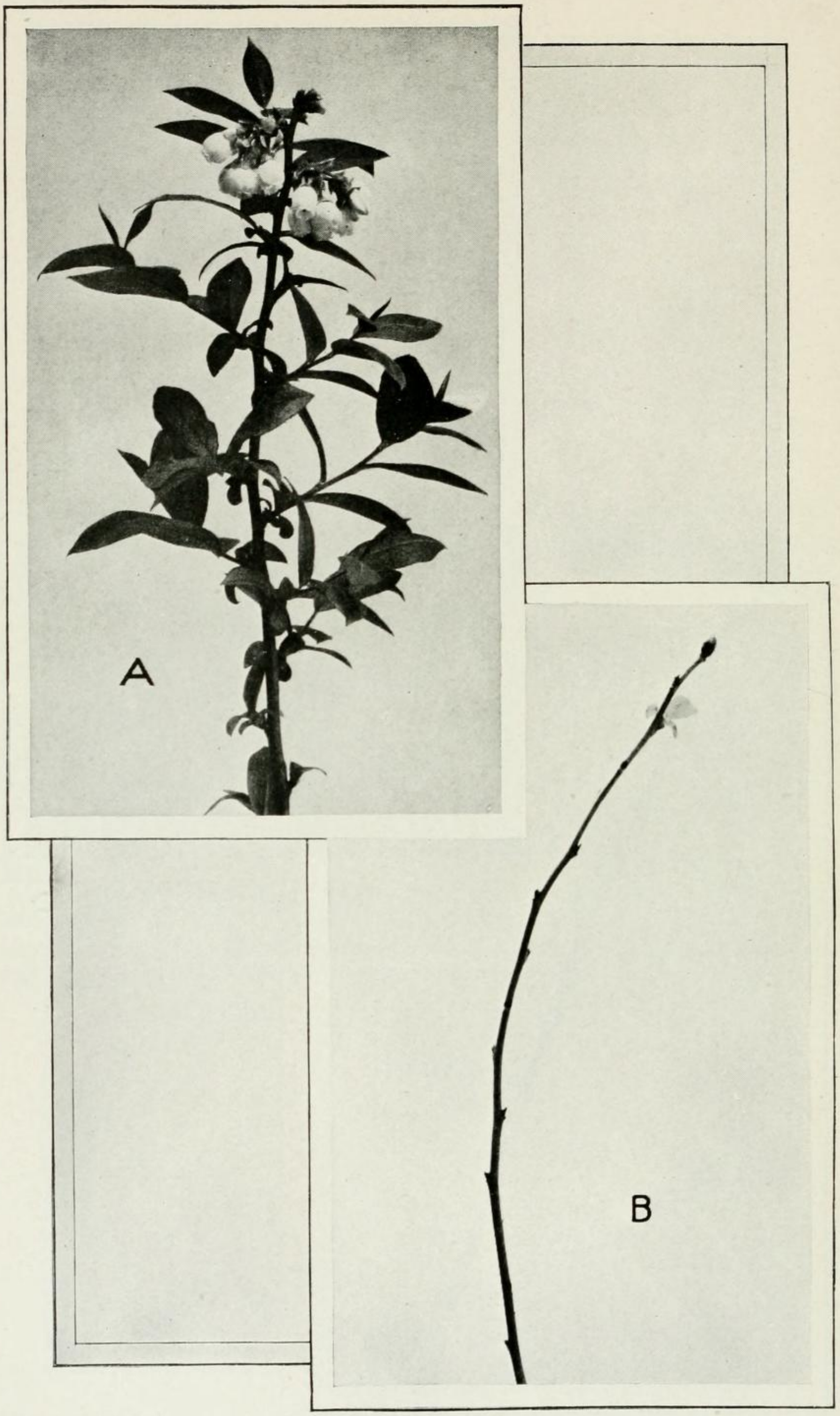

A
B

PLATE 27

A.—Normal spring growth on a blueberry stem. This illustration is from a photograph taken April 24, 1909. In the preceding season the plant had sent up an unbranched shoot. After an outdoor chilling through the winter and early spring it put out flowers and new twigs as shown in the illustration. The fact to be especially noted is that the new growth on this stem took place from numerous buds.

B.—Abnormal spring growth on a blueberry stem, due to lack of chilling. This photograph was taken on May 19, 1913. Growth is taking place from only one bud, the third from the tip. The uppermost bud is a flowering bud, the second a leaf bud. Both are dead or dying. This plant had stood in the warm greenhouse all winter and spring. If it had had the usual two to three months' chilling its starch would have been transformed into sugar and the stem would have flowered and put out new twig growth from numerous buds in the same manner as the stem shown in A.

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PLATE 28

Blueberry leaf exuding sugar from glands interpreted as osmotic-pressure safety valves.

This is a leaf of the highbush blueberry, *Vaccinium corymbosum.* The photograph was taken May 19, 1916. The sugar-secreting glands, sometimes called extra-floral nectaries, are situated in this plant on the back of the midrib and along the margins of the leaf, toward its base. The drops of sugar solution have been wiped away from the glands on the left-hand margin and from two glands on the midrib at the base of the second and fourth lateral veins above the sugar drop shown near the middle of the picture. × 4.

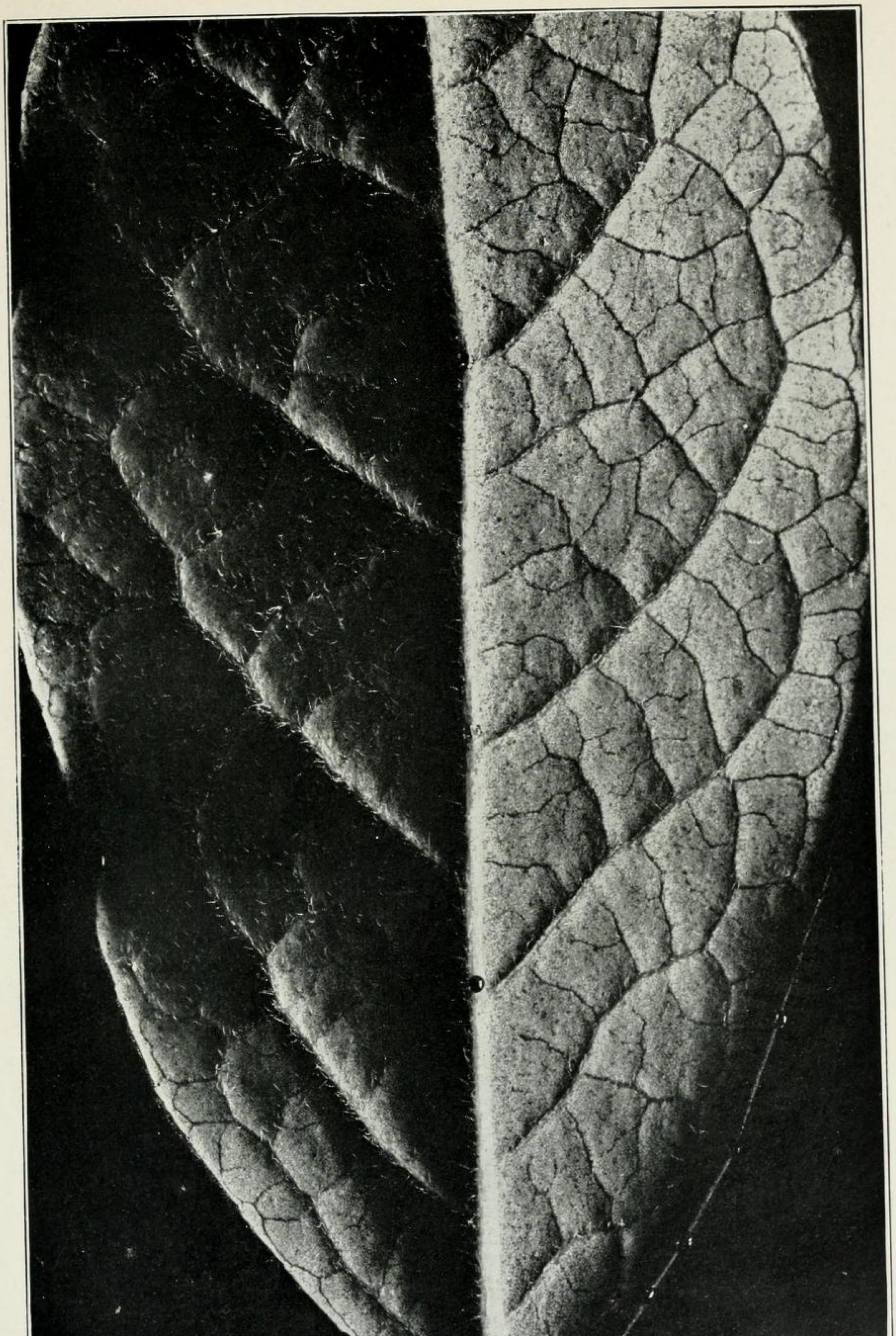


PLATE 29

A plant of bunchberry, *Cornus canadensis*, the seeds of which do not germinate without chilling.

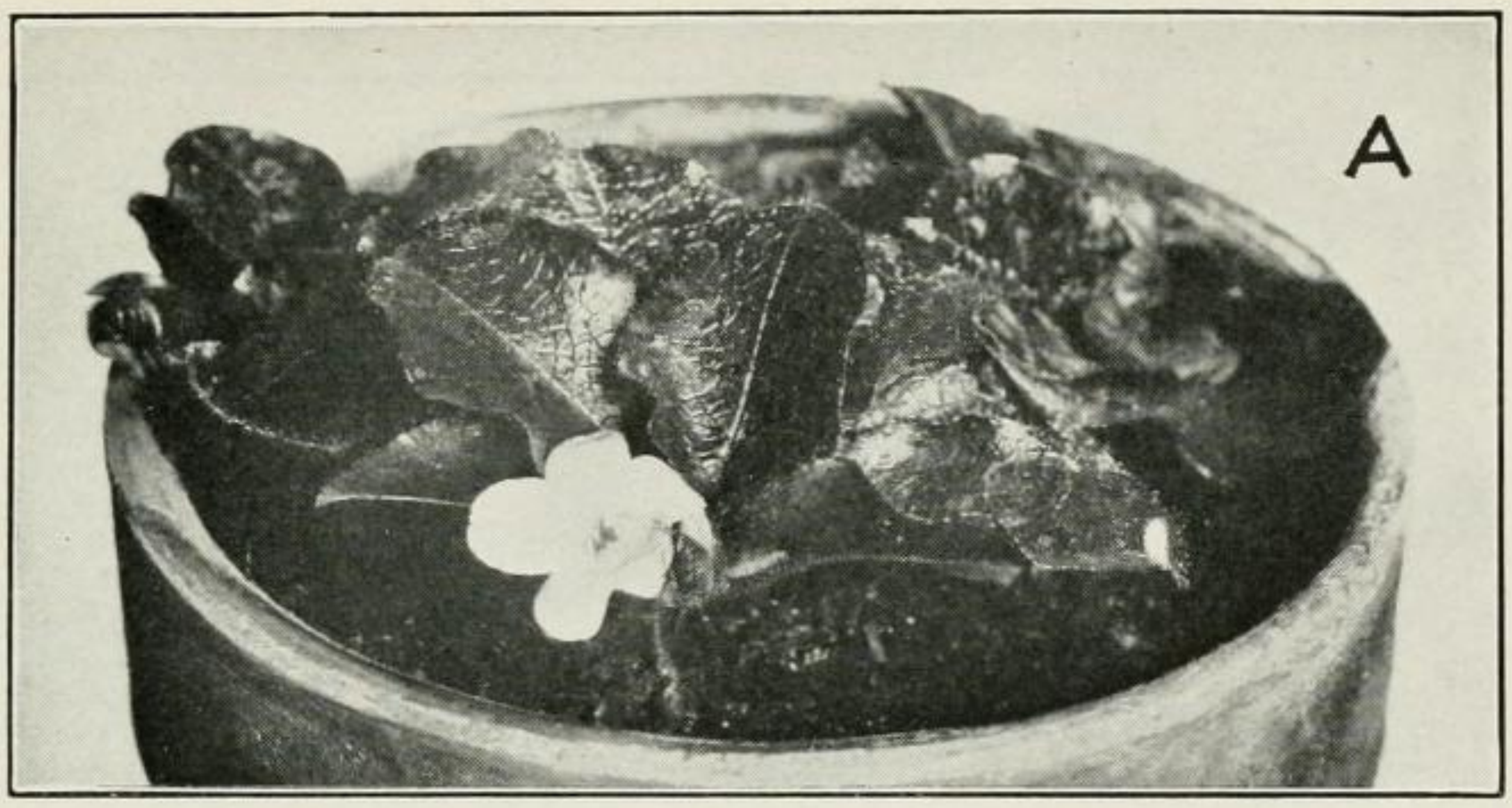
Bunchberry seeds sown October 9, 1912, and chilled during the winter germinated promptly the following spring. Another lot of the same seeds sown on the same date but kept in a greenhouse at a temperature of not less than 55° F. showed no germination in 12 months. These seeds were then chilled for 2 months at a temperature of 35° to 40° F., and when brought back into the greenhouse they germinated within a month. The very healthy plant shown in the illustration grew from one of these long-dormant seeds. The exposure of seeds to winter weather is sometimes practiced by gardeners, but they usually attribute its beneficial effect to freezing, which in all the cases tried in these experiments is unnecessary.

PLATE 30

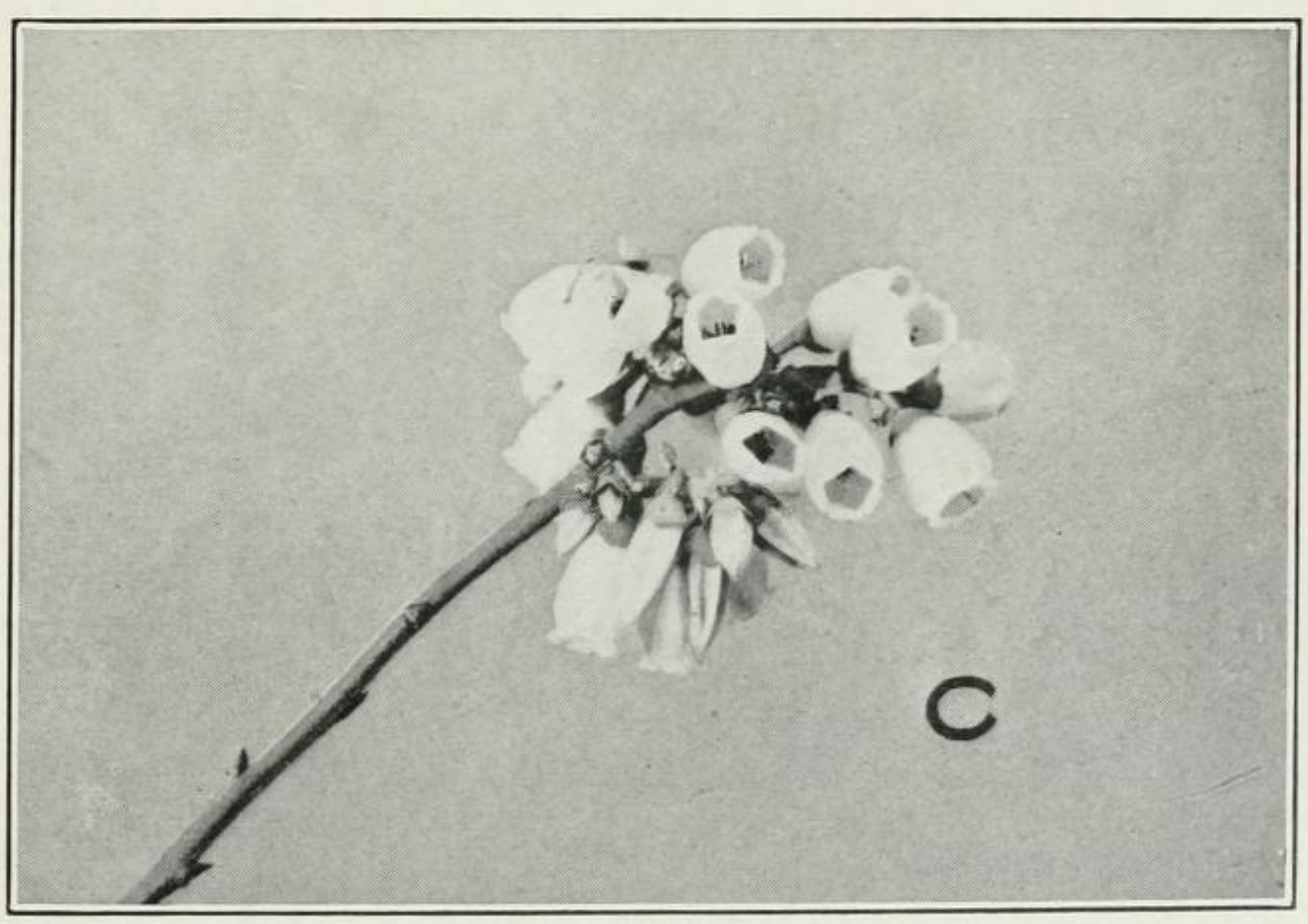
A.—Trailing arbutus, *Epigaea repens*, flowering sparingly from lack of chilling. This plant of trailing arbutus was grown from seed. In the autumn, when about a year old, it laid down clusters of flowering buds. It was kept in a warm greenhouse all winter, but when flowering time came most of its flower buds were dead and brown. Only a single flower opened.

B.—Trailing arbutus plant flowering normally after chilling. This plant had the same history as the plant described under A, except that it was kept outdoors during the winter and brought back into the greenhouse in the spring. At the age of 14 months, when the photograph was taken, March 27, 1911, the plant was in full flower, healthy and normal.

C—Blueberry plant forced into flower in September by artificial chilling. This plant was brought indoors in late winter. It made new growth, and during the cool weather of May it laid down flowering buds for the next year, as a blueberry plant ordinarily does in autumn. During the summer, however, the plant was given an artificial winter by chilling it for three months in an artificially refrigerated glass-covered frame exposed to daylight. When brought out of the frame, in September, the plant promptly flowered, as shown in the illustration.


A


B


C

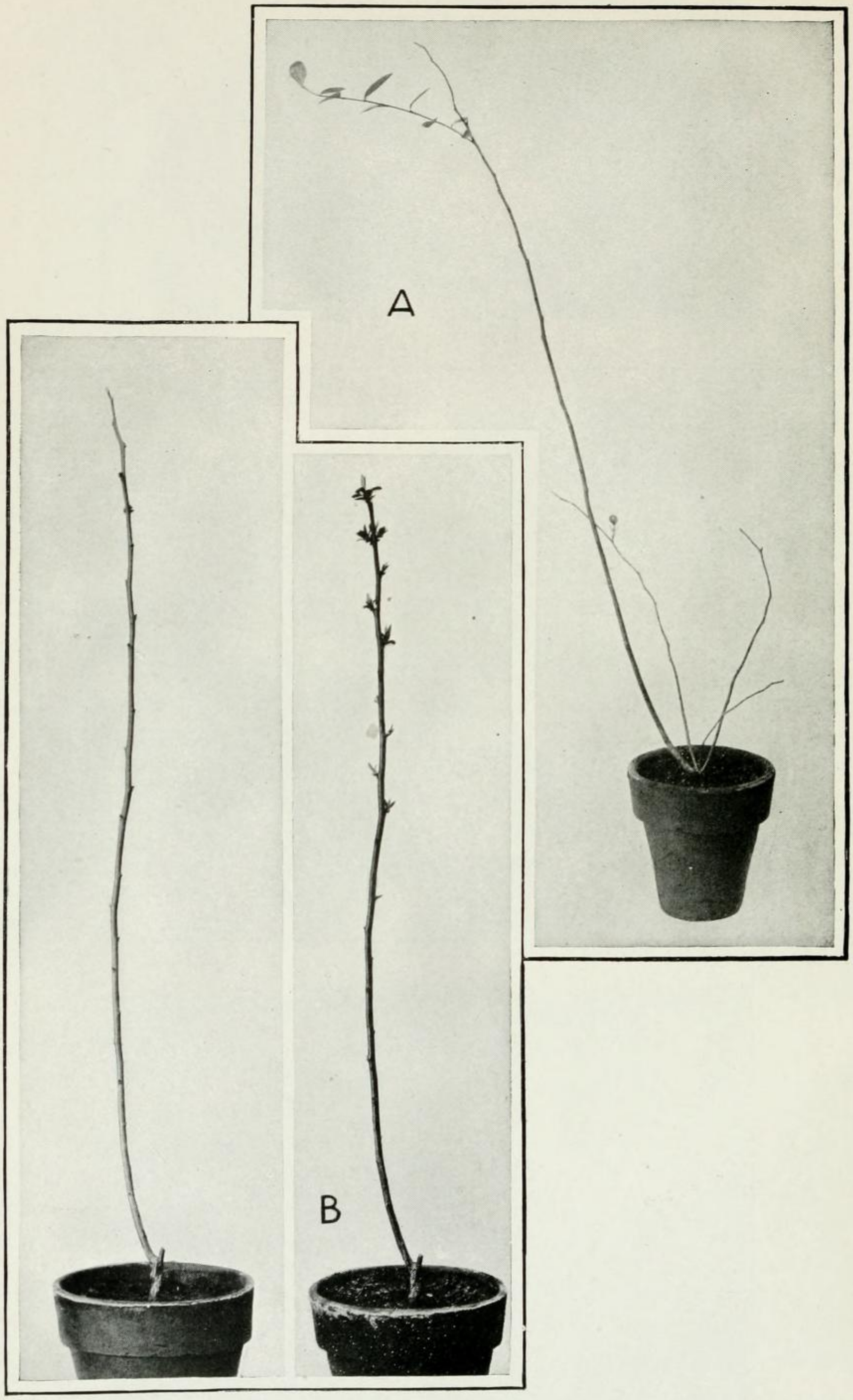

A
B

PLATE 31

A.—Abnormal growth of an unchilled blueberry plant. This plant became dormant in the autumn in a warm greenhouse, and since it was not chilled it continued its dormancy through spring and summer for a period of nine months. Then three of its stems began to die at the tips and, following this, growth began to take place from a single bud next below the dying tip on each stem. For the explanation of this abnormal activity see p. 156. The photograph was taken October 12, 1916.

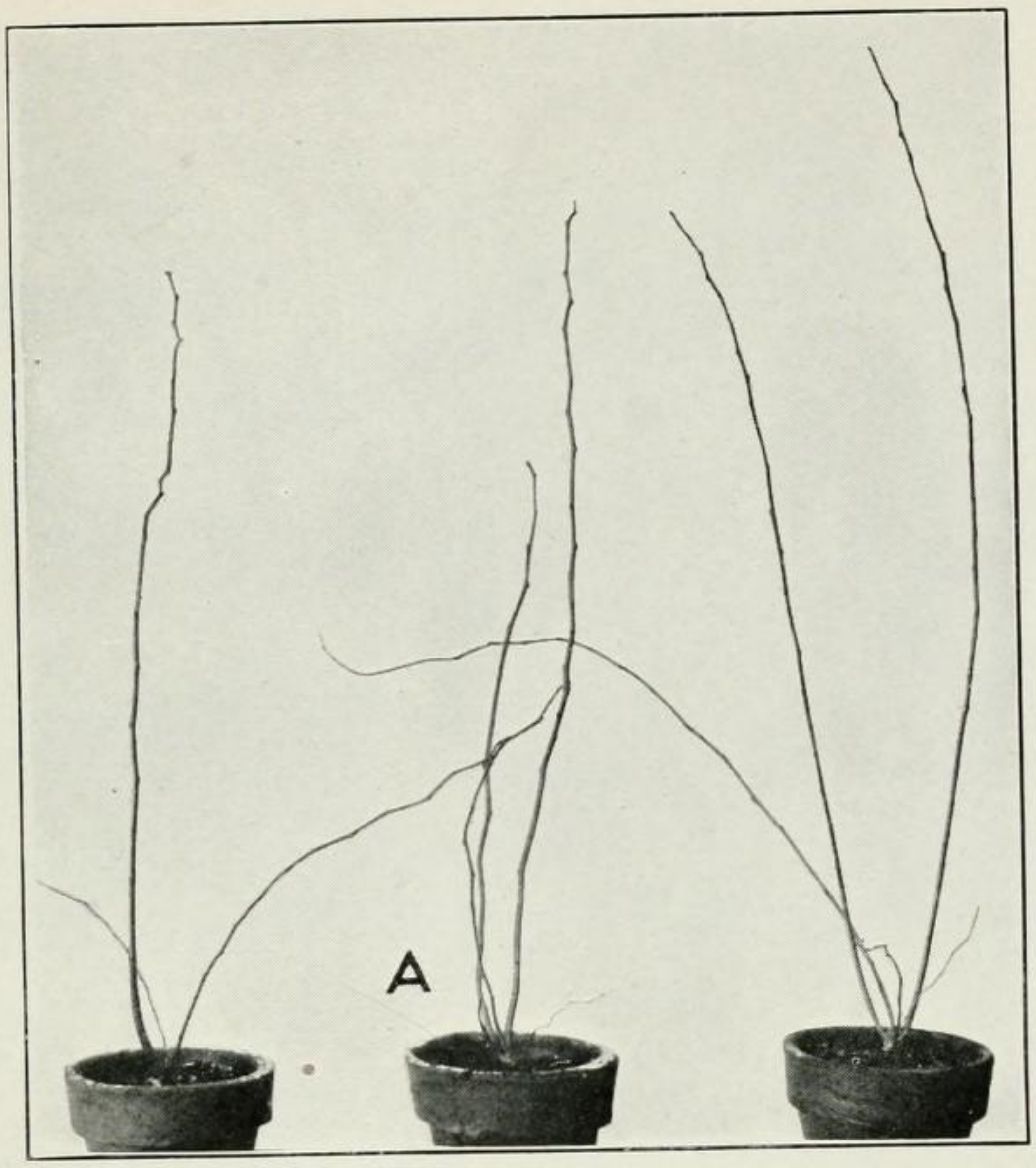
B.—Awakening of long dormant plants by artificial chilling. The illustration consists of two photographs of the same plant. At the left is shown the condition of the plant on December 26, 1916, after more than a year of warmth and dormancy. The figure at the right, from a photograph taken April 27, 1917, shows the appearance of the plant after it had been subjected to artificial chilling for a period of three months and then had been returned to the warm greenhouse. It began to put out new growth from 10 or more of its leaf buds. Even after its extraordinarily long period of dormancy the plant had been brought back to normal activity by a suitable period of chilling.

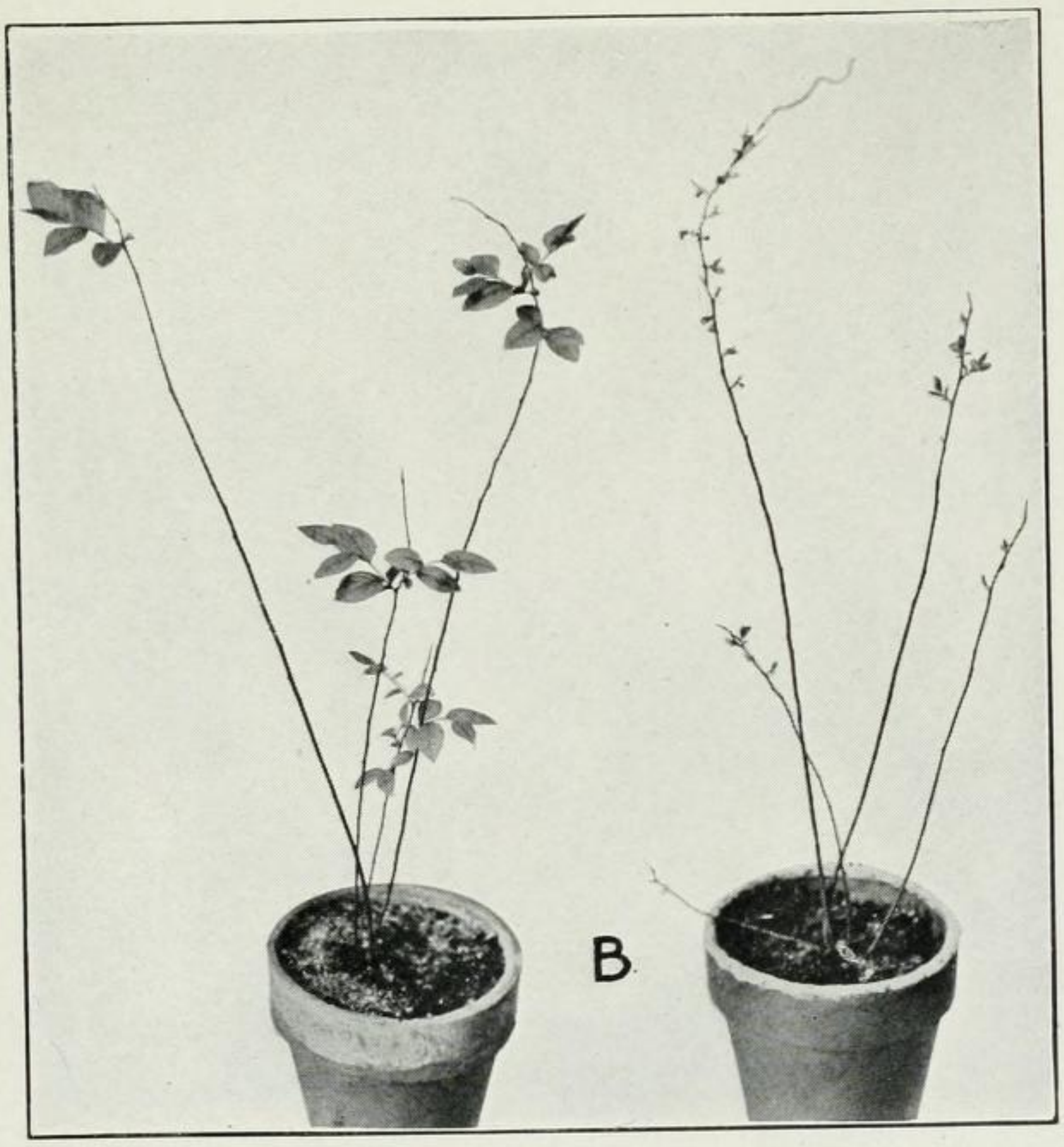
PLATE 32

Plants brought out of dormancy at a specified time.

A.—Blueberry plants from a lot that had been kept in a dormant condition by warmth for nearly a year. On October 30, 1917, plants from this lot were placed under chilling conditions at a temperature of about 35° F. At the end of a month's chilling eight plants were taken out, repotted, and brought into a greenhouse maintained at a temperature of 50° to 70° F., and after two months' chilling eight other plants were brought out.

B.—Representative plants from each of the two chilled lots described under A, from photograph made January 18, 1918. The plant at the left, which was kept under refrigeration for a month, was only imperfectly chilled, and although it started growing the growth was from abnormally few buds. But the plant at the right, under refrigeration for two months, was adequately chilled and started into growth from many buds in a normal manner. It is evident that by the proper application of this procedure a plant of this nature can be brought into proper condition for shipment and planting on any date desired.






A
B

PLATE 33

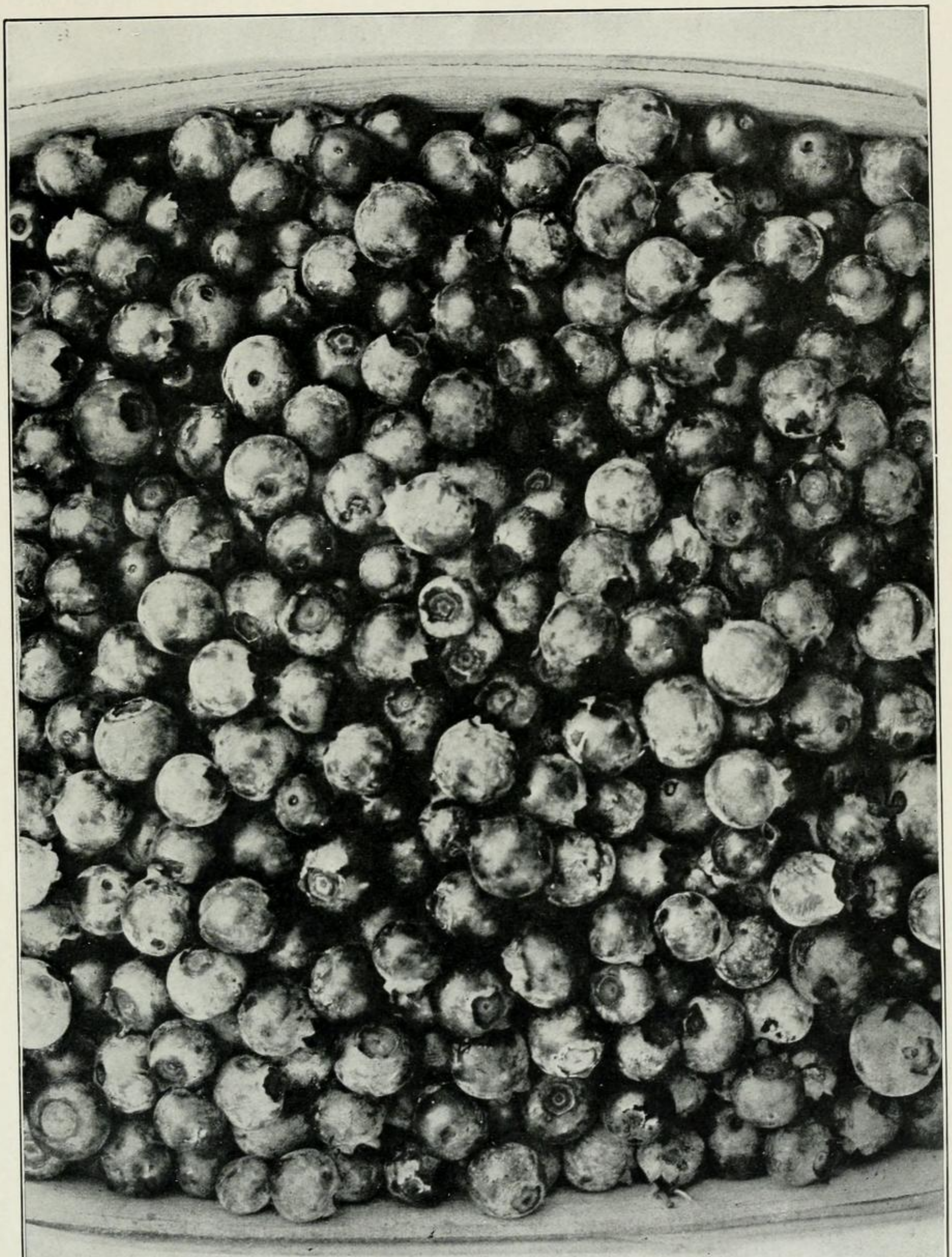
A.—Plantation at Whitesbog, N. J., for the testing of blueberry hybrids. From very carefully selected wild blueberry plants hybrid seedlings are raised in the greenhouses of the Department of Agriculture at Washington. In order to bring them into fruit under favorable outdoor conditions so that selections of the best hybrids can be made for further propagation, the young seedlings are sent to a plantation at Whitesbog, 4 miles east of Browns Mills, in the pine barrens of New Jersey. In the photograph 2-year-old hybrids are shown at the right and 3-year-olds in the row at the left.

B.—Four-year-old blueberry hybrid in full fruit. This illustration shows the vigor, beauty, and productiveness of a hybrid blueberry bush when it is given the proper and peculiar conditions which by its nature it requires for successful growth. From a 1/3-acre patch of hybrid bushes a yield of berries was secured in 1919 at the rate of 96 bushels per acre. They sold at a little over $10 a bushel, bringing gross receipts at the rate of $966 per acre. In 1920 this planting yielded at the rate of 117 bushels per acre, which sold at a little less than $11 a bushel, yielding gross receipts at the rate of $1,280 per acre.

PLATE 34

The ordinary wild blueberry of New Jersey.

This is a photograph, natural size, of a quart box of wild New Jersey blueberries, rather better than the average. It was taken for the purpose of comparison with the selected hybrid blueberries shown in Plate 35.



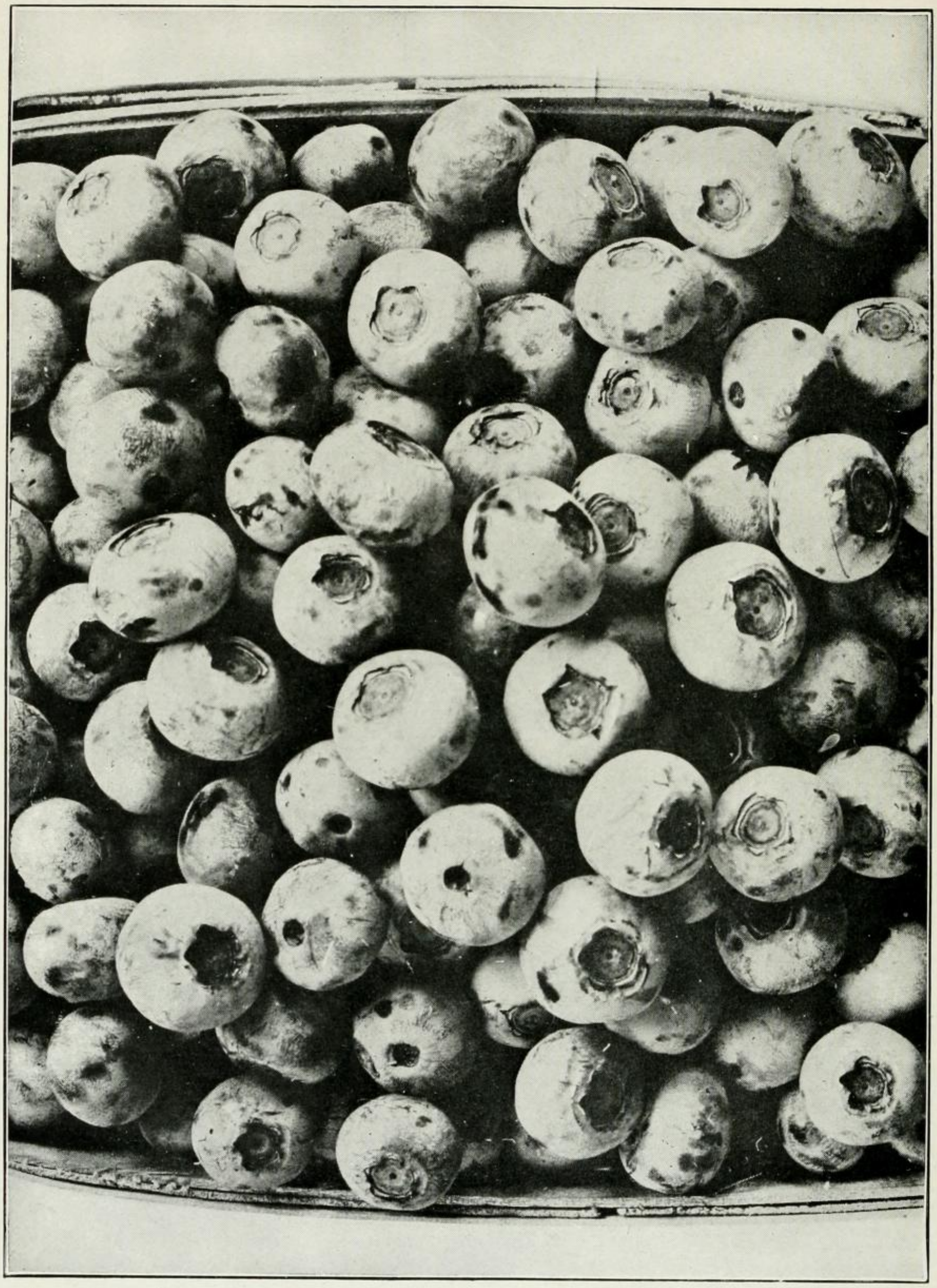


PLATE 35

Fruit of a selected hybrid blueberry.

This illustration shows in natural size a quart box of blueberries from a hybrid produced at Washington and fruited at Whitesbog. The photograph represents the average product of the bush, for it was taken from a clean picking, including the small berries as well as the large ones. Hybrids with berries of still larger size have been fruited at Whitesbog.