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B. T. GALLOWAY, *Chief of Bureau.*

# EXPERIMENTS IN BLUEBERRY CULTURE.

BY

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
*Washington, D. C., July 19, 1910.*

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 193 of the series of this Bureau a manuscript by Mr. Frederick V. Coville, Botanist in Charge of Taxonomic and Range Investigations, entitled " Experiments in Blueberry Culture." Mr. Coville has found by experiment how blueberries differ from ordinary plants in their method of nutrition and in their soil requirements, and by means of this knowledge he has worked out a system of pot culture under which these plants attain a development beyond all previous expectations. There is good prospect that the application of the knowledge thus gained will establish the blueberry in field culture and that ultimately improved varieties of these plants will be grown successfully on a commercial scale.

A particularly interesting and significant feature of these experiments is the light they shed on the possible utilization of the naturally acid lands that occupy extensive areas in the eastern United States. These lands are generally valued at a low price, and the chief expense involved in their utilization for ordinary agricultural crops is the cost of correcting their acidity and its effects by liming, fertilizing, and cultural manipulation. The question presents itself, " May we not more effectively utilize such lands by growing on them crops which, like the blueberry, thrive in acid soils? "

Some of the experimental methods and equipment utilized by Mr. Coville are commended to other plant experimenters, especially the use of darkened and drained glass pots for the intimate observation of the behavior of roots, and the plunging of pots in moist sand to maintain equable moisture and aeration conditions.

Respectfully,

Wm. A. Taylor,
*Acting Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# EXPERIMENTS IN BLUEBERRY CULTURE.

## INTRODUCTION.

In the grounds of the Smithsonian Institution at Washington are two blueberry bushes of large size and great age. The taller is about 9 feet high. The largest stem is nearly 3 inches in diameter. It is known that these bushes were growing prior to 1871, thirty-nine years ago, and all the evidence indicates that they were planted at a much earlier date. They are probably over 50 years old.[a] In the Arnold Arboretum, near Boston, are many blueberry bushes 30 years old or more, grown from the seed by Mr. Jackson Dawson or transplanted from their wild habitats prior to 1880.

The two cases here cited demonstrate the fallacy of the popular idea that the blueberry can not be transplanted or cultivated. This idea rests on the unsuccessful experience of those who have taken up wild bushes and set them in a rich, well-manured garden soil. These are exactly the conditions, as shown by experiments described in this publication, under which blueberry plants become feeble and unproductive.

Four agricultural experiment stations, those of Maine, Rhode Island, New York, and Michigan, have attempted to grow the blueberry as a fruit, but none of these attempts has resulted in the commercial success of blueberry culture, and the experimental results have been chiefly of a negative character. This outcome appears to have been due to a misunderstanding of the soil requirements of the blueberry, which, as will be shown later, are radically different from those of our common cultivated plants.

[a] The plants are *Vaccinium atrococcum*, a species closely related to *Vaccinium corymbosum*, the well-known swamp or high bush blueberry of the Northern States. In a list of the trees and shrubs of the Smithsonian grounds prepared by Arthur Schott in 1871, these bushes are included, but identified, however, as *Vaccinium fuscatum*. The late Mr. George H. Brown, for more than a generation the superintendent of planting in the parks of Washington, also assured the writer that these plants were not set out since he first became responsible for the Smithsonian grounds, in 1871. The present plan of the grounds was made by Mr. Andrew J. Downing, but the actual planting was not done until after his death, in 1852. It is possible that the blueberry bushes may have been set out as early as 1848, in which year a partial planting of the Smithsonian grounds was made by Mr. John Douglass.

In the Boston market there is a wide variation in the wholesale price of blueberries. Shipments begin in early June from North Carolina, followed in the latter part of the month by blueberries from Pennsylvania, New Jersey, and New York. In early July, or in some years in the last days of June, Massachusetts and New Hampshire shipments begin to arrive, succeeded in late July or early August by berries from Maine, Nova Scotia, and New Brunswick. Receipts from these last two localities continue until late September. The blueberries that bring the highest price are those from Massachusetts and New Hampshire. At the time when other berries are selling at 8 to 15 cents per quart wholesale, the first shipments of New Hampshire berries often bring 20 to 23 cents.

The owner of a blueberry pasture in southern New Hampshire who superintended the picking of his own berries and shipped them to one of the secondary New England cities has courteously shown his shipment records, from which the following data have been compiled:

*Records of shipments from a blueberry pasture in southern New Hampshire, 1905–1909.*

| Year. | Date of shipment. | Total shipments. | Highest and lowest price per quart.[a] | Average price per quart.[a] |
|---|---|---|---|---|
| | | *Quarts.* | *Cents.* | *Cents.* |
| 1905 | July 1 to Aug. 14 | 2,233 | 12½ to 8 | 10.7 |
| 1906 | July 17 to Aug. 15 | 2,756 | 15 to 8 | 9.6 |
| 1907 | July 20 to Aug. 15 | 2,538 | 14⅓ to 11 | 12.2 |
| 1908 | June 29 to Aug. 15 | 3,602 | 16 to 9¼ | 10.8 |
| 1909 | July 15 to Aug. 16 | 1,255 | 14 to 9 | 10.7 |

[a] This is the net price that the shipper received after deducting express charges.

The average net price for the five years was 10.8 cents per quart. The record indicates the substantial returns that are secured from ordinary wild berries picked and sent to market in rather better than ordinary condition.

That the market would gladly pay a high price for a cultivated blueberry of superior quality there can be no doubt. From the market standpoint the features of superiority in a blueberry are large size; light-blue color, due to the presence of a dense bloom over the dark-purple or almost black skin; "dryness," or freedom from superficial moisture, especially the fermenting juice of broken berries; and plumpness, that is, freedom from the withered or wrinkled appearance that the berries begin to acquire several days after picking. While the connoisseur in blueberries who picks his own fruit knows the widely varying flavors in the berries of different bushes, the buyer in the city market is content to select his fruit according to its appearance, knowing that the flavor will be good enough in any event.

The size of the seed gives the buyer in New England markets very little concern, for there the name blueberry is restricted to plants of the genus Vaccinium, all of which have seeds so small as to be unnoticeable when the berry is eaten, while the name huckleberry is applied with nearly the same precision to the species of the genus Gaylussacia, in which the seed is surrounded by a bony covering like a minute peach pit, which crackles between the teeth. In southern cities the fruits of both Vaccinium and Gaylussacia are called huckleberries, and it is probable that the low estimation in which the fruit of Vaccinium is there held is largely due to the lack of a distinctive popular name. To distinguish the two berries by their appearance is difficult for any but an expert, for while huckleberries are mostly black and blueberries mostly blue, some of the blueberries, or species of Vaccinium, are black, and some of the huckleberries are blue, notably *Gaylussacia frondosa*, a species often abundant in the sandy soils of the Atlantic Coastal Plain, which has a large, handsome berry of a beautiful light-blue color and passable flavor, but with the disagreeably crackling seed pits characteristic of the other true huckleberries.

The blueberry withstands the rough treatment incident to shipment so much better than most other berries that with proper handling it should always reach the market in first-class condition. But its good shipping qualities are often abused, and the fruit not infrequently is exposed for sale partly crushed and the berries covered with soured juice and made further offensive by the presence of flies. This is the prevailing condition of blueberries and huckleberries in the markets of Washington, in striking contrast with the dry, plump berries of the Boston market. This bad condition is due usually to improper picking.

The small size of the blueberry, compared with other berries, renders the picking of it expensive. The owners of blueberry pastures commonly pay two-thirds the net price of the berries to their pickers. In order to reduce the cost of picking, various devices have been employed. The most widely used of these is an implement known as a blueberry rake, a scoop shaped somewhat like a deep dustpan, provided in front with a series of long, pointed fingers of heavy wire. With this implement an ordinary picker in the blueberry canning districts of Maine, for example, gathers 3 to 5 bushels a day, for which he receives $1\frac{3}{4}$ to 2 cents per quart. Blueberries can be picked with a rake at about a fourth the cost of picking by hand. For this reason many of the berries that go to market are picked with a rake, and it is these berries which, broken and fermenting, make up the greater part of the low-grade stock so offensive to the eye and the taste. Blueberries intended for the market should never be picked with a rake.

What has been said regarding the high cost of picking ordinary blueberries by hand indicates the importance of securing a berry of large size if the plant is to be cultivated. Large size and abundance mean a great reduction in the cost of picking. Large size means also a higher market price, and when taken in connection with good color and good market condition it means a much higher price.

The writer's interest was attracted to the subject of blueberry culture in 1906. In the autumn of that year some experiments were made for him by Mr. George W. Oliver to ascertain a suitable method of germinating the seeds. In the autumn of 1907 special cultural experiments were taken up. In 1908 experiments were begun in the propagation of bushes bearing berries of large size, the most satisfactory of these being a New Hampshire bush of the swamp blueberry (*Vaccinium corymbosum*) having berries a little more than half an inch in diameter. The largest berries tried, a little more than five-eighths of an inch in diameter, were from Oregon bushes of *Vaccinium membranaceum*. Except where otherwise stated, the experiments described in this paper were made with *Vaccinium corymbosum*. The principal results of the experiments are given under brief numbered statements, each followed by a detailed explanation.

## PECULIARITIES OF GROWTH IN THE BLUEBERRY PLANT.

### SOIL REQUIREMENTS.

(1) THE SWAMP BLUEBERRY DOES NOT THRIVE IN A RICH GARDEN SOIL OF THE ORDINARY TYPE.

Although the statement just made might well rest on the direct observation of experimenters who have failed to make blueberries grow luxuriantly, or sometimes even remain alive, in rich garden soils, nevertheless the citation of one of the writer's experiments may serve to accentuate the fact. The soil chosen for the purpose was the one used at the United States Department of Agriculture for growing roses. A sample of this soil, as mixed by the rose gardener, consisted, according to his specifications, of "five shovelfuls of loam, one shovelful of cow manure, and a handful of lime." The loam used was a rotted grass turf grown on a rather clayey soil. The cow manure was well rotted, having lain in the pile for several months, with almost no admixture of straw. The lime was of the ordinary air-slaked sort.

The pots used in the experiment were of glass, small 5-ounce drinking glasses, about 2 inches in diameter at the bottom, 2½ at the top, and 2¾ inches deep. A small hole bored through the bottom gave the necessary drainage to the soil in the pot. Since the walls of these pots were transparent, the normal growth of the roots and the prevention of an obscuring green growth of microscopic algæ required some arrangement for keeping the light away. This was accomplished either by sinking, or, as gardeners say, "plunging," the pots nearly to the rim in sand, moss, or soil, or, when the pots were not plunged, by fitting closely to the outside of each a removable cuff, as it were, made of the opaque gray blotting paper used in pressing specimens of plants. The use of a pot with transparent walls was found to be of very great importance in the study of these plants, for plants identical in appearance so far as the parts above ground were concerned sometimes showed the most pronounced differences in the growth and behavior of the roots, differences which otherwise would not have been observed but which were in reality responsible for the conspicuous changes that later took place in the growth of the stems and leaves. The use of such glass pots, drained and darkened, is strongly recommended to plant experimenters who use pot cultures, as they afford a means of acquiring easily an intimate knowledge of the great variations in the behavior of the feeding organs, the roots, under different conditions.

On December 22, 1908, six glass pots were filled with the garden soil described above, and a seedling blueberry about an inch in height was transplanted into each. The seed bed from which the seedlings were taken had been allowed to become partially dry before the transplanting was done. In this condition there was no difficulty in removing all of the sandy soil adhering to the roots of a seedling, so that after it was transplanted it must derive its soil nourishment from the new soil exclusively. In potting, the roots of the plant were laid against the glass on one side of the pot so that their behavior could be observed from the very first.

A transplanting of six other plants was then made, similar in all respects to the first except that the soil used was a peat mixture known from earlier experiments to be productive of vigorous growth in blueberry plants. The exact character of this soil will be discussed later in this publication.

This peaty blueberry soil is ill suited to the growth of ordinary plants, while in the garden soil ordinary plants flourish luxuriantly. In order to bring out this fact clearly by an experiment six glass pots containing this garden soil were planted with five alfalfa seeds each, and six more with one rooted rose cutting each. An identical planting was made in twelve pots of blueberry soil.

Average examples of the growth that took place in these plantings are shown in figures 1 to 6, reproduced from drawings carefully made from actual photographs. In the garden soil the rooted rose cutting, which was of the variety known as Cardinal, made vigorous growth of both root and stem, and in forty-four days, when the photograph was taken, had about quadrupled its leaf surface. In the blueberry soil the cutting was barely alive, the roots it had at the time it was potted were nearly all dead, no new stem growth had been made, and the leaflets it bore were only those still persisting from the parent plant.

The alfalfa seeds began to germinate in both soils in three days. At the end of a week a distinct difference in the color of the plants was discernible. In the blueberry soil the seed leaves were darker green in color, the midrib, which shows on the back of the leaf, was

FIG. 1.—Rose cutting in rich garden soil. (One-half natural size.)

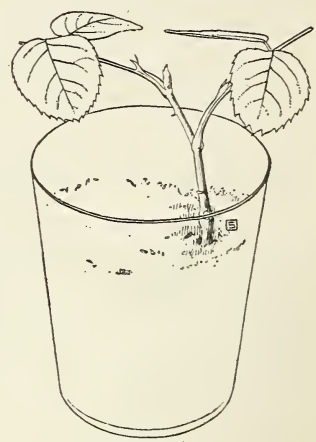


FIG. 2.—Rose cutting in peat mixture. (One-half natural size.)

purple, the stem was purple, and in some of the seed leaves the whole under surface was purple. In the garden soil the seed leaves were lighter green in color, and in only a few were the stems, and in still fewer the midribs, somewhat purplish. At the end of forty-four days, when the photographs reproduced in figures 3 and 4 were taken, the alfalfa plants in the garden soil were 3 inches in height and vigorous, while the soil was crowded with roots on which nitrogen tubercles had already begun to develop. In the blueberry soil the plants were small leaved and sickly, about a third the height of the others, and the roots though long were slender and otherwise weak and bore no tubercles.

In the case of the blueberry plants the relative growth in the two soils took exactly the opposite course. At the end of the first week new root growth had begun in all the pots containing blueberry soil, while in those containing garden soil new root growth was apparent in only one. At the end of forty-four days vigorous root growth had taken place in the blueberry soil pots, and stem growth, which had been interrupted at the time of transplanting, was well under way again. In the garden soil, however, almost no root growth was discernible, the old leaves were strongly purpled and stem and leaf growth had not been resumed. Little attention was paid to these cultures during the summer of 1909, but the relative condition of the two is fairly

FIG. 3.—Alfalfa seedlings in rich garden soil. (One-half natural size.)

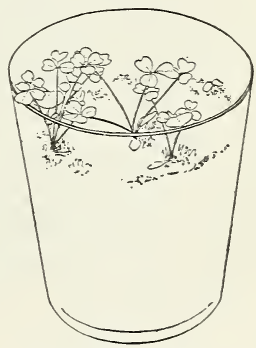


FIG. 4.—Alfalfa seedlings in peat mixture. (One-half natural size.)

illustrated in figures 5 and 6, from photographs taken November 22, 1909, after the leaves had fallen. The garden-soil pot contained only a few stray roots, and the slender stems were only 2 inches high. The pot containing blueberry soil was filled with a dense mass of roots, and although the plant had not been repotted when it needed repotting, the largest stem was nevertheless 11 inches long and the weight of that part of the plant above ground was fifty-one times that of the corresponding part of the garden-soil plant.

(2) THE SWAMP BLUEBERRY DOES NOT THRIVE IN A HEAVILY MANURED SOIL.

In May, 1909, two healthy and vigorous blueberry seedlings were sent for trial to one of the agricultural experiment stations. They were set out in a soil that was known to be suitable for these plants, for old blueberry bushes had been growing there for several years.

The man who put the blueberry seedlings in the ground, however, misunderstanding the directions sent him, filled in the holes in which he set the plants with alternate layers of soil and well-rotted stable manure. The writer examined the plants on August 27, 1909, when they should have been either growing vigorously or, with mature foliage, ripening their wood for the winter. Instead they had lost nearly all their older leaves though still maintaining a feeble and spindling growth at the ends of the larger stems. The adjacent old bushes growing in precisely the same soil, except that it had not received the heavy application of manure, bore at the same time vigorous dark-green foliage and were ripening the wood of their stout twigs and laying down their flowering buds for the following year. The manured plants when dug up and examined showed no new root growth whatever in the manured soil outside the old earth ball, and most of the roots on the surface of the ball itself were dead.

Another experiment may be cited to show the injurious effect of heavy manuring. On December 22, 1908, six blueberry seedlings were transplanted into as many glass pots in a good blueberry soil, and six other seedlings were potted in the same manner, except that to each two parts of blueberry soil one part of well-rotted but unleached cow manure was added. At first the manured plants appeared, superficially, to be doing better than those not manured, for in the former the production of new leaves and the continued growth of the stem tip

FIG. 5.—Blueberry seedling in rich garden soil. (One-half natural size.)

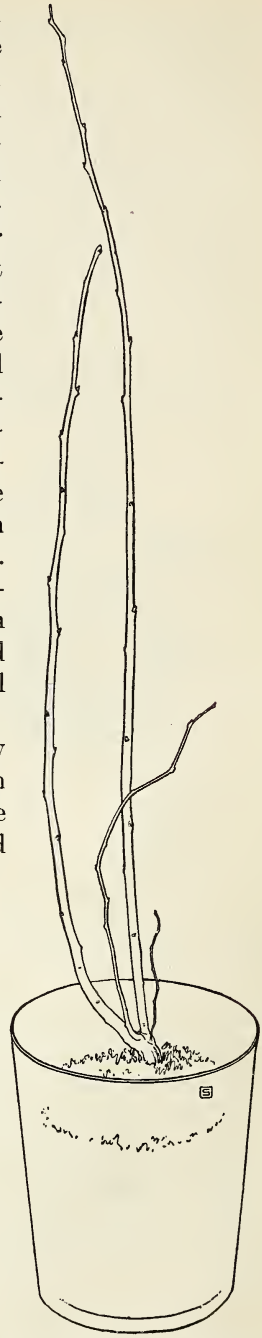


FIG. 6.—Blueberry seedling in peat mixture. (One-half natural size.)

were not interrupted by the potting, while in the plants not manured there was a temporary but definite stopping of stem growth immediately after the potting. The apparent superiority of growth in the manured plants, above ground, continued for about three weeks. Below ground, the roots of the two cultures showed directly opposite results. In the plants without manure, new root growth began a few days after potting. At the end of three weeks the development of an extensive root system was well under way and the plants were nearly ready for a period of vigorous stem growth. In the manured plants, however, either no root growth took place or only a slight amount, the new rootlets being fewer, shorter, and stouter than in normal plants. The old rootlets turned brown and appeared to be dead or dying. (See p. 64.) At the end of five weeks the growth of the tops was very slow. About ten days later, on February 6, a bright warm day, the lower leaves on three plants withered, and within a few weeks all six of the manured plants were dead.

(3) THE SWAMP BLUEBERRY DOES NOT THRIVE IN A SOIL MADE SWEET BY LIME.

In its natural distribution the blueberry, like almost all plants of this and the heather family, avoids limestone soils. The fertile limestone areas of western New York, of Ohio, of Kentucky, and of Tennessee lack the blueberry, the huckleberry, the laurel (*Kalmia latifolia*), and the trailing arbutus (*Epigaea repens*). The State of Alabama, as described by Charles Mohr in volume 6 of Contributions from the United States National Herbarium, is traversed from east to west in the general latitude of Montgomery by a strip of dark calcareous soil, 35 to 45 miles in width, the so-called "black belt," which constitutes the great agricultural region of the State. The noncalcareous areas north and south of this strip have in their forests a characteristic undergrowth of blueberries and closely related plants, including huckleberries, farkleberries, and deerberries. In the intermediate belt of black limestone soil, just described, the plants of blueberry relationship are almost wholly wanting.

In an article entitled "The Soil Preferences of Certain Alpine and Subalpine Plants,"[a] Mr. M. L. Fernald discusses the natural distribution of over 250 species of plants found in the cold parts of the northeastern United States and Canada. All the blueberries he enumerates, five species, avoided calcareous soils, and the other plants of the blueberry and heather families almost without exception occurred likewise on noncalcareous formations.

The writer's own experiments in growing blueberries in limed soils have not proceeded with the same smoothness as some of his other experiments, but the results, though at first misleading, have uniformly been exceedingly instructive, though not always in the

[a] Rhodora, vol. 9, 1907, pp. 149–193.

direction originally contemplated, and in the end have been fully conclusive.

On May 26, 1908, six blueberry seedlings were potted in six 14-ounce drinking glasses in a good peaty blueberry soil, in which, however, 1 per cent of air-slaked lime [a] had been mixed immediately before the potting was done. Six other plants were similarly potted, but without the addition of lime. The unlimed plants grew normally. The younger leaves of the limed plants, however, began to wilt the same day on which they were potted. On June 1 all the leaves on all six plants were withered, though parts of the stems were still green and plump. The leaves did not turn purplish or yellowish, as is usual with sickly blueberry plants, but either retained their green color after withering or turned brown. No new root growth took place in any of the limed pots, and by July 10 all the plants were dead.

Another series of six plants, also potted on May 26, 1908, but in a sterile soil containing no peat, by accident received a very small amount of lime. Most of the leaves on these plants withered during the first few days, but the plants subsequently recovered and made as good growth as could have been expected from the general character of their soil.

From these experiments the writer concluded that the blueberry was exceedingly sensitive to lime and that the slightest admixture of it in the soil would be immediately fatal to the life or at least the health of a blueberry plant. This conclusion, however, was erroneous, as subsequent experience showed. This first experiment may therefore be dismissed with the explanation that in all probability the immediate collapse of the plants was due to a caustic effect of the lime used. In none of the later lime experiments did this immediate collapse occur and in none was the lime so applied that it came into contact with the blueberry roots while in a caustic condition.

Still laboring under an erroneous conception of the supersensitiveness of the blueberry plant to minute quantities of lime, the writer, desiring to produce fresh examples of this phenomenon, in November, 1908, placed a very small quantity, a few milligrams, of air-slaked lime on the surface of the soil in each of three 2-inch pots containing a small blueberry plant. No effect was produced either at first or for several weeks. On December 19, 1908, a large surface application of carbonate of lime was made to the same three plants, a gram to each pot, and the lime was washed down with water. The expected collapse did not occur. The limed plants continued to grow as luxuriantly as their unlimed neighbors. The con-

[a] Computed on the dry weight of the soil.

clusion was reached that the reason why the growth of the plants had not been affected was because the lime had not penetrated sufficiently into the soil. Another and more drastic experiment was therefore determined upon.

On March 10, 1909, six blueberry plants in 4-inch pots containing a good blueberry soil were set apart from their fellows and watered with ordinary limewater, a saturated solution of calcium oxid, 1.25 grams per liter of water. The applications made were of such an amount that the soil in the pot was thoroughly wetted each time, and usually a small excess quantity ran through the hole in the bottom of the pot.

For more than seven months, until October 22, 1909, these pots received no other water than limewater. During this period the plants continued to grow in a normal manner, their average height increasing from 4½ to 14 inches. The lime appeared to have no deterrent effect whatever on the growth of the plants. A computation based on the total amount of limewater used showed that each pot must have received about 18 grams of lime. An analysis of the soil in one of the pots after the limewater applications had ceased gave 14 grams. This amount was enormous, considered from the standpoint of agricultural usage. The soil, which had about one-third the weight of an ordinary soil, was over 8 per cent lime. This is the equivalent of about 25 tons of lime per acre mixed into the upper 6 inches of the soil.

Now, it was already known from the experiment described on page 23 that in this soil when containing as much as 1 per cent of lime blueberry plants should either die or barely remain alive. As a matter of fact these limewater plants were making excellent growth. A careful examination of the contents of one of the pots was then made. The surface of the soil was covered with a hard gray crust of lime. Immediately underneath for a depth of about half an inch the soil was black and contained no live blueberry roots. There was a zone of the same black rootless soil along the wooden label that reached from the top to the bottom of the pot. In all other parts of the dark-brown peaty soil there was a dense mass of healthy roots, which reached down also into the open spaces among the broken crocks in the bottom of the pot. The lime appeared to have penetrated only into the superficial portions of the soil. A chemical test showed that the black rootless layer was densely impregnated with lime, while the brown peaty portion containing the growing roots still gave the acid reaction that was characteristic of the whole potful of soil before the limewater applications began.

Since all the water that the limeless root-bearing portion of the soil had received during the preceding seven months had come from the limewater applications, it was evident that the lime contained in the limewater had been deposited in the upper layers of the soil. The following laboratory experiment confirmed this. A small quantity of the acid peaty soil used in growing blueberries was placed in a glass vessel and moistened. Then dilute limewater reddened by the addition of phenolphthalein, a substance giving a delicate color test for alkalies such as lime, was stirred into the soil and the mixture poured into an ordinary paper filter. The water came through the filter without a trace of red color, showed none after boiling, to drive off any possible carbonic acid, and when tested with ammonia and ammonium oxalate showed not a trace of lime. The precipitation of the lime had been complete and practically instantaneous. Only ten seconds had elapsed between the time when the limewater was added to the soil and the time when the liquid entirely free from lime began to drop through the filter.

In order to ascertain whether a large part of the lime in the limewater used on the plants may not have passed through the pots by running down the partially open channel along the label, some limewater was poured upon the surface of one of the pots. The excess water that soon began to drip through the bottom of the pot was tested for lime. It was found that while the limewater poured into the pot contained 0.1014 per cent of lime, the water that came through contained only 0.0046 per cent. In other words a pot of soil that for over seven months had been used essentially as a limewater filter still continued to extract over 95 per cent of the lime contained in the limewater that was passed through it, notwithstanding the fact that there was a partially open channel down one side of the pot. It is believed that had the soil been evenly compacted in the pot no lime whatever would have been able to pass through, but that all would have been precipitated in the uppermost layers.

While the experiment has no important bearing on the subject of blueberry culture it is of very great significance in its bearing on the method of applying lime to acid soils in ordinary agricultural practice. A surface application of lime would have no appreciable effect in neutralizing the acidity of a soil unless the soil was so sandy or gravelly or otherwise open that the rain water containing the dissolved lime could run down through it practically without obstruction. A surface dressing of lime would have little effect in neutralizing the acidity of an old meadow or pasture. To secure full action of the lime, as now generally recognized in the best agricultural practice, requires its intimate mixing with the soil, such as can be accomplished by thorough harrowing, especially after putting the lime beneath the surface with a drill. A full discussion of the physical reasons for the deposition of the lime in the upper layers of the soil, when not worked into it mechanically, is given in Bulletin 52 of the Bureau of Soils, published in 1908.

Among the experiments with blueberry seedlings in different soil mixtures started on December 22, 1908, was one in which six plants were set in glass pots in a peaty soil thoroughly intermixed with 1 per cent of carbonate of lime. The first difference that showed between these and unlimed plants in the same soil was the much feebler root growth of the limed plants. This was followed by an evident tendency toward feebler stem growth. The relative condition of the two cultures on April 13, 1909, is shown by photographs of representative plants reproduced as figures 7 and 8. The later progress of this

FIG. 7.—Blueberry seedling in peat mixture limed. (One-half natural size.)

FIG. 8.—Blueberry seedling in peat mixture unlimed. (One-half natural size.)

experiment was interrupted, however, and its average results vitiated because the roots of some of the limed plants found their way through the holes in the bottom of the pots and obtained nourishment from the unlimed material in which the pots were plunged. Such plants made nearly as good growth as the unlimed plants. On November 27, 1909, there remained only one of the limed plants whose roots were all inside the pot. This plant was feeble and small, its stem being only 2½ inches high. Its inferiority to the unlimed plants was almost as conspicuous as that of the garden-soil plants described on page 17 and illustrated in figure 5.

(4) The swamp blueberry does not thrive in a heavy clay soil.

In its natural geographic distribution the blueberry shows an aversion to clay soils. Its favorite situations are swamps, sandy lands, or porous, often gravelly loams. When a blueberry plant grows upon a clay soil it is usually found that its finer feeding roots rest in a layer of half-rotted vegetable matter overlying the clay. Often in such situations the dense covering of interwoven rootlets and dark peatlike soil may be ripped from the surface in a layer little thicker than a door mat and of much the same texture. The roots of the blueberry do not penetrate freely into the underlying clay.

In greenhouse cultures the blueberry shows the same aversion to clay soils. Various series of blueberry seedlings were potted on May 26, 1908, in different soils in ordinary large drinking glasses. For one set of six plants a stiff clayey soil was used, such as is common in the neighborhood of Washington, D. C. The soil in the glass was mulched to the depth of nearly an inch with half-rotted leaves. In another six glasses were set six similar plants in a peat soil, the surface mulched in the same way as the others.

In other experiments with this clay soil in earthen pots, the growth of the plants had always been poor. The present experiment was no exception. But the feature of greatest interest was the behavior of the roots. Plate I, from photographs taken October 5, 1908, shows the root systems of typical plants in the two soils. In the clay soil almost no root development took place, and in the illustration no roots are visible. The interrupted black lines in the clay are tunnels made by larvæ or other animals. In the moist leaf mulch covering the clay, however, the plant developed its roots extensively. Some of the plants, probably because they were set too deeply in the clay when the potting was done, failed to send their roots up into the mulch, and such plants were much inferior in their growth to those that found the rotted leaves. In the other glass is shown the normal root growth of a blueberry in a soil suited to it.

(5) The swamp blueberry does not thrive in a thoroughly decomposed leaf mold, such as has a neutral reaction.

It had been found in earlier experiments that certain soils composed in part of imperfectly rotted oak leaves were good for growing blueberries. On the supposition that the more thoroughly rotted this material was the better suited it would be for blueberry growing, a quantity of old leaf mold was secured for an experiment. The mold was black, mellow, and of fine texture. The mixed oak and maple leaves from which it was derived had been rotting for about five years, until all evidences of leaf structure had disappeared. It had the same appearance as the black vegetable mold that forms in rich woods where trilliums, spring beauty, and bloodroot delight to grow.

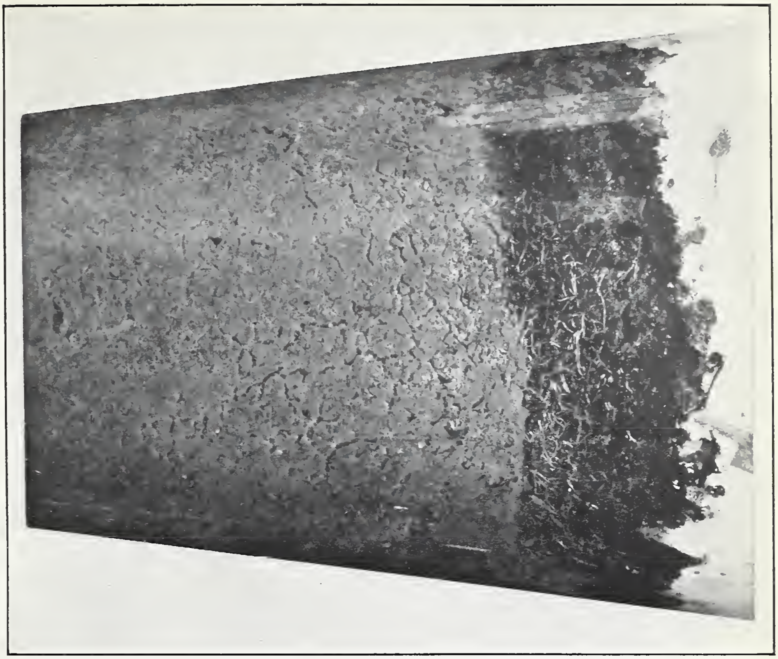


FIG. 1.—ROOT GROWTH OF A BLUEBERRY PLANT IN CLAY MULCHED WITH LEAVES.
(Natural size.)

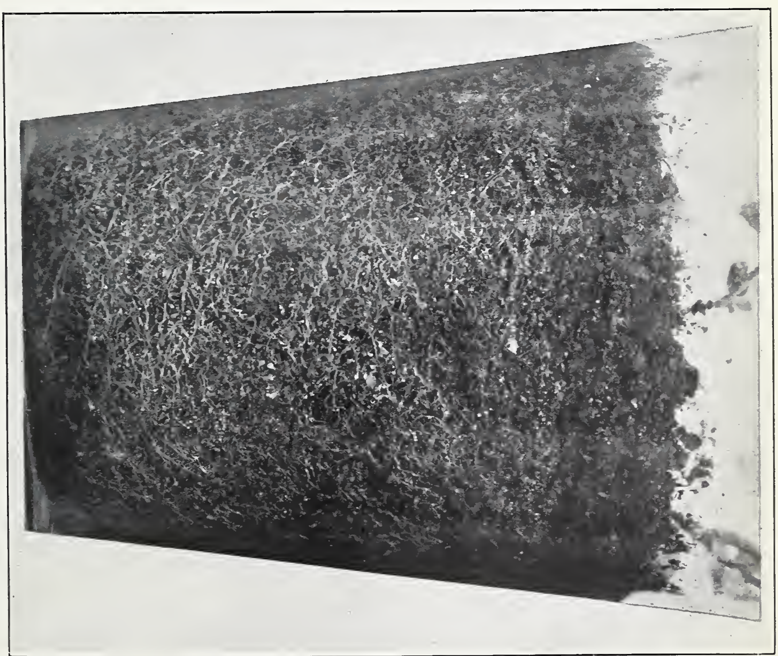


FIG. 2.—ROOT GROWTH OF A BLUEBERRY PLANT IN PEAT.
(Natural size.)

On February 20, 1909, 25 blueberry seedlings were potted in 3-inch earthenware pots in a mixture consisting of eight parts by bulk of the leaf mold just described, one part of clean sand, and one part of clayey loam derived from rotted grass turf. Fifty other plants were potted in the same manner except that in place of the mold a peat was used known from earlier experiments to be well suited to blueberry growing. The plants were kept in the greenhouse until warm weather when they were placed outdoors. All were given the same treatment, a treatment favorable to good growth.

It had been expected that the plants in the leaf mold would show a vigorous growth, and it was hoped that the mold might prove even superior to the peat for blueberry soil mixtures. The experiment as it progressed, however, showed that such was not the case. The leaf mold proved to be not merely not a good soil for blueberries but an extremely poor one, as the following particulars will show.

When the plants were potted they averaged about 2½ inches in height. On May 29 the peat-soil plants had an average height of 7¼ inches, while the leaf-mold plants averaged 4¼ inches. At this time the herbage of the leaf-mold plants was decidedly purpled and yellowish, a coloration which they had taken on soon after they were potted and from which they never fully recovered. At the end of the season, after the leaves were shed, the peat-soil plants averaged 13¼ inches in height and the leaf-mold plants 7¾ inches. On November 29, 1909, five average plants from each lot were cut off at the surface of the ground and weighed. The weight of the stems from the leaf-mold plants was less than one-fifth that from the plants in the good blueberry soil.

When these plants were removed from their original seed bed to be transplanted to the 3-inch pots, such of the original soil as clung to their roots was not shaken off. It is believed that the leaf-mold plants fed in part on this original soil in making their new growth, and that without it they would have shown still less increase in height than they did. The peat-soil plants, moreover, were badly in need of repotting, even in early summer, and had they been placed in larger pots the difference in the growth of the plants in the two soils would have been much greater than it was.

That the influence of the leaf mold was directly deleterious and that the poor growth of the blueberry plants in it was not due to the lack of some element that might have been furnished by the addition of a small amount of the good blueberry soil is shown by certain intermediate experiments. Along with the cultures described above were carried two others in which the soil mixtures contained both peat and leaf mold. In the first, in which the proportion was peat 5, mold 3, sand 1, and loam 1, the average height of the plants on May 29 was 6 inches, and at the end of the season 12½ inches. In the second lot, in which the proportion was peat 3, mold 5, sand 1, and loam 1, the average height on May 29 was 4½ inches, and at the end of the season 11¾ inches. It will be observed that these two lots of plants are intermediate in their growth between the first two and that in all four lots the poverty of growth is roughly proportional to the amount of leaf mold used in the soil.

That the weak growth of the plants in leaf mold was not caused by a compacting of the soil and a lack of aeration, due to too small a proportion of sand in the mixture, is shown by still another lot of 25 plants which were potted in a soil mixture having the proportion of mold 6, sand 3, and loam 1. These plants averaged only 4 inches in height on May 29 and 6¼ inches at the end of the season. They grew even less, therefore, than the plants with only 1 part of sand and 8 parts of mold.

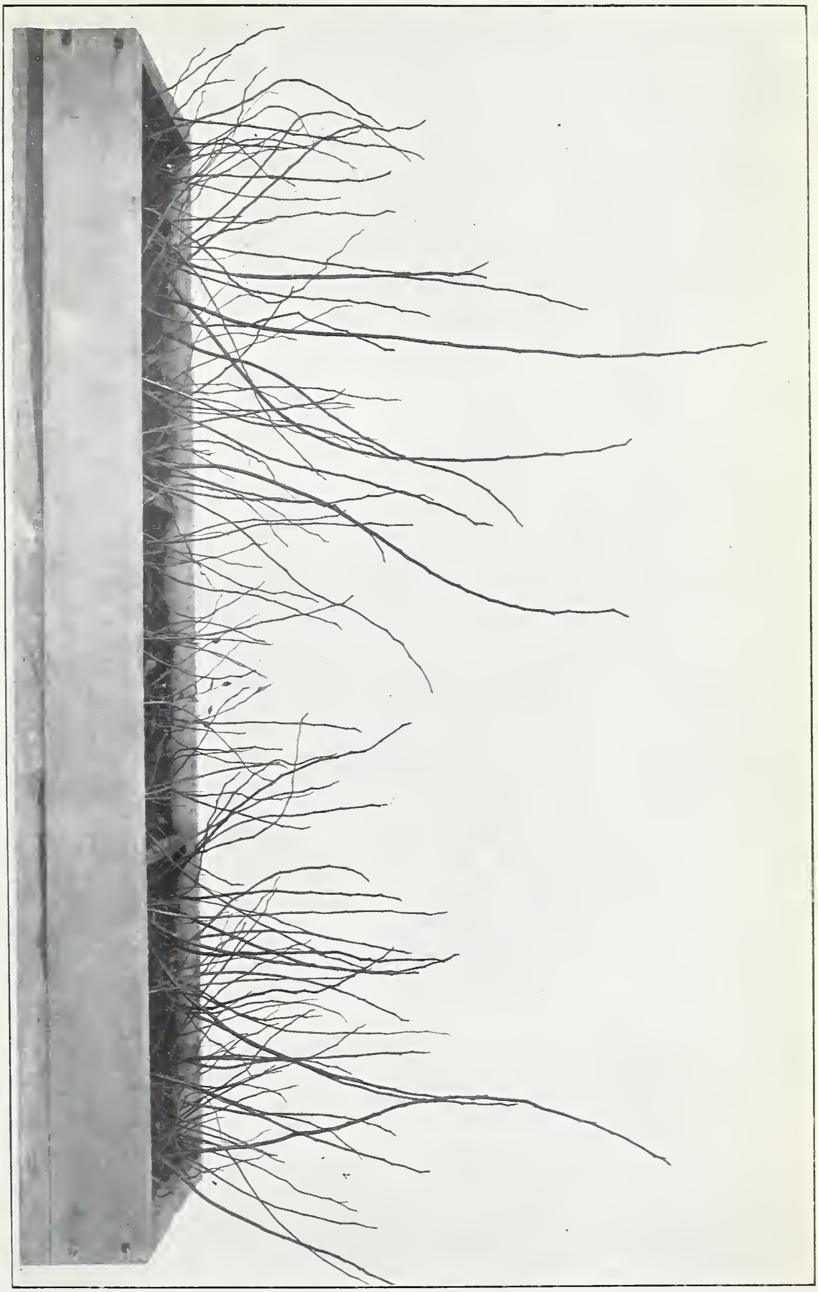
In Plate II, from a photograph made in the winter of 1909–10, is shown a flat divided into three parts and set on February 10, 1909, with blueberry seedlings of uniform size. The soil in the middle compartment is a mixture of leaf mold 8 parts, sand 1 part, and loam 1 part. In the compartment to the left the soil is in the proportion of kalmia peat 8, sand 1, and loam 1; and in the right-hand compartment, kalmia peat 4, leaf mold 4, sand 1, and loam 1. It will be observed that the greater the amount of leaf mold the poorer the growth of the blueberry plants.

The reason for the unexpected deleterious effect of leaf mold, as shown by these experiments, is given on page 29 and further discussed on page 35.

(6) THE SWAMP BLUEBERRY DOES NOT THRIVE IN SOILS HAVING A NEUTRAL OR ALKALINE REACTION, BUT FOR VIGOROUS GROWTH IT REQUIRES AN ACID SOIL.

The consideration of this statement requires first an understanding of the means used to determine whether a soil is acid or alkaline. The simplest means is the litmus test.

While one may become sufficiently expert in the use of the litmus test to form a fair judgment of the degree of alkalinity or acidity in a soil, an exact determination requires some different method. It was found that for the weak acids prevalent in the peat soils to the examination of which the present experiments led, the phenolphthalein test was the most satisfactory. If a few drops of phenolphthalein indicator be added to a solution, the solution, if alkaline, turns instantly pink, and if acid or neutral its color does not change. The application of this phenomenon to the determination of the degree of acidity of an acid solution is as follows: A definite amount of the solution, usually 100 cubic centimeters, is placed in a beaker, a few drops of an alcoholic solution of phenol-



BLUEBERRY SEEDLINGS IN PEAT AND LEAF MOLD.

(One-sixth natural size.)

phthalein are added, and into this is stirred drop by drop from a graduated glass tube provided with a stopcock, known as a burette, a measured amount of some alkaline solution of known strength, commonly a one-twentieth normal solution, as it is known to chemists, of sodium hydrate. When a sufficient amount of the sodium-hydrate solution has been dropped into the beaker, the acidity of the acid solution becomes neutralized and it turns pink. A reading is made on the burette showing the exact amount of the sodium-hydrate solution used in effecting the neutralization. From this reading is computed the degree of acidity expressed in fractions of a normal acid solution. Now 100 c. c. of a normal acid solution would require for its neutralization 100 c. c. of a normal solution of sodium hydrate, or 2,000 c. c. of a one-twentieth or 0.05 normal solution. In a test of one of the acid nutrient solutions used in the blueberry cultures, 18 c. c. of a 0.05 normal solution was required to neutralize the acidity of 100 c. c. of the acid solution. Since 18 c. c. of a 0.05 normal solution is the equivalent of one-twentieth that amount, or 0.9 c. c. of a normal solution, the degree of acidity of this acid solution is 0.009 normal. It requires an equal amount of a 0.009 normal alkaline solution to neutralize it.

In applying this phenolphthalein test to soils the same scale is used. A soil is regarded as having normal acidity when the acid existing in a gram of the soil if dissolved in 1 c. c. of water gives a normal acid solution. If a soil were described as having an acidity of 0.02 normal, it would mean that the extract of 100 grams of it in 100 c. c. of water would be a 0.02 normal acid solution; that is, that 100 c. c. of the solution would contain 2 c. c. of a normal acid solution.

The method of extraction followed for all the soil acidity tests given in this paper is as follows: The soil is first air dried at an ordinary room temperature. Ten grams are then weighed out, shaken thoroughly with 200 c. c. of hot water, and allowed to stand over night. In the morning 100 c. c. is filtered off and boiled to drive away any carbon dioxid present. The solution is then titrated with a 0.05 normal solution of sodium hydrate, using phenolphthalein as an indicator. All the tests were made by Mr. J. F. Breazeale, of the Bureau of Chemistry, to whom the writer is greatly indebted for many courtesies and suggestions on the chemical side of the experiments.

The expression "normal solution" used in this paper, it must be understood, is the normal solution of chemists, not of surgeons. Surgeons use the expression "normal salt solution" to describe a certain weak solution of common salt in water which has the same osmotic pressure as the blood. A normal solution in chemistry is a solution of certain fixed strength, or concentration, based on the molecular weight of the substance under consideration. Normal solutions of the various acids have the same degree of acidity. Normal solutions of alkaline substances are equal to each other in alkalinity. A measured amount of a normal solution of an acid will exactly neutralize an equal amount of a normal solution of an alkaline substance.

In considering the degree of acidity from the standpoint of the sense of taste it is convenient to remember that the juice of an ordinary lemon is very nearly a normal solution of citric acid. The juice of the lemon contains usually from 6 to 7 per cent of citric acid. A normal solution of citric acid is 6.4 per cent. When the juice of a lemon is diluted to about ten times its original bulk, as in a large drinking glass, one has approximately a 0.1 normal acid solution. When diluted to 100 times, making about a 0.01 normal solution, there remains only a faint taste of acidity. The acidity of water after standing long in contact with peat in a barrel sometimes reached 0.005 normal. Bog water, or peat water, is sometimes appreciably acid to the taste.

Returning now to a consideration of the statement that the swamp blueberry does not thrive in a neutral or alkaline soil an experiment in this direction may first be cited. The experiment was made with twelve small glass pots, each containing a blueberry seedling. The soil in the pots was a clean river sand. The plants had been in these pots for eight weeks, watered with tap water. The amount of nourishment they had received during this time was therefore very small, especially since, when transplanted into the pots, all the soil of the original seed bed had been carefully removed from the roots. Nevertheless during these eight weeks all the plants had made extensive, even luxuriant, root growth. The tops, however, had made no growth. There had been complete stagnation or withering of the youngest leaf rudiments, and the mature leaves became and remained deeply purpled.

Beginning on February 17, 1909, eight weeks after the plants had been potted in the sand, as already stated, five of the pots were watered with an acid nutrient solution made up, in accordance with the advice of Mr. Karl F. Kellerman, of the Bureau of Plant Industry, as follows:

| | |
|---|---|
| Potassium nitrate ($KNO_3$) | 1.0 gram. |
| Magnesium sulphate ($MgSO_4$) | 0.4 gram. |
| Calcium sulphate ($CaSO_4$) | 0.5 gram. |
| Calcium monophosphate ($CaH_4P_2O_8$) | 0.5 gram. |
| Sodium chlorid ($NaCl$) | 0.5 gram. |
| Ferric chlorid ($FeCl_3$) | Trace. |
| Water | 1,000 c. c. |

This solution gave an acidity test of 0.012 normal.

Five other plants from the same twelve were watered with an alkaline nutritive solution of the following composition:

| | |
|---|---|
| Potassium nitrate ($KNO_3$) | 1.0 gram. |
| Magnesium sulphate ($MgSO_4$) | 0.4 gram. |
| Calcium sulphate ($CaSO_4$) | 0.5 gram. |
| Potassium diphosphate ($KH_2PO_4$) | 0.4 gram. |
| Sodium chlorid ($NaCl$) | 0.5 gram. |
| Ferric chlorid ($FeCl_3$) | Trace. |
| Water | 1,000 c. c. |

By the addition of a sufficient quantity of sodium hydrate the reaction of this solution was made alkaline to the degree of 0.006 normal.

Two of the twelve plants were left as checks, being still watered with tap water.

On March 25, thirty-six days after the watering began, the five plants fed with the acid nutritive solution were restored to a nearly normal green color, and all had begun to put out healthy new growth. The two check plants watered with tap water were still red-purple and stagnant. Of the five plants watered with the alkaline nutrient solution, three were stagnant and somewhat purplish, one was dying, and one was dead.

Figures 9 and 10, from photographs taken on April 15, 1909, show a typical stagnant plant that had been watered with the alkaline solution, and a typical plant watered with the acid solution which had begun to make new growth from the summit of the old stem and was pushing out a vigorous new shoot from the base. The experiment was terminated not long afterwards, but there was every prospect that had it been continued the acid-fed plants would soon have made growth comparable with that shown in figure 8 (p. 23).

Looking toward the acidity or alkalinity of the other cultures thus far cited, it may be stated that the rich garden soil described on page 14, which was so remarkably deleterious to blueberry seedlings, was alkaline. The rose cuttings and the alfalfa, which grew so well in that mixture, much prefer a somewhat alkaline soil. Indeed, alfalfa can not be grown with any degree of success in any soil except one with an alkaline reaction. When grown in the humid eastern United States alfalfa is rarely successful, except on calcareous soils, unless the natural acidity of the soil has been neutralized by suitable applications of lime.

The limed soil, deleterious to blueberry plants, described on page 23, gave a neutral reaction with phenolphthalein.

The heavy clay soil described on page 24, in which blueberry plants made very little growth, was neutral.

The thoroughly decomposed leaf mold described on pages 24 to 26, which was shown by experiment to be markedly deleterious to the blueberry, was distinctly alkaline. A chemical analysis of this mold showed that it contained 2.86 per cent of calcium oxid.

The good blueberry soils in all the experiments were acid, the acidity at times of active growth varying from 0.025 normal down to 0.005 normal.

It is of interest and suggestive of utility in indicating the acid or nonacid character of soils to record that in the case of the alkaline leaf mold described on page 24 the surface of the soil in all the pots became covered in a few months with a growth of a small moss identified through the courtesy of Mrs. N. L. Britton as *Physcomitrium immersum*. On the surface of acid kalmia-peat soils the characteristic green growth consisted of microscopic algæ, accompanied often by fern prothallia and other mosses, but never Physcomitrium.

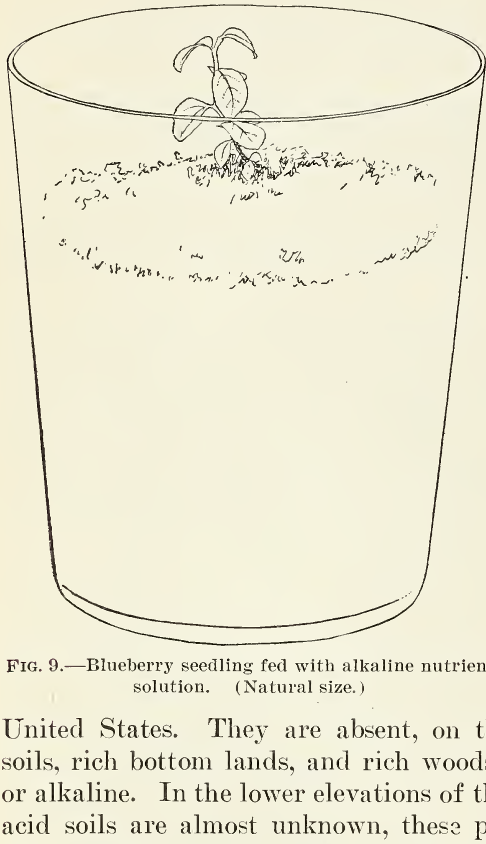


FIG. 9.—Blueberry seedling fed with alkaline nutrient solution. (Natural size.)

The natural distribution of blueberries and their relatives indicates their close adherence to acid soils. They occur in abundance throughout the sandy Coastal Plain of the Atlantic seaboard. They occur generally through the cool humid hill lands of New England. They occur in sandy pine barrens and peat bogs throughout the eastern United States. They are absent, on the contrary, from limestone soils, rich bottom lands, and rich woods, where the soils are neutral or alkaline. In the lower elevations of the whole subarid West, where acid soils are almost unknown, these plants do not occur. Within reach of the fogs and heavy rainfall of the Pacific coast or on the higher mountains of the interior, where conditions favor the development of acid soils, blueberries occur again in characteristic abundance.

From an examination of the reports of those who have attempted at the agricultural experiment stations to domesticate and improve the blueberry, it is evident in the light of the present experiments that the primary reason for these failures was that they did not recognize soil acidity as a fundamental requirement of these plants. It was perhaps natural to give the blueberry the same garden culture that when applied to other bush fruits has resulted in their distinct improvement. But the ordinary garden operations tend to make even an acid soil neutral or alkaline, and in such a soil the blueberry does not thrive.

The death and decay of blueberry roots, with which the injurious effect of alkaline soils is associated, are discussed on pages 64 and 65.

(7) The favorite type of acid soil for the swamp blueberry is peat.

Although the swamp blueberry sometimes grows on upland soils its typical habitat, as its name implies, is in swamps or bogs. The cranberry, it is well known, is cultivated almost exclusively in bogs. In clearing bog land preparatory to the planting of cranberries one of the necessary precautions is to remove all roots of the swamp blueberry. If the roots are allowed to remain in the ground, they send up vigorous shoots, and these, unless pulled, develop into robust plants which occupy the ground to the great injury of the cranberries. Large, healthy, and productive bushes of the swamp blueberry are frequent, almost characteristic, inhabitants of the uncultivated borders of cranberry bogs.

Fig. 10.—Blueberry seedling fed with acid nutrient solution. (Natural size.)

Peat bogs, in the conception of geologists, are incipient coal beds. The transformation of peat into coal occupies very long periods, perhaps some millions of years. Peat is made up chiefly of vegetable matter, the dead leaves, stems, and roots of bog plants which are only partly decayed. Their full decay is prevented primarily by the presence of water, which keeps away the air. The bacteria, fungi, and other organisms by which ordinary decomposition progresses can not live under this condition and decay is suspended. The acids developed by this vegetable matter in the early stages of its decomposition are also destructive to some of the organisms of decay, especially bacteria. These acids act therefore as preservatives and greatly assist in preventing decomposition. So effective are these conditions of acidity and lack of oxygen, assisted in northern latitudes by low temperature, which is also inimical to the organisms of decay, that bogs sometimes preserve for thousands of years the most delicate structures of ferns and mosses.

Tests have been made of the acidity of typical peat bogs in New England where swamp blueberries are growing. These peats were always found to be acid and the degree of acidity was within the range found satisfactory for blueberry plants in pot cultures.

The reason why peat is a particularly satisfactory type of acid soil for blueberries is, apparently, because the acidity of peat is of a mild type, yet continually maintained.

Not all peats are acid. About the larger alkaline (but not destructively alkaline) springs of our southwestern desert region are deep deposits of rather well-decayed vegetable matter that must be classed as peat. The characteristic vegetation growing on these peats is tule (*Scirpus occidentalis* and *S. olneyi*). The water of one of the great tule swamps of the West (Lower Klamath Lake in southern Oregon), which contains thick beds of peat formed chiefly from *Scirpus occidentalis*, has been examined recently by Mr. J. F. Breazeale, at the request of Mr. C. S. Scofield. It was found to contain sodium carbonate, and the peat gave a distinctly alkaline reaction.

The peat formed about marl ponds in the eastern United States is also, in all probability, alkaline unless formed at a sufficient distance from the lime-laden water to be beyond the reach of its acid-neutralizing influence.

Such alkaline peats, while not actually tried, are believed from other experiments to be quite useless for growing blueberries. Certain it is that neither blueberries nor any of their immediate relatives are found on these soils in a wild state. In the eastern United States, however, such alkaline peats are comparatively rare, and the use of the word "peat" conveys ordinarily the idea of acidity. All the soils used by gardeners under the name of peat are acid.

(8) Peat suitable for the swamp blueberry may be found either in bogs or on the surface of the ground in sandy oak or pine woods.

In the vicinity of Washington deposits of bog peat are few and of limited extent, and the peat is thin. As a matter of fact no bog peat of local origin is used by the gardeners and florists of Washington. For growing orchids, ferns, azaleas, and other peat-loving plants, either peat shipped from New Jersey is used or a local product sometimes known as "Maryland peat." This material is not a bog peat at all, and since it is of very great interest in connection with these blueberry experiments, for it was the principal ingredient in a majority of the successful soil mixtures used, it is desirable that the reader have a comprehensive idea of its character.

Maryland peat, as brought to the greenhouses of the United States Department of Agriculture, consists of dark-brown turfs or mats, 2 to 4 inches thick, made up of partially decomposed leaves interlaced with fine roots. It is found in thickets of the American laurel (*Kalmia latifolia*) where the leaves of this shrub, usually mixed with those of various species of oak, have lodged year after year and the accumulated layers have become partly decayed.

The nature of the deposit may be easily comprehended by means of the accompanying illustrations. The photographs from which the illustrations were made were secured through the courtesy and skill of Mr. G. N. Collins, of the Bureau of Plant Industry. The photographs were made in the month of April, 1908, in a laurel thicket at Lanham, Md. After one photograph was made, the layer of leaves represented by it was removed and another photograph was taken showing the layer immediately underneath.

In Plate III, figure 1, is shown the top layer of the leaf deposit as it appeared in April, 1908, consisting of oak leaves of various species which fell to the ground in the autumn of 1907. The next underlying layer is shown in Plate III, figure 2. The laurel leaves here shown are those that fell in the summer of 1907. Laurel being an evergreen, its leaves are not shed in the autumn like those of the oaks. They remain on the bush until the new leaves of the following spring are fully developed and then the old leaves begin to fall. It is this circumstance of the fall of the oak and laurel leaves at different periods of the year that enables one to recognize the different layers and know their exact age. The third layer, shown in Plate IV, figure 1, consists of oak leaves of the autumn of 1906. This layer was moist and decomposition was well started. The presence of fungous growth is evident, as is also the excrement of various small animals. Myriapods, or thousand-legged worms, and the larvæ of insects must play a very important part under some conditions in hastening the decomposition of leaves. The fourth layer, Plate IV, figure 2, consisting of laurel leaves shed in the summer of 1906, is in about the same condition as the preceding layer. In the fifth layer, Plate V, figure 1, are shown the leaves of 1905, but the layer of oak leaves is not readily separable from the laurel. The rotted leaves crumble readily and decomposition has so far progressed that a few oak rootlets are found spread out between the flattened leaves. Plate V, figure 2, shows the rotted leaf layers of 1904 interlaced with the rootlets of laurel and oak. It is this root-bearing layer, 2 inches or more in thickness, of which

Maryland peat is composed. The lower portions of it reach a somewhat greater degree of decomposition than is here shown.

In a rich woods of the trillium-producing type, such as a fertile sugar-maple forest, one may observe that the leaves in rotting seldom retain their form longer than two years and that the line of demarcation between the thin leaf litter of the forest and the underlying woods mold is sharp and clear.

In the sugar-maple woods the decomposition of the leaves is rapid. In the Maryland or kalmia peat, as it may be called with more exactness, the decomposition is slow. The cause of this difference in the rate of decomposition is the difference of acidity in the two cases, and this in turn is dependent on the nature of the leaves and of the underlying soil, particularly whether the soil is acid or alkaline. A slight alkalinity in a soil greatly favors the decomposition of the leaves overlying it. An acidity as strong as that shown to occur in newly fallen oak leaves (see p. 62) can not help having a pronounced effect in maintaining the acidity of the lower leaf layers; for it must be remembered that these acids are soluble in rain water, and are therefore continually leaching down from the upper through the lower layers of rotting leaves.

These upland leaf deposits, in which decomposition is retarded for many years, the writer regards as essentially peat, and to distinguish them from bog peats he would call them upland peats. An upland peat may be described as a nonpaludose deposit of organic matter, chiefly leaves, in a condition of suspended and imperfect decomposition and still showing its original leaf structure, the suspension of decomposition being due to the development and maintenance of an acid condition which is inimical to the growth of the micro-organisms of decay.

The use of the name "leaf mold," sometimes applied to this upland peat, should be restricted to the advanced stages in the decomposition of leaves, in which leaf structure has disappeared. True leaf mold, furthermore, is neutral or alkaline, so far as tested.

When kalmia peat is to be used for growing blueberries it should be piled and rotted for several months. An experience which emphasizes the need of this treatment is given on page 60. If stacked as soon as it is dug it usually retains sufficient moisture to carry the rotting forward, even if the stack is under cover.

Kalmia peat has proved to be a highly successful soil for growing blueberries. It has been tried both pure and in many mixtures, as will be described in the paragraphs beginning on page 51.

An upland peat formed of the leaves of scrub pine (*Pinus virginiana*) has also been tried for blueberry seedlings. They grow well in it.

Oak leaves, it is believed, rotted for one or two years would make a good blueberry soil. In the Arlington National Cemetery is a ravine

FIG. 1.—FORMATION OF KALMIA PEAT, TOP LAYER.

Oak leaves of the preceding autumn. (Natural size.)

FIG. 2.—FORMATION OF KALMIA PEAT, SECOND LAYER.

Kalmia leaves of the preceding summer. (Natural size.)

FIG. 1.—FORMATION OF KALMIA PEAT, THIRD LAYER.

Oak leaves 2 years old. (Natural size.)

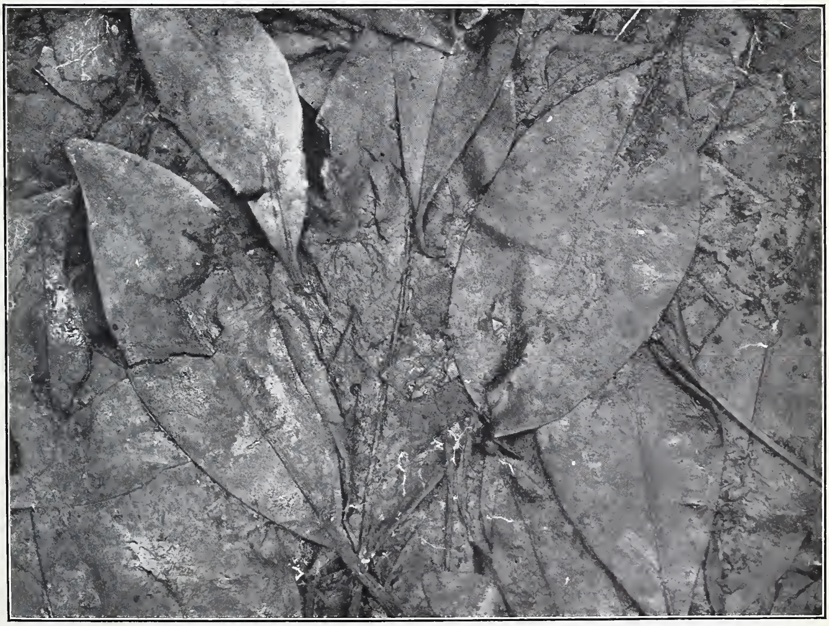


FIG. 2.—FORMATION OF KALMIA PEAT, FOURTH LAYER.

Kalmia leaves 2 years old. (Natural size.)

FIG. 1.—FORMATION OF KALMIA PEAT, FIFTH LAYER.

Mixed oak and kalmia leaves 3 years old. A few live rootlets of oak are shown. (Natural size.)

FIG. 2.—FORMATION OF KALMIA PEAT, SIXTH LAYER.

Mixed oak and kalmia leaves 4 years or more old interlaced with live rootlets of oak and kalmia. (Natural size.)

in which large quantities of leaves, chiefly oak, have been dumped for many years. Samples taken there in late November, 1909, show an acidity in the case of freshly fallen leaves of 0.4 normal; in leaves apparently 1 year old, 0.006; and in leaves about 2 years old, 0.002.

A condition of great interest was found in one of these piles of leaf mold which was several years old. It was mellow and black, and the evidence of leaf structure had disappeared. When submitted to the phenolphthalein test it proved to be alkaline, and upon chemical examination it was found to contain 3.55 per cent of lime (CaO). In this case decomposition had progressed so far, it is suggested, that the lime in the leaves, remaining constant in amount and probably having been changed to a more soluble state, had neutralized the remaining acidity. The material, then becoming alkaline, had proceeded to decompose with greater rapidity, until a real mold had been formed.

The condition here observed is doubtless the same as that which occurs in the drained bog, or so-called "muck," lands of Michigan. When first plowed they will grow only certain acid-resistant crops, such as buckwheat or potatoes, but later, as their acidity disappears, they come to attain a very high degree of fertility. It is probably a phenomenon of similar character which is taking place in the drained swamp lands of the lower Sacramento River in California, where the soil, which is already in a state of remarkable fertility, is becoming increasingly alkaline.

Here allusion may be made to another phenomenon, that of the occurrence of the swamp blueberry and certain other plants, such as the purple lady's-slipper (*Cypripedium acaule*) and the swamp honeysuckle (*Azalea nudiflora*), in two kinds of situations—one a peat bog, the other a sandy, well-drained, and often dry upland. The favorite explanation of this phenomenon among botanists is that these plants are naturally adapted to the drier situation and that in the bog they find a situation of "physiological dryness," or vice versa. While the existence of physiological dryness in peat bogs is not questioned, the explanation that a bog plant finds an upland situation congenial because it is dry certainly will not answer for the blueberry. Its occurrence in these two habitats is dependent on the acidity of both situations. These experiments have shown that no amount of dryness will make a blueberry flourish in an upland soil if that soil is not acid.

(9) For active growth the swamp blueberry requires a well-aerated soil. Conversely, the swamp blueberry does not continue in active growth in a soil saturated with water.

In its natural distribution the swamp blueberry does not grow in the lower, wetter type of bog. In a typical leatherleaf (*Chamaedaphne calyculata*) bog, for example, the swamp blueberry is found either about the margin of the bog or on hummocks. In both these situations most of the roots of the blueberry bushes stand above the summer level of the water. When a bog has been built up by the growth of vegetation and the accumulation of the débris until the surface is above the summer water level, the swamp blueberry will occur generally over the bog.

An examination of blueberry plants occurring on hummocks and bog margins has shown that such roots as extend beneath the permanent summer water level bear few feeding rootlets or none at all.

In one experiment it was attempted to grow blueberry seedlings in water cultures containing various dissolved nutrients. It was found that the roots made no new growth, that the new leaves were few and small, and that the general health of the plants was not good, whatever the character of the nutrient substances in the solutions. It was frequently observed also in the various soil cultures, particularly those in undrained glass pots, that the continued saturation of the soil with water reduced the root growth and enfeebled the whole plant. Continued excessive watering of potted blueberry plants was always found injurious.

The observations just recorded must not be understood to mean that submergence of the roots is always injurious to the swamp blueberry. In winter and early spring the water level of bogs containing blueberries often remains high enough for several months to completely submerge the whole root system of the plants. On the lower end of the Wankinco cranberry bog near Wareham, Mass., are some native bushes of the swamp blueberry, the roots of which have been submerged in 3 feet of water from December to May each year for about twenty years. These bushes when observed in September, 1909, gave every evidence of vigor. Their twig growth was of good length and thickness, their foliage was dense and of a healthy color, their flowering buds for the next year were fairly numerous, and the bushes were said to be as productive of fruit as neighboring bushes on higher ground.

It would appear from these facts that, while submergence during the dormant period is not injurious to the swamp blueberry, its roots during their actively growing period must be kept above the water level so as to be well aerated.

(10) Aeration conditions satisfactory for the swamp blueberry are prevalent in sandy soils.

The experiment cited above on this page showed that blueberry seedlings having their roots suspended in nutrient solutions failed to make a normal growth even though the solutions were suitably acidulated. This failure was ascribed to lack of aeration. In another experiment, described on pages 28 and 29, it was shown that a similar nutrient solution when used to water a blueberry plant potted in sand produced a normal growth of both roots and stems. The sand furnished no appreciable nourishment and the only essential difference in the two cases was the abundant root aeration afforded by the sand culture. Sand is therefore regarded as having been shown experimentally to furnish conditions suitable for soil aeration.

In all the experiments in which blueberry seedlings were grown in sand cultures suitably acidulated, the root growth was good, even when very little nourishment was given the plant, and when fed with a weakly acid nutrient solution or with peat water the sand-potted plants always made a luxuriant root growth.

In their wild state blueberries are especially prevalent on the sandy soils of the Atlantic Coastal Plain, as well as on sandy plains and pine barrens in the interior. The drainage of such soils is good and their aeration is excellent.

(11) Aeration conditions satisfactory for the swamp blueberry are found in drained fibrous peat.

Kalmia peat when in the original turfs or mats is full of small roots of oak, kalmia, and other plants. In that condition it is remarkably porous and well aerated. Pieces of these turfs were used with great success in the bottoms of pots, in place of crocks, to afford drainage. For a potting soil, however, kalmia peat can not easily be used until the soil has been shaken from the mass of roots or has been rubbed through a screen. Even in that condition the fragments of leaves and rootlets make the whole mass porous. A pot containing pure kalmia peat prepared by such rubbing often remains moist, yet well aerated, for days at a time without watering. This moisture condition is due to two remarkable properties of peat, its ability to hold a large amount of water, and the tenacity with which it clings to it.

Kalmia peat taken from the interior of a stack after it has remained several months under cover ordinarily contains 100 per cent of water, computed on the dry weight of the peat. Even with this very high water content a peat soil is in a beautiful condition of tilth, mellow, well aerated, and to the sight and touch apparently only moderately moist. Ordinary loam in a similar condition contains only about 18 per cent of water, and sand about 3 per cent. When saturated with water the moisture content of kalmia peat is about 500 per cent of its dry weight.

The ability of peat to retain its moisture depends in part on the gradual drying of the superficial layers and the consequent formation of a mulch, but more particularly is it dependent on a certain physical affinity that peat possesses for water. The comparative strength of this water-holding power in different soils may be tested by subjecting them to a powerful centrifugal force, which tends to throw the moisture out of the soil. The standard centrifugal force used is a thousand times the force of gravity. The percentage of moisture remaining in the soil after this treatment is known as the moisture equivalent of that soil. A test of kalmia peat made by Dr. Lyman J. Briggs, of the Bureau of Plant Industry, the originator of this method of measurement, showed a moisture equivalent of 142 per cent, as compared with about 30 per cent for clay, 18 per cent for loam, and 2 to 4 per cent for sand.

From what has been said it is evident that fibrous kalmia peat has physical characteristics that allow the soil to be amply aerated, while at the same time holding abundant moisture for the supporting of plant growth.

In this connection reference may be made to the influence of earthworms on potted blueberry plants. Late in the winter of 1908–9 it was noted that among the blueberry seedlings of 1907, which had been brought into the greenhouse, were several in which the growth was feeble, although others of the same lot were growing vigorously. It was noted also that the soil in the pots in which the feeble plants were growing contained earthworms, as evidenced by the excrement or casts deposited by them on the surface. The worms themselves were easily found by knocking the earth ball out of the pot, and the soil was seen to have been thoroughly worked over by the worms.

It was supposed at first that the soil (a mixture of peat 8, sand 1, loam 1) in the process of digestion to which it had been subjected in passing through the alimentary canal of the earthworms might have become alkaline and for this reason injurious to the blueberry plants. When tested with phenolphthalein, however, the soil in the pots containing earthworms and feeble plants was found to be of the same acidity as that in the pots containing no earthworms and with vigorously growing plants. Furthermore the fresh casts themselves were of a similar degree of acidity.

The texture of the soil, however, in the pots containing worms was very different from that in the others. It was plastic, very fine grained, almost clayey, the organic portion having been very finely ground evidently in passing through the gizzard and other digestive apparatus of the earthworms. The aeration of the soil in this condition must have been far poorer than in the coarser soil containing a large amount of leaf fragments not worked over by worms, and it may be that the difference in growth of the blueberry plants was due to the difference in aeration. It is not by any means certain, however, that the plants in the pots containing earthworms may not have been injured directly through the eating of their rootlets by the worms.

(12) Aeration conditions satisfactory for the swamp blueberry are found in masses of live, moist, but not submerged sphagnum.

In some swamps the water level remains permanently above the general surface of the ground. When the swamp blueberry occurs in such situations it grows on hummocks the summits of which stand above the water during the growing season. Unless the water level is extremely variable or the ground is densely shaded, these hummocks are usually covered with a cushion of live sphagnum moss. It is a peculiarity of this moss that it absorbs water with great avidity; indeed, sphagnum is one of the most absorbent substances known. If one end of a nearly dry branch of sphagnum is brought into contact with a little water, the whole branch becomes wet almost instantly. The water rushes along with marvelous rapidity through the cells of the plant and especially through the interstices between the minute overlapping leaves. The white air spaces between the half dry leaves flash out of existence one after the other like candle flames in a gust of wind. The same ability to absorb water is characteristic of masses of this plant. If the lower part of a cushion of sphagnum is in contact with free water the fluid is conveyed from stem to branch and from plant to plant in sufficient amount to render the whole mass as wet as a sponge. When one squeezes a handful of such moss taken perhaps a foot or more above the source of moisture the water runs out in streams. A sample of live sphagnum with less moisture than usual but still with enough to maintain itself in a growing condition was found to contain 991 per cent of water, computed on the dry weight of the sphagnum, while saturated live sphagnum carried 4,005 per cent of water. On the basis of its dry weight, therefore, sphagnum contains about ten times as much water as peat, which itself contains about six times as much as ordinary loam and about thirty-five times as much as sand.

The innumerable extracapillary air spaces between the branches of sphagnum plants and between the plants themselves furnish good aeration, even when the individual branches are saturated with water. When the moisture is less the aeration is still better. The cushion of sphagnum on a hummock tends to build itself up by the gradual process of growth and decay to the maximum height to which it can convey the large amount of water réquired for its growth, and an increasing degree of aeration is found from the water line upward.

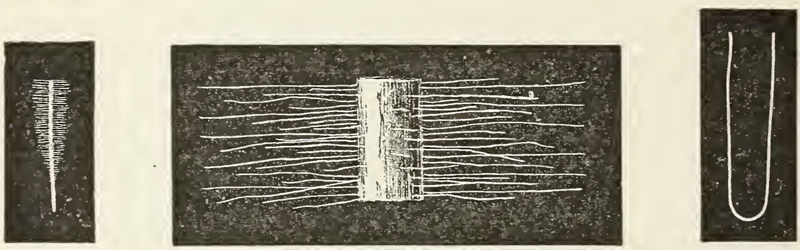
If the sphagnum cushion on a blueberry hummock is examined the whole mass will be found interlaced with the minute rootlets of the blueberry, far above the level of the underlying soil. The conditions of permanent moisture and thorough aeration found in these sphagnum cushions seem to be almost ideal for the development of blueberry roots.

It must not be assumed that the vigorous growth of blueberry roots in sphagnum is due to any high nutritive quality of the sphagnum itself. Such a conclusion would be erroneous. When set out in sphagnum and watered with tap water, blueberry plants remain healthy and develop a very large root system, but the stems do not grow as luxuriantly as when the plants are in a peat soil. From experiments with the growing of blueberries in sand watered with peat water it is known that such water furnishes the food materials necessary for vigorous growth. It is reasonable to conclude, therefore, that the chief nourishment of a blueberry plant growing on a pure sphagnum hummock comes from the bog water sucked up by the sphagnum and not from the sphagnum itself.

### PECULIARITIES OF NUTRITION.

(13) THE SWAMP BLUEBERRY IS DEVOID OF ROOT HAIRS, THE MINUTE ORGANS THROUGH WHICH THE ORDINARY PLANTS OF AGRICULTURE ABSORB THEIR MOISTURE AND FOOD.

The structure of the rootlets of ordinary agricultural plants may be understood by reference to figures 11 to 13, which illustrate these organs as they occur in a wheat seedling germinated between layers of moist blotting paper. Attention is directed particularly to the



11 12. 13.

FIG. 11.—Root of a wheat plant, showing the root hairs. (Natural size.)
FIG. 12.—Portion of a wheat root, with root hairs. (Enlarged 10 diameters.)
FIG. 13.—Tip of the root hair of a wheat plant. (Enlarged 1,000 diameters.)

root hairs. It will be observed that the wall of the root hair is very thin, appearing in optical section as a mere line with barely measurable thickness, even when highly magnified. Furthermore, the surface area of the root hairs is many times greater than that of the root itself. The chief function of these root hairs is to absorb for the use of the plant the soil moisture and the plant-food materials dissolved in it, a function which the root hairs are enabled to perform with great efficiency because of the two characteristics just mentioned—their large surface area and the thinness of their walls.

The rootlets of the blueberry are remarkable in having no root hairs whatever, as may be seen by reference to figures 14 to 16. The walls of the superficial, or epidermal, cells of the rootlets are thick, measuring 0.00005 to 0.0001 of an inch (1.3 to 2.5 $\mu$), while the walls of the root hairs of wheat are one-fourth to one-sixth as thick, so thin, in fact, that they could be measured only with difficulty even when enlarged 5,900 diameters. Notwithstanding the fact, therefore, that the blueberry roots are fine and numerous, their actual absorptive capacity would appear to be small, in consequence of the absence of root hairs.

FIG. 14.—Root of a blueberry plant. (Natural size.)

It is found by a computation that a section of a blueberry rootlet having no root hairs presents about one-tenth the absorptive surface of an equal area of a wheat rootlet bearing root hairs, and the thickness of the surface membranes in the wheat is certainly not more than a quarter that in the blueberry. Furthermore, the blueberry rootlet grows only about 0.04 inch (1 mm.) a day under favorable conditions, while the wheat rootlet often grows twenty times as fast. In all this provision for rapid food absorption in the one plant and retarded absorption in the other we find a reason for

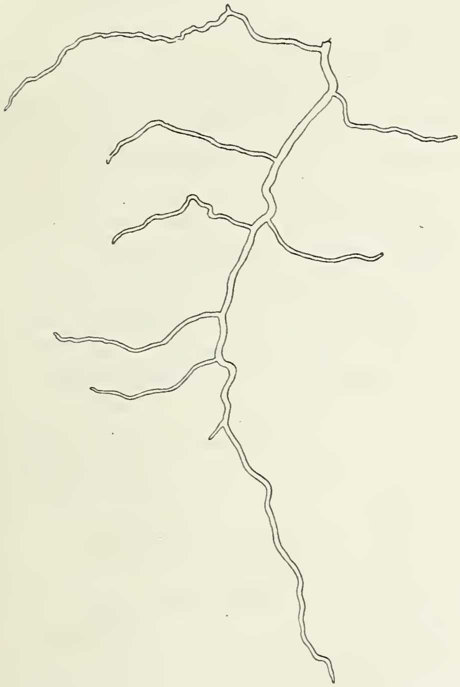


FIG. 15.—Root of a blueberry plant. (Enlarged 10 diameters.)

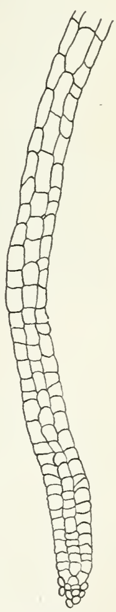


FIG. 16.—Blueberry rootlet. (Enlarged 100 diameters.)

the comparatively very slow rate of stem growth that characterizes the blueberry plant. The importance of slow root absorption and the danger to which these plants would be subjected if their roots absorbed water rapidly are discussed on page 50.

The young rootlets of the blueberry before they branch are exceedingly slender, varying from 0.002 to 0.003 of an inch (50 to 75 $\mu$) in diameter. This makes them very susceptible to actual drying and they are easily killed by it. This characteristic has an important bearing on the treatment of these plants when in pots. The matter is discussed on pages 65 to 67.

(14) THE ROOTLETS OF HEALTHY PLANTS OF THE SWAMP BLUEBERRY ARE INHABITED BY A FUNGUS, OF THE SORT KNOWN TECHNICALLY AS AN ENDOTROPHIC MYCORRHIZA.[a]

As already stated, the ultimate rootlets of the blueberry are very fine, their diameter varying from 0.002 to 0.003 of an inch (50 to 75 $\mu$). In rootlets of the smaller size about three rows of epidermal cells are visible in a lateral view, in the larger rootlets about five rows. In a newly grown rootlet not contaminated with soil particles these epidermal cells, and, indeed, all the underlying cells as well, are as transparent as glass, and were it not for the difficulties due to the refraction of light the examination of the contents of the cells would not be difficult. As a matter of fact the study of the contents of the live cells is difficult, their intelligent examination requiring the use of an oil immersion objective and microscopic enlargements of 1,000 to 1,500 diameters. The darkened window installation for a microscope, devised by Dr. N. A. Cobb, of the Bureau of Plant Industry, and used in his laboratory, has been found almost indispensable in this work.

Clean rootlets may be procured readily from active blueberry plants in the open spaces between half-rotted leaf blades, in clean sand, in live sphagnum, or at the outer surface of the ball of soil in earthen pots. Rootlets taken from live sphagnum are especially clean. They are conveniently studied when simply placed in water on a microscope slide under a thin cover glass held in place by a ring of paraffin.

Ordinarily the only thing visible in one of the live epidermal cells is the minute cell nucleus lying close to the cell wall. The protoplasmic membrane lining the cell is very thin and is invisible except where it is thickened to envelop the nucleus. The remainder of the cell is filled with the colorless cell sap. An examination with medium enlargements will show some of the cells faintly clouded in appearance. A higher power, such as is afforded by a 2-mm. oil immersion objective and a 12-mm. eyepiece, with proper illumination, will resolve the cloudiness into a mass of fungous threads, or hyphæ. These may be few, making only two or three irregular turns about the interior of the cell, as occasionally found, or they may be more numerous, even occupying the whole sap space, as shown in figure 17, in a dense knot

[a] The spelling *mycorhiza* is also in good standing and is used in many German, English, and American botanical works.

of interwoven and irregular snakelike coils. These hyphæ are about 0.00006 to 0.00012 of an inch (1.5 to 3 $\mu$) in diameter.

On the outer surface of the cells containing these fungous threads others of similar or a little greater thickness may be observed. Sometimes they are transparent and their detection requires the same high power of the microscope as do those in the interior of the cells. Sometimes, however, these exterior threads have a pale-brown color and are then readily seen. Their surface is smooth, devoid of markings of any kind. Ordinarily the thread wanders loosely along the surface of the root giving off an occasional branch and having an occasional septum. Sometimes the threads and their branches may form an open network about the rootlet, but they never form a dense sheath of hyphæ such as is characteristic of the mycorrhiza of the oak.

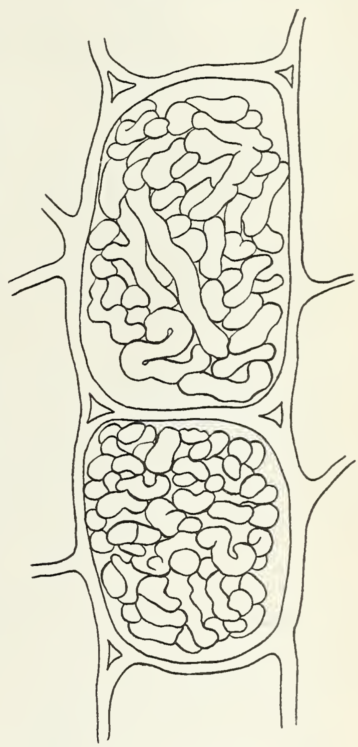


FIG. 17.—Mycorrhizal fungus of a blueberry plant densely crowded in two epidermal cells of the root. (Enlarged about 1,200 diameters.)

The connection between the external and the internal hyphæ is not easy to see at a single observation, for the passage of the hyphæ through the cell wall is rarely caught in optical section, and even then a clear observation is usually rendered difficult because of refraction. A very clear case, however, was observed in a rootlet of laurel (*Kalmia latifolia*), a shrub which has a mycorrhizal fungus similar to that of the blueberry. A drawing of that specimen is shown in figure 18.

The passage of the fungus through the cell wall may frequently be observed in the blueberry by first focusing on the external hypha at a point where it appears to have a lateral hump or a very short branch, and then focusing slowly downward. In this way one passes from the external to the internal part of the fungus, having had some portion of the intervening hypha continuously in view. The hypha always appears much constricted at the point where it goes through the cell wall.

This fungus is of the type named by Frank in 1887 an endotrophic mycorrhiza to distinguish it from an ectotrophic mycorrhiza, such as occurs on the roots of oaks. In the latter type of mycorrhiza the hyphæ of the fungus form a dense sheath around the rootlet, completely shutting it off from direct contact with the surrounding soil. The loose hyphæ on the outside of the sheath resemble root hairs and it is supposed to be a part of their function to absorb soil moisture and transmit it to the oak rootlet just as root hairs do.

It has not yet been possible, for want of time, to study the life history of this mycorrhizal fungus of the blueberry. There is, however, a clew to its identity in the work of Miss Charlotte Ternetz, Ph. D., described on page 49.

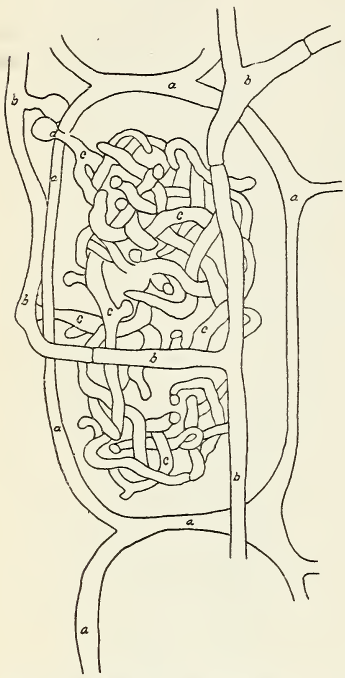



FIG. 18.—Mycorrhizal fungus of *Kalmia latifolia* in an epidermal cell of the root: *a*, Cell walls; *b*, external hyphæ of the mycorrhizal fungus; *c*, internal hyphæ; *d*, point of penetration of the cell wall by the mycorrhizal fungus. (Enlarged about 1,000 diameters.)

The experiments thus far made do not warrant a supposition that any good peat soil requires inoculation with the mycorrhizal fungus before blueberry plants will grow well in it. The fungus appears either to be already in the soil or to accompany the seeds when they are sown in it.

(15) THE MYCORRHIZAL FUNGUS OF THE SWAMP BLUEBERRY APPEARS TO HAVE NO INJURIOUS EFFECT, BUT RATHER A BENEFICIAL EFFECT, UPON THE BLUEBERRY PLANT.

The epidermal cells in which the mycorrhizal fungus occurs are not swollen nor distorted, nor do their contents collapse or show any of the other effects usually produced by pathological fungi. They appear to differ in no respect from other epidermal cells of the blueberry rootlets. In rapidly growing rootlets the fungus seems not to be able to keep pace with the rootlet itself and may not occur for a considerable distance back from the growing tip. The fungus-filled cells ordinarily are most numerous on certain small, short, and crooked lateral rootlets the growth of which is slow. When root growth of a vigorous plant is retarded or becomes even stagnated, the fungus may invade the epidermal cells to the very apex. Sometimes half the cells in such a rootlet are gorged with fungi, yet the delicate cell walls show no displacement or distortion. There is no indication whatever that the fungus causes any pathological disturbance or is in any way obnoxious to the plant. On the contrary, the uniformity with which it has been found to occur on healthy plants and its frequent absence or scarcity on sickly plants are facts suggestive of a beneficial influence. The nature of this beneficial influence is discussed on pages 48 to 50.

(16) THE ACID PEATY SOILS IN WHICH THE SWAMP BLUEBERRY THRIVES ARE DEFICIENT IN "AVAILABLE" NITROGEN, ALTHOUGH CONTAINING LARGE AMOUNTS OF "NONAVAILABLE" NITROGEN.

Ordinary agricultural plants absorb their nitrogen from the soil in the form of nitrates. Whether any are able to utilize directly other forms of nitrogen, particularly ammonia nitrogen, has been the subject of much experiment and of discussion by many authors. It is true in general, however, that the common plants of agriculture when their other food requirements are satisfactory make their growth in direct proportion to their ability to secure their nitrogen in the form of nitrates. For this reason the processes of agriculture are largely devoted to the securing and maintenance of conditions that will bring about the transformation of nonavailable nitrogen into nitrates. Soils in which this can not be done without great expense in proportion to their productiveness are generally considered poor.

The acid soils in which wild blueberries thrive are always looked upon as infertile in their natural state, and unless these soils are extensively manipulated cultivated plants do not do well in them. Whether or not a part of this infertility is due to the directly injurious effect of acid or other poisonous substances, it is known that the conditions existing in these soils are directly antagonistic to the formation of nitrates. (See p. 47.)

That kalmia peat, the soil found in these cultures to be most successful for blueberries, is deficient in nitrates, although containing an abundance of nitrogen in other forms, is shown by the following nitrogen determinations:

TOTAL NITROGEN IN KALMIA PEAT.

(Determinations made by Mr. T. C. Trescott.)

| Sample. | Per cent. |
|---|---|
| 1 | 0.95 |
| 2 | 1.46 |
| 3 | 1.18 |
| 4 | 1.15 |
| 5 | 1.40 |
| 6 | 1.12 |
| Average of total nitrogen | 1.21 |

NITROGEN IN KALMIA PEAT IN THE FORM OF NITRATES.

(Determinations made by Mr. Karl F. Kellerman.)

| Sample. | Per cent. |
|---|---|
| 7 | 0.0012 |
| 8 | .0022 |
| 9 | .0008 |
| 10 | .0013 |
| 11 | .0025 |
| 12 | .0008 |
| Average of nitrate nitrogen | .0015 |

(17) THE DEFICIENCY OF AVAILABLE NITROGEN IN THE ACID PEATY SOIL IN WHICH THE SWAMP BLUEBERRY GROWS BEST IS DUE TO THE INABILITY OF THE NITRIFYING BACTERIA TO THRIVE IN SUCH A SOIL BECAUSE OF ITS ACIDITY.

In order to understand the conditions antagonistic to nitrification which exist in good blueberry soils it is necessary first to discuss the source and transformation of nitrogen in ordinary soils.

The available nitrogen in the soil, such as is absorbed by an ordinary plant, is commonly derived, unless fertilizers have been applied, from the decomposition of the humus contained in the soil, and the humus is itself a product of the decomposition of plant and animal remains. These remains consist ordinarily and chiefly of the partially rotted leaves, stems, and roots of plants.

In the older agricultural literature the name humus was applied to a particular kind of soil which is more properly covered by the terms vegetable mold, leaf mold, and woods mold. (See p. 24.) Later the application of the word humus was restricted to that portion of a soil consisting of the plant and animal remains, in whatever stage of decomposition. The proper designation of these remains is, however, organic matter. In the sense just described the word humus is still frequently used, but not with correctness and precision. Humus, as now understood by agricultural chemists, represents a stage in the decomposition of organic matter in which the cellular structure has wholly disappeared and the original substance is or at some stage has been entirely dissolved.

Since it is often necessary to allude to organic matter in the earlier stage, as distinguished from organic matter as a whole, which includes the humus stage as well, the term cellular organic matter, or, more simply still, cellular matter, is suggested as a convenient designation. In cellular matter the cellular structure of the animals or plants still remains and may be detected either by the eye or by the microscope.

Humus, which is a complex mixture of diverse substances, does not ordinarily exist in the soil in a dissolved condition, but is usually combined with lime or magnesium. The resultant compounds, often indiscriminately blanketed under the names calcium and magnesium humate, are not soluble in water, but form a usually black precipitate, which gives a dark color to the soil.

To extract its humus a soil is first washed with dilute acid, by which the lime, magnesium, or other humus-precipitating substance is dissolved and leached away. The humus itself is then removed from the soil by long-continued washing with a weak solution, commonly 4 per cent, of ammonia. Upon the application of this treatment to kalmia peat an inky-black extract is secured. When this is evaporated to dryness the residue is a black substance which when scraped from the dish resembles coal dust or, even more closely, burned sugar. This substance is one of the forms of humus. It absorbs water readily, assuming the texture of thin jelly. It has a somewhat sooty odor and taste. It dissolves in water, the solution being acid in reaction. A liter of water in which had been dissolved a gram of humus extracted from kalmia peat showed when tested a 0.002 normal acidity. Such a solution is black unless viewed in a thin layer, and when diluted to 10,000 c. c. it has a brown color similar to that of ordinary cider vinegar. If lime is added to the solution the humus unites with it and is thrown down as a black precipitate, leaving the liquid clear. As stated in the preceding paragraph, it is in such a precipitated and neutral or alkaline form that humus ordinarily occurs. The characteristic brown color of the water in bogs indicates an acid condition, the presence of humus in solution, and the absence of soluble lime.

The process of decomposition by which cellular matter is transformed into humus, in which the cellular structure has entirely disappeared, is known as humification.

Humus contains nitrogen, but the nitrogen is not in the form of nitrates and therefore can not be assimilated by ordinary plants. The transformation of humus nitrogen into nitrates occurs during a further process of decomposition known as nitrification.

The nitrification of humus is brought about by certain bacteria which, growing in the humus-laden soil under suitable conditions, produce first ammonia, then nitrites, and then nitrates. In artificial cultures, in addition to proper conditions of temperature and moisture, and good aeration, these nitrifying bacteria require for vigorous growth a neutral or slightly alkaline medium. In a distinctly acid medium the nitrifying bacteria grow little or not at all.

In order to ascertain the degree of nitrification, if any, taking place in kalmia peat, a series of nitrification tests of this material was made by Mr. Karl F. Kellerman. These tests showed that neither in fresh peat nor in peat rotted for three months was nitrification in progress, but when the acidity of the peat was neutralized by the addition of lime nitrification began.

(18) From the evidence at hand the presumption is that the mycorrhizal fungus of the swamp blueberry transforms the nonavailable nitrogen of peaty soils into a form of nitrogen available for the nourishment of the blueberry plant.

It is a well-established principle of plant physiology that (with the possible exception of a few bacteria) those plants which contain no chlorophyll, the green coloring matter of leaves, are unable to grow with mineral nutrients alone, since they are unable to manufacture their own carbohydrates. Plants without chlorophyll, including the fungi, are dependent for the fundamental part of their nourishment on the starch or other related carbohydrates originally elaborated from carbon dioxid and water by the chlorophyll-bearing plants. They also differ from the higher plants in being able to supply their nitrogen requirements directly from organic nitrogen compounds.

Fungi may be directly parasitic on a chlorophyll-bearing plant, as in the case of the mildew fungus of rose leaves, or they may grow on substances derived from chlorophyll-bearing plants, such as bread or jelly.

Fungi are particularly abundant in the decaying vegetable matter forming the leaf litter of a forest, even though this litter may be distinctly acid in its chemical reaction. They are known, indeed, to grow luxuriantly on vegetable remains containing no nitrates and of such acidity that nitrification, or the conversion of the humus nitrogen into nitrates by means of bacteria, can not take place.

That the mycorrhizal fungi, like other fungi, are able to extract nitrogenous food from the nonnitrified organic matter with which their external portions are in contact is a reasonable supposition. It is furthermore a reasonable supposition that the blueberry plant is able to absorb nitrogenous material from the internal portion of its mycorrhiza; for we know that the clover plant is able to absorb nitrogen under essentially the same conditions from the nitrogen-fixing bacteria growing in its root tubercles.

To establish by direct experiment the ability of the mycorrhizal fungus of the blueberry to act in accordance with the supposition outlined above, the fungus should be separated from the plant and grown by itself in suitable nutrient media. Preliminary trials were made to isolate the fungus, but without success, and a lack of time has prevented thus far the pursuit of that branch of the experiments.

(19) It is possible that the mycorrhizal fungus of the swamp blueberry transforms the free nitrogen of the atmosphere into a form of nitrogen suited to the use of the blueberry plant.

The fact of the fixation of atmospheric nitrogen by the bacteria inhabiting the root tubercles of clovers is now well known, and we are able to understand how the abundant nitrogen of the air, unavailable for the direct nutrition of ordinary plants, is made available for the use of leguminous crops.

It is not so generally known that there are in soils certain species of bacteria not connected with the roots of plants which also possess the faculty of taking up the nitrogen of the air and making it over into plant food. The extent of the distribution of these organisms and the amount of nitrogen fixation effected by them are not fully known, but the fact that such action does take place and that the bacteria causing it occur in many localities has been well established by the experiments of several investigators. The bacteria of this class most fully investigated are *Clostridium pasteurianum*, *Azotobacter chroococcum*, and several other species of this latter genus.

It has been shown also that certain fungi, such as *Penicillium glaucum*, possess this same power of assimilating atmospheric nitrogen.

After the writer had discovered the mycorrhizal fungus of the swamp blueberry in December, 1907, and while he was making observations on it, his attention was called to the work of Miss Charlotte Ternetz on the mycorrhizal fungi of certain related European plants. Miss Ternetz published in 1904 a paper [a] in which she made the preliminary announcement that a fungus isolated from the roots of the European cranberry (*Oxycoccus oxycoccus*) had developed pycnidia and that the mycelium produced from spores from these pycnidia when grown in a nitrogen-free nutritive solution, but with full access to air, showed upon analysis that it had assimilated free atmospheric nitrogen to the extent of 0.6 per cent of the dry weight of the mycelium. The fungus consumed only one-eighth as much dextrose in assimilating a given amount of nitrogen as was consumed by *Clostridium pasteurianum*. Similar but not identical fungi were isolated from other related plants.

In 1907, in a more detailed account of her investigations,[b] Miss Ternetz described, as new species of Phoma, five pycnidia-bearing fungi bred from the roots of the European cranberry (*Oxycoccus oxycoccus*), the marsh rosemary (*Andromeda polifolia*), two species of heather (*Erica tetralix* and *E. carnea*), and the mountain cranberry (*Vaccinium vitisidaea*). She was unable to demonstrate absolutely that these fungi were identical with the endotrophic mycorrhiza of the host plants because (1) it was extremely difficult to observe the fungous threads of the internal mycorrhiza grow through the cell wall of the rootlets into the culture medium without, and (2) be-

[a] Ternetz, Charlotte, Ph. D. Assimilation des atmosphärischen Stickstoffs durch einen torfbewohnenden Pilz. Berichte der Deutschen Botanischen Gesellschaft, vol. 22, 1904, pp. 267–274.

[b] Ternetz, Charlotte, Ph. D. Ueber die Assimilation des atmosphärischen Stickstoffes durch Pilze. Jahrbücher für Wissenschaftliche Botanik, vol. 44, 1907, pp. 353–408.

cause when she proposed to inoculate mycorrhiza-free seedlings of the host plants with spores from the pycnidia that formed in her cultures she was unable to grow any seedlings that were free from mycorrhiza.

Notwithstanding the lack of an absolute demonstration that the nitrogen-fixing fungi grown by Miss Ternetz were identical with the mycorrhizal fungi of their hosts, it is regarded as quite possible that the mycorrhizal fungi that occur in perhaps all plants of the heather and blueberry families, including the swamp blueberry, are nitrogen fixers, and that the host plants absorb this nitrogen, giving in exchange, for the use of the fungus, sugar or some other carbohydrate.

The experiments thus far described in the present paper, and the accompanying discussions, appear to warrant the following theory of the method of nutrition of the swamp blueberry:

(*a*) The swamp blueberry grows in peaty soils which contain acid or other substances poisonous to plants.

(*b*) As a protection against the absorption of amounts of these poisons great enough to prove fatal, this plant, like many other bog and acid-soil plants, is devoid of root hairs and consequently has a restricted capacity for absorbing soil moisture. This low absorptive capacity is correlated with a low rate of transpiration. Many bog shrubs, although living with an abundant supply of moisture at their roots, have been recognized as showing adaptations for retarded transpiration similar to desert plants.

(*c*) The special danger to which the swamp blueberry is exposed by reason of its low transpiration and its corresponding reduced capacity for absorption is insufficient nutrition. The danger of nitrogen starvation is particularly great since these soils contain very little nitrates.

(*d*) Some bog plants similarly threatened with insufficient nutrition, such as the sundews (Drosera), the bladderworts (Utricularia), and the pitcher plants (Sarracenia), possess means of securing the requisite nitrogen by catching insects and digesting and absorbing their nutritive parts.

(*e*) In the swamp blueberry the required nitrogen is secured in a different way. The plant associates with itself a mycorrhizal fungus which is able to assimilate nitrogen from the surrounding organic matter, and perhaps from the atmosphere also, and to convey it into the plant without taking along with it a large amount of the poisonous soil moisture.

Whether this theory of the nutrition of the swamp blueberry is or is not substantiated in all its details by future investigation, it has afforded a useful basis for cultural experimentation, as will be evident from the results about to be described.

## A METHOD OF POT CULTURE.

(20) Seeds of the swamp blueberry sown in August from fresh berries germinate in about five weeks.

The experiments in the raising of blueberry seedlings have covered such a great diversity of soil mixtures, methods of potting, manner of watering, amount of shade, and day and night temperatures that an account of all of them is out of the question. The more important results of these experiments may be presented, however, in an account of the seedlings of 1908, the latest that have been grown for an entire year, with allusions to the experiments of other years whenever additionally useful. The parent plant of the seedlings of 1908 is described on page 80.

The method followed in germinating the seed was that developed by Mr. George W. Oliver, of the Bureau of Plant Industry, in 1902. All other experimenters, apparently, have considered it necessary to keep the seeds dormant by stratification or some equivalent means until late winter or early spring and then to give them the warmth necessary for germination. By Mr. Oliver's method, however, the seeds are sown in August, soon after the maturity of the berries; they begin to germinate in about five weeks, and by proper handling in the greenhouse they are robust plants by the beginning of summer instead of tiny seedlings.

Pursuing this method the detailed operations were as follows: The berries (Pl. VI, fig. 1) when fully matured and slightly fermented were mashed to a pulp and rubbed thoroughly under water. The juice and floating pulp were washed away, and the heavy seeds, which sank to the bottom, were taken out and their superficial moisture dried off by exposure to the air for a few hours. When thus prepared and placed in a closed bottle blueberry seeds will retain their vitality for several weeks, probably for several months.

From the 2 quarts of berries were secured 12.5 grams of dry seeds. The seeds numbered about 9,000 per gram, of which about three-fourths were small and contained no embryos. About 11 grams were used to raise seedlings, computed to contain about 25,000 germinable seeds. It furnished an abundant amount for seeding four ordinary gardener's flats, and from these over 1,000 seedlings were actually transplanted and as many more might easily have been utilized.

The mature seeds (Pl. VI, fig. 2) are roughly orbicular to narrowly oblong in outline, strongly flattened, with a deeply pitted seed coat. They vary in length from 0.04 to 0.06 of an inch (1 to 1.5 mm.).

The seeds were sown in shallow wooden flats 10 by 34 by 3 inches, inside measurement. After crocks had been placed over the drainage holes the bottom was covered to a depth of about an inch with kalmia peat in fibrous form to insure good drainage. Over this was placed the finely sifted soil of the seed bed, trodden down with the whole weight of the body, the total thickness of the soil and drainage being 2.5 inches.

The soil of the seed bed in this instance was a mixture of the following, each rubbed through a wire sieve with $\frac{1}{16}$-inch square openings:

| | |
|---|---|
| Kalmia peat | 8 parts by bulk. |
| Sand | 2 parts by bulk. |
| Live sphagnum | 2 parts by bulk. |
| Loam | 1 part by bulk. |

While this mixture gave good results, certain modifications in the direction of simplicity have been found equally satisfactory so far as growth is concerned, and more satisfactory with regard to the ease of transplanting. These changes involve the omission of the loam, which from other experiments is now regarded as never advantageous and sometimes actually injurious, and the omission of the sphagnum, which, although a good moisture-holding and aerating medium, appears to be superfluous in a peat and sand mixture. The sphagnum also interferes somewhat with the clean pricking out of the seedlings in the first transplanting. From experience with various other seedlings of blueberries a mixture of 2 parts of finely sifted kalmia peat to 1 part of sand is regarded as satisfactory and preferable. The peat should be well rotted and the sand clean and free from lime. This matter is more fully discussed on page 60.

After the seed bed had been prepared, as already described, the dry seeds were scattered upon it and covered with about an eighth of an inch of the same soil lightly sifted over it. The surface was then sprinkled with water from a sprinkling pot provided with a very fine rose.

So far as moisture is concerned the ideal condition of the seed bed is that the soil should be just damp enough so that it shall not become dry on the surface. The drying of this peat is indicated by a conspicuous color change, from dark brown to light brown. If exposed directly to an ordinary greenhouse atmosphere, the tendency of the seed-bed surface to become dry will necessitate frequent applications of water, and the bed will be in danger of repeated periods of sogginess. These conditions may be very much improved by covering the flat with panes of glass. An opening about an inch wide should be left at either end to permit the circulation of air over the seed bed. This ventilation will prevent the excessive accumulation of moisture in a stagnant atmosphere and will also prevent overheating on sunny days, both of which conditions are injurious to seedlings. A flat thus covered may not require watering for intervals of several days. The advantages of the glass covering are par-

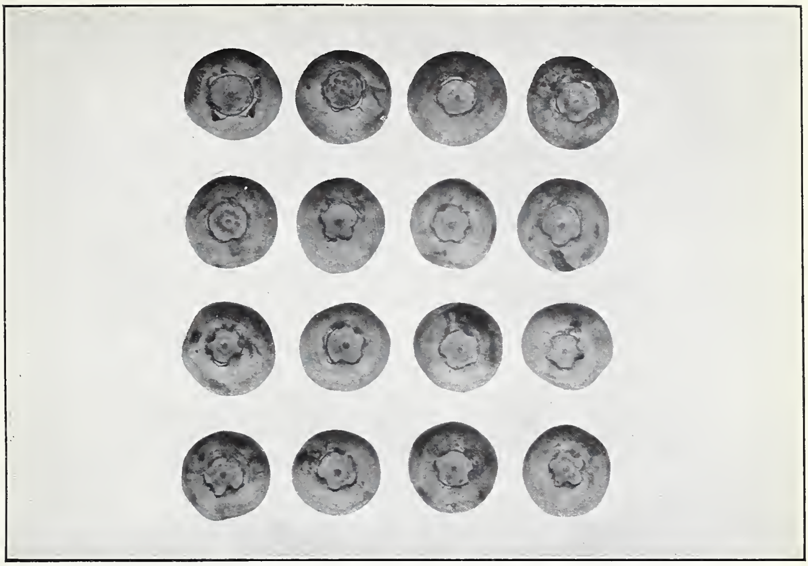


FIG. 1.—SWAMP BLUEBERRIES FROM THE PARENT BUSH OF THE SEEDLINGS OF 1908.

The berries were photographed after remaining nearly a year in formalin, and the illustration does not show their maximum size and plumpness. (Natural size.)

FIG. 2.—SEEDS OF THE SWAMP BLUEBERRY.

(Enlarged 10 diameters.)

ticularly evident when germination begins, for many of the seeds have been washed to the surface in the process of watering and have germinated without any soil covering. It may be several days before the root penetrates the soil, but the moisture maintained in the air underneath the glass keeps these naked seedlings from death by drying. After germination has progressed so far that a good stand of seedlings is assured the glass should be gradually removed.

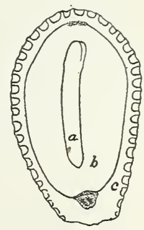



FIG. 19.—Section of a blueberry seed: *a*, Embryo; *b*, endosperm; *c*, outer seed coat. (Enlarged 18 diameters.)

The flats seeded on August 12, 1908, were kept in a greenhouse as cool as practicable and shaded from the sunlight. When started in winter, seed flats should be kept at a temperature not less than 50° to 60° F. at night and about 15 degrees higher in the daytime. Under such conditions sunlight during the whole day seems to benefit them.

Germination began on September 18, thirty-seven days after seeding, and continued for more than two months. In other seedings of this and the closely related blueberries known as *Vaccinium atrococcum* and *V. pallidum*, germination has begun in as short a period as twenty-five days. This slowness of germination might be considered merely a feature of the general sluggishness of growth in these plants. It is in fact, however, due to a much more specific cause. The food stored in the seed for the nourishment of the plantlet is not located in the cotyledons, as in the bean or pea, for example, but it lies in a mass called the endosperm, quite outside the embryo. (See fig. 19.) It requires several weeks for the minute embryo, feeding on the large mass of surrounding endosperm, to grow to sufficient size to burst open the seed coats. Until the embryo has attained such size it is physically impossible for the seed to germinate.

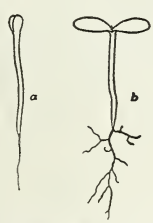



FIG. 20.—Blueberry seedlings in the cotyledon stage: *a*, Before the expansion of the cotyledons; *b*, at the beginning of the development of the first foliage leaf. (Enlarged 2 diameters.)

When the seedlings had straightened themselves out they were about 0.2 to 0.3 of an inch (5 to 8 mm.) high and the newly expanded cotyledons about 0.06 of an inch (1.5 mm.) long. (See fig. 20.) Within a few days the first foliage leaf began to appear between the cotyledons, and at the end of a month the plants were 0.4 to 0.6 of an inch (10 to 15 mm.) high, the erect unbranched stem bearing four or five foliage leaves, and the cotyledons having expanded to a length of 0.12 of an inch (3 mm.). (See fig. 21.)

Although the leaves of the parent plant had entire margins, the leaves of the young seedlings were invariably serrulate. It was only after the plants were several months old that any of the branches began to produce leaves with entire margins, and some of the seedlings from this parent give promise of permanently retaining the serrulate leaf character. (See p. 82.)

(21) THE SEEDLINGS ARE FIRST TRANSPLANTED AT THE AGE OF ABOUT SIX WEEKS, WHEN THEY ARE APPROACHING AN INCH IN HEIGHT.

On October 24 the first transplanting was done from the seed flats of 1908. A new flat was filled to a depth of 2 inches, trodden down hard, with the following mixture:

| | |
|---|---|
| Kalmia peat, rotted for several months and rubbed through a quarter-inch sieve | 8 parts by bulk. |
| Sand, coarse, washed | 1 part by bulk. |
| Loam, clayey, finely sifted | 1 part by bulk. |

This soil mixture was used as the result of experience of the two preceding years. From a few experiments made in the winter of 1906–7 it had been found that a mixture of equal parts, by bulk, of peat, sand, and loam was decidedly superior to loam and manure or to sand, sphagnum, and loam. In the winter of 1907–8 it was found that the amount of sand and loam could be reduced with distinct advantage, and as a result of the experiments then made many of the cultures of 1908–9 were grown in the mixture described above (peat 8, sand 1, loam 1). The retention of the loam was due to an idea that this ingredient would furnish some necessary mineral nutrient not furnished by the peat. From an experiment made in the summer of 1909, however (p. 69), it was found that under the system of handling the pots described on page 67 large plants repotted in a peat soil with no loam whatever made a better growth than those potted in a peat containing a tenth part of loam. There is some reason, therefore, to suspect that loam, even in such a small quantity, may be slightly injurious, and more reason to suspect that it may be superfluous. Experiments intended to throw light on this question are now in progress.

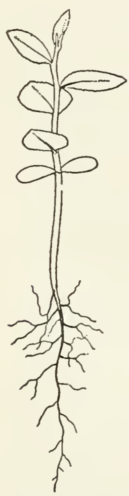


FIG. 21.—Blueberry seedling about six weeks old, with five foliage leaves. (Enlarged 2 diameters.)

In the soil of the flat, prepared as described above, 80 plants were set 2 inches apart. They were pricked out of the seed bed and set in the new soil by means of a small dibble. These plants were half to three-fourths of an inch high and had three to six true leaves.

It is believed that a spacing of 2.5 inches in the flat is better than 2 inches, as the plants have a little more room and the 2.5-inch square of earth is a very convenient size when the next transfer is made, into 4-inch pots.

From this time on during the winter the plants were kept in a cool greenhouse in which the night temperature was 55° to 60° F., and which was given a large amount of ventilation. The day temperature reached ordinarily 65° to 70° F. It was found that a house with a night temperature of 40° F. and a day temperature of 60° F. was too cold for such seedlings, as they made almost no growth at all. In a warm house, 65° to 70° at night and 80° to 90° F. in the daytime, blueberries grow fairly well, but they are much subject to injury by red spider (*Tetranychus bimaculatus*), and their new growth while sufficiently extensive does not appear so robust as in the 55° to 70° F. house.

For the first few days the newly transplanted seedlings were sheltered from direct sunlight. Later, however, they were given all the sunlight possible. It was found that during the winter, when well established in a suitable soil and under proper moisture conditions, the plants grew better when they received the fullest sunlight that the greenhouse afforded. This statement applies to the plants in all stages, whether in a seed bed or after the first transplanting or in larger pots.

In watering, the plants should be kept "on the dry side," as gardeners say. Water may advantageously be withheld until the surface of the soil is dry, but this condition should not be allowed to extend to a depth of more than about an eighth of an inch. Then a rather thorough watering should be given, which will carry moisture to the bottom of the soil, but not run through. Such a watering at infrequent intervals is preferable to frequent light sprinklings that moisten the surface only. Except for the brief period of percolation immediately after watering, the movement of water in the soil should be a capillary one, and from the bottom upward. Under such conditions, if the soil is of proper texture, good aeration is insured.

The shock of transplanting checks the growth of the seedlings for several days. This checking of growth may manifest itself in one or more of three ways: (*a*) The withering of the stem tip; (*b*) the "stagnation," or stoppage of expansion of the uppermost leaf rudiment; and (*c*) the purpling of the older leaves. As these phenomena when persistent have been much utilized in these experiments as warnings of the existence of conditions antagonistic to growth and as they may be of similar assistance to other experimenters, a description of them will be given.

The withering of the tip includes the uppermost leaf rudiment and the growing point of the stem inclosed within its folded base. The tissues turn brown and become dry, and the growth of that axis is terminated. The resumption of growth from such a stem, if it occurs, takes place through the formation and expansion of a bud in the axil of the leaf next below the withered one. This withering of the tip is readily distinguishable by its color from a partial blackening of the uppermost tender leaves which sometimes occurs, apparently a pathological disturbance of a temporary character and usually not affecting the growing point of the stem itself. The brown withering of the tip seldom takes place when the leaf rudiment involved in the withering is more than 0.1 inch (2.5 mm.) in length. When longer than that it usually keeps on expanding. This withering of the tips has been almost wholly prevented when the shock of transplanting was rendered as light as possible by suitable precautions, including (*a*) a soil in perfect condition for the nutrition of the plants, especially that in which the peat is well rotted (p. 61); (*b*) the transfer of the plants to their new bed without injury, especially without destroying any part of the roots; (*c*) the shading of the plants from direct sunlight for two weeks or more, until their new root growth is well established, and their subsequent gradual adjustment to full sunlight; and (*d*) the holding of the transplanted plants in a warmer, moister atmosphere, about 65° at night and 80° F. in the daytime. Whether or not this last condition had a real influence on the prevention of the tip withering is not definitely known.

The stagnation of the uppermost leaf rudiment does not attract the inexperienced observer's attention so readily as its withering. With a little experience, however, it is easily detected. Ordinarily the leaves of a growing stem follow each other at a rather close interval, so that by the time a half-grown leaf is ready to flatten out, from its boat-shaped folding in the younger stage, the succeeding leaf is commonly a third or more the length of the one that is flattening (fig. 22). When stagnation occurs, however, the uppermost leaf rudiment promptly stops growing, usually at a length of 0.04 inch (1 mm.) or less, while the young leaf next below it goes on flattening and growing to nearly its normal size. The end of the stem, therefore, shows a nearly full-grown flat leaf with a minute leaf rudiment at its base seldom more than a fifth and often not more than a tenth its own length.

The purpling of leaves, to which allusion has been made, does not refer to the reddish translucent appearance of the growing twig tips. That is the normal coloration in the blueberry, as it is, for example, in the rose. The purpling now under consideration occurs in the mature leaves, which are normally green, and is of a dark shade. It is commonly accompanied by a conspicuous reddening of the leaf veins. This purpling of the old leaves is evidence of a severe stoppage of growth and in these experiments has been observed to be caused by low temperature, about 40° F. or lower, or by lack of nutrition from any cause, or, apparently, by poisoning.

If the soil into which young blueberry seedlings are transplanted is suited to their growth, purpling of the old leaves seldom occurs, the evidence of the shock of transplanting being confined to the possible withering of a few of the stem tips and the temporary stagnation of others. In some transplantings no withering of tips occurs.

During the period of cessation of stem growth after transplanting, the plant is by no means idle, for the roots, as shown in glass-pot cultures, continue to make new growth, and when this has sufficiently progressed stem growth is resumed.

(22) When about ten weeks old and nearly two inches in height the seedlings begin to send out basal branches.

An important phase in the development of the seedlings of 1908 began on November 25, when one of the plants commenced to send out a branch from the axil of a cotyledon. At the expiration of another month 75 per cent of the plants in the flat had put out similar basal branches, and the remaining 25 per cent ultimately did the same.

Fig. 22.—Normal tip of stem in a blueberry seedling. (Enlarged 4 diameters; the smaller figure natural size.)

These basal shoots are of the highest importance in the economy of the blueberry plant, for they soon far outstrip the first stem and become the principal seat of growth, until they themselves are overshadowed by later and still more vigorous basal shoots. The original stem of the seedling never develops into an ultimate main stem or trunk, but, as will be seen later (p. 58), stops growing while the plant is still young, and afterward dies. It is this habit of sending up basal shoots that makes the swamp blueberry a many-stemmed bush, not a miniature tree with a single trunk.

The development of basal shoots began when the seedlings had about 12 leaves and were about 1.5 to 2 inches high. In this first basal branching the number of branches varied from 1 to 3. Out of 73 plants on which the branching was recorded 39 had 1 branch, 30 had 2 branches, and 4 had 3 branches. The branches occurred in the axils of the cotyledons or of one of the first four leaves. Of the 39 plants with 1 branch, 11 had the branch in the axil of a cotyledon, 17 in the axil of the first leaf, 8 the second, 2 the third, and 1 the fourth. Of the 30 plants with 2 branches, 11 had both branches in the axils of the cotyledons, 13 had neither branch so situated, and 6 had 1 branch from a cotyledon axil and 1 from a leaf axil. Of the 4 plants with 3 branches, 3 had all 3 branches in the axils of the cotyledons and the first leaf, 1 had a branch in the axil of a cotyledon and of the first and second leaf. Of the total 111 branches 46 were in the axil of one of the two cotyledons, an average of 23 to each, 36 in the axil of the first leaf, 20 the second, 7 the third, and 2 the fourth. In the order of the frequency of production of a basal shoot, therefore, the first leaf stands first, a cotyledon next, then the second, third, and fourth leaves, in order.

While the exact location of the basal branches appears to have no special significance, the number of the branches does, for the habit of producing two or more branches is a persistent one and such seedlings tend to produce diffuse plants with many and small stems and small stature, while the plants with the single-branch tendency are taller and have fewer and more robust stems. The differences in general appearance caused by the two types of branching are well illustrated in figures 24 and 25, from photographs of two seedlings of 1907 made at the age of 10 months.

### (23) When the seedlings are about four months old and about three inches in height the growth of the original stem terminates.

On January 5, 1909, the growing tip on the original stem of one of the plants withered. At that time this stem was about 2.5 inches high, had 14 leaves, and had 2 vigorous basal shoots about an inch in length. This withering differed in one important respect from the withering due to shock, described on page 56. In that case it was an ordinary leaf rudiment that withered. In the present case the withering was foreshadowed by the development of a minute bract (fig. 23). This differed from the ordinary leaf rudiment in the absence of the glandular hairs characteristic of young leaves, and it remained small until the leaf next below it had become more than ten times as long. Then the bract withered and the growth of the original stem was permanently terminated. The same development went on in the other plants until at the end of a month 65 per cent and in two months 95 per cent of the plants had terminated the growth of their original stems.

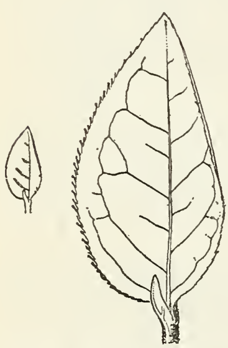


Fig. 23.—Bract and young leaf at the end of the original stem in a blueberry seedling. (Enlarged 4 diameters; the smaller figure natural size.)

In the individual plant the termination of growth on the original stem took place after the basal shoot or shoots had reached a stage of vigorous development. Out of fifty-nine normal cases observed prior to the second transplanting of the seedlings, the length of the new shoot, or when more than one the longest of them, at the time of termination of growth on the old stem varied from 0.4 of an inch to 5 inches, with an average of 1.8 inches. It would appear that the

FIG. 24.—Blueberry seedling with diffuse type of branching. This will become a low, many-branched bush. (One-third natural size.)

FIG. 25.—Blueberry seedling of the type with few branches. The branch is more than twice as tall as the original main stem. (One-third natural size.)

immediate cause of the termination of growth on the old stem is the diversion of food materials into the new vigorous growth.

(24) WHEN THE PLANTS ARE ABOUT FIVE MONTHS OLD AND FOUR TO SIX INCHES IN HEIGHT THEY ARE POTTED IN FOUR-INCH POTS IN THE BEST PEAT OR PEAT MIXTURE.

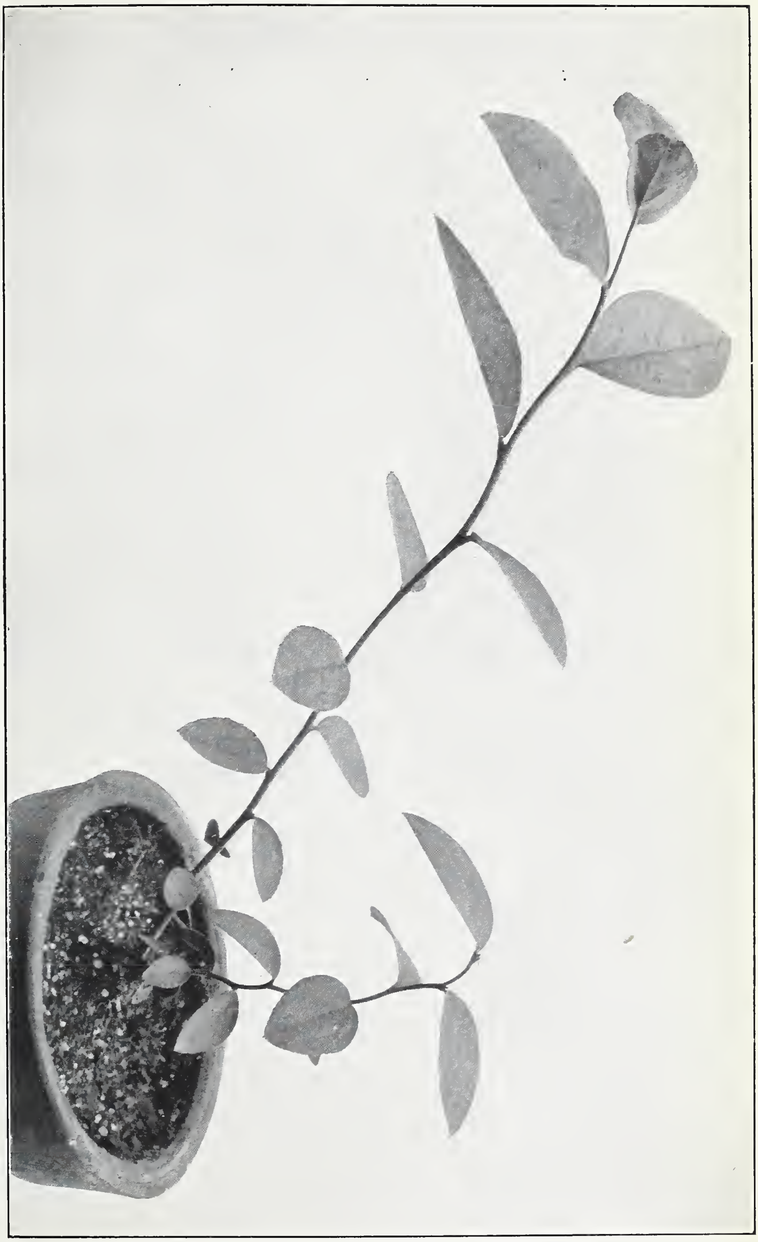
On February 17, when the plants were 4 to 6 inches high, they were transplanted into 4-inch pots in the same soil mixture as was used in the transplanting of October 24 (peat 8, sand 1, loam 1). As stated in the discussion of that transplanting, the plants would probably have done somewhat better without the loam. In addition to the crock over the drainage hole, a mass of fibrous kalmia peat was placed in the bottom of the pot, filling it, when pressed down, to the depth of an inch or more. After cutting the soil in the flats into rectangular cakes, the plants were lifted and transferred to the pots with the least possible disturbance of the roots.

Several experiments had been made earlier to ascertain whether at the first transplanting from the seed bed it is better to set the plants in flats or to put them in 2-inch pots, or thumb pots as they are more commonly called. It was found that when the plants in thumb pots were set on a greenhouse bench they tended to dry out so rapidly that it was impracticable to keep them in the right condition of moisture. They became so frequently too wet or too dry that their growth was interrupted and they were much inferior to the plants in the flats. Other plants in thumb pots (Pl. VII), plunged in either sand, peat, or sphagnum, made about the same growth as the plants in the flats, but showed no uniform advantage over them, either while they were in the thumb pots or after a second transplanting. The labor of transplanting and of maintaining uniform moisture is somewhat greater in the case of the potted plants. All things considered, in the original transplanting the use of flats is regarded as preferable to 2-inch pots.

It is desirable to consider at this time the exact qualities of the soils used in the potting mixtures. As already stated, it is regarded as preferable to omit the loam.

The sand should be free from lime, as most sand is, in fact. It should also be as clean as possible. If the only sand obtainable is mixed with clay, this should be removed by repeated washing in water.

The condition of the peat should also be carefully considered, as shown by the following experience during the progress of these experiments. From the seedlings of 1908 many series of transplantings were made on various days in October, November, and December. In the latter part of December it was noticed that while in some of the transplantings the seedlings were growing vigorously, other cultures were not doing well at all. Many of the tips were withered, over 25 per cent in some of the cultures; the rest became stagnated and dark purple, and remained so for nearly two months. All possible causes of the trouble having been eliminated except those due to the soil, the characteristics of the various soils used were considered with care. At this time the writer was possessed of the erroneous idea that lime in the minutest quantities was very injurious to the blueberry (p. 20), and consequently it was sus-



BLUEBERRY SEEDLING FOUR AND A HALF MONTHS OLD.

The original stem, erect in the illustration, has terminated its growth and is much exceeded by the vigorous basal shoot. (Natural size.)

pected that the sand was impure and contained lime. An examination of the sources of the different kinds of sand used showed that lime could not have caused the trouble. Finally, however, the various cultures were arranged by the dates of potting, and it was then found that the purpled plants had all been potted after a certain date, on which a new lot of peat had been received at the greenhouses. The peat in the earlier cultures had been received in June and at the time of the first transplantings had been rotting for four months at a warm summer temperature. The seedlings transplanted into this peat did not lose their tips, and growth was resumed almost immediately. The peat used after the middle of November was freshly gathered, and it was in this fresh peat that the seedlings suffered as already described. It should be stated here, however, that by the end of two months these seedlings, which meanwhile had been making good root growth, began to make rapid top growth also and later overtook their competitors.

Acidity tests of peat from the various cultures and in different stages of decomposition showed a remarkable correlation between the acidity of the peat and the behavior of the seedlings. In the fresh deleterious peat the acidity was excessive, varying from 0.03 to 0.046 normal. In the older peat in which the plants grew well the acidity was usually not in excess of 0.02 normal, in one case 0.024. Fresh peat rubbed through a quarter-inch sieve and showing an acidity of 0.034 normal had lessened its acidity to 0.02 normal after remaining in a moist well-aerated condition for three weeks in the warm air of a greenhouse. In view of these facts the conclusion was reached that the deleterious effect of fresh peat is due to its excessive acidity.

In the undisturbed peat of a kalmia thicket wild blueberry plants are often found growing luxuriantly. After this peat is stripped from the ground it becomes injurious, as has been shown, to blueberry plants that are potted in it, this injurious quality being correlated with an excessive acidity. The question arises, What causes this increase in acidity and in what particular part of the soil does it reside? It was at first suspected that the excessive acidity was located in the less decomposed upper layers of leaves which the roots of the blueberry plants in a wild state do not reach, but which, when the peat is rubbed through a sieve, go into the resulting mixture. The leaf layers to which reference is here made are not the uppermost, nearly dry layers a year or less old, for these are removed in gathering the peat, but the partially rotted layers one to two years old, such as those shown in Plate IV. An examination of such material showed that it was not excessively acid, but came well within the range of acidity beneficial to blueberry plants.

An acidity determination was then made of the roots in the peat. These are the roots, chiefly of oak and kalmia, that interlace the partly decomposed portions of the peat into mats or turfs. Their appearance in the upper part of these turfs is shown in Plate V, figure 2. Taking some of these turfs, freshly gathered, the soil was all shaken from them, leaving only the "fiber," consisting entirely of these fine live roots. This fiber was allowed to rot for a few days, and an acidity test was then made. It proved to be 0.07 normal, an acidity far in excess of that which had proved injurious to the blueberry seedlings. The excessive temporary acidity of freshly gathered kalmia-peat turf and its consequent temporary injuriousness to blueberry plants are therefore attributed to the diffusion through the peat of the acids originating in the roots killed in the process of gathering the turfs.

It should be added here that the acidity of the uppermost layer of undecomposed leaves a year or less old is very great, and that care should consequently be exercised to keep these out of the soil used. A test of dry, brown, newly fallen sugar-maple leaves showed an acidity of 0.22 normal, and a mixture of the leaves of various species of oak in a similar condition, 0.4. Incidentally, attention may be called to the presumable efficiency of a mulch of such leaves in maintaining, by means of its leachings, under the influence of the natural rainfall, the acidity of the underlying more fully decomposed layers, which without the addition of fresh organic matter would ultimately become alkaline. (See the account of an alkaline oak-leaf mold on p. 35.)

(25) Blueberry plants potted in peat may be made to grow more rapidly if they are watered occasionally during the growing season with water from a manure pit.

In the winter of 1907–8 pottings of seedling blueberries from seeds sown in August, 1907, were grown in various greenhouses of the Department. The most successful of these pottings consisted of 89 plants in a mixture of peat, sand, and loam in 3-inch pots. Two of these plants are illustrated in figures 24 and 25. It had been supposed that the superior growth of these plants was the result of specially favorable conditions of light, temperature, and watering, as indeed it was in part; but in the following winter, during an inquiry about certain details of the handling of this culture, the gardener in charge of the greenhouse in which the plants were grown admitted that during a portion of the spring, without consultation, he had given the pots an occasional watering with manure water. As manure when used with loam in the winter of 1906–7 had proved positively injurious to blueberry plants, its possible beneficial effect when used in conjunction with peat seemed worth testing further. In the spring of 1909, therefore, various cultures were watered with manure water once a week, the amount applied being the same as that given in an ordinary watering with tap water, about 50 c. c. for each 4-inch pot. The application was made to six cultures, containing altogether 156 plants, exactly comparable with a similar number of plants receiving no manure water. The applications were made in April and May and varied in number from five to eight.

In all six cultures the plants to which manure water had been applied made a more vigorous growth, temporarily at least, than those that received none.

Similar results were secured by the use of one-tenth cow manure, freshly rotted, in the peat mixture in which the plants were potted.

It was after the beneficial effect of this manuring had begun to show itself that a statement of similar results nearly a century old, in the culture of heaths, came to the writer's attention. It is contained in a book by William McNab entitled "A Treatise on the Propagation, Cultivation, and General Treatment of Cape Heaths," published in 1832. The original is now rare, but a reprint was published in 1908 in Notes from the Royal Botanic Garden, Edinburgh, volume 3, pages 351 to 374. McNab, who was the superintendent of the Edinburgh garden from 1810 to 1848, was undoubtedly the most intelligently successful grower of Cape heaths at the period of their greatest popularity. His treatise is original and practical and delightfully written. With reference to the manuring of heaths he states:

I may mention that I have used a small quantity of manure in the foregoing compost with very good effect, about one-eighth part of cow dung. This should be well rotted before it is used. The way that I have always prepared this dung before using it is to take a barrow load of it and place it in thin layers between layers of peat earth, and after it has lain for some time, chop the whole up together, and turn it over at intervals till the dung disappears and the whole mass assumes the appearance of black peat earth and sand; and where this manure is applied about an equal quantity of sand should be added (that is, about one-eighth part of the whole) in addition to the sand that I have before recommended to be mixed up with the earth. This, I know, can be used with very good effect, but for all ordinary purposes I consider it quite unnecessary, as there is no difficulty in growing heaths very soon too large for the accommodation that is generally allotted for them, with the compost that I have mentioned without manure. I merely mention this because I know it is the opinion of some that heaths will not thrive with manure added to the peat earth in which they are grown.

I know, however, that some heaths may be grown to a larger size, in the same space of time, with manure than without it; but, as I have already mentioned, I consider it quite unnecessary for all ordinary purposes, and any person who wishes to try its effects should do so very sparingly at first, till he is enabled to judge of the effect produced by it, as a little excess of manure is sure to injure the plants. Perhaps liquid manure might be used with very good effect for growing some kinds of heaths, but I am unable to give any particular directions in what proportion it should be used, as, from what trials I have made, I can not come to any certain conclusion. But this much I know, that whoever wishes to try it should do so at first with great caution, with quite as much as in using an excess of manure in its solid state.

McNab's conclusion that manure, while beneficial in small quantities, should be used with caution or not at all agrees with the conclusion reached from these blueberry experiments. On page 18 of this paper is described the disastrous results of the heavy manuring of blueberry plants, and in view of the fact that the blueberry makes satisfactory growth without manure and that we are not sufficiently informed of the exact conditions under which manure may become injurious, the use of even small amounts for blueberries is not now recommended.

A suggestion may be made, however, as to a possible reason for the injury of blueberry plants by manure. In the glass-pot experiment described on page 18, in which plants grown in a mixture containing half as much manure as peat made exceptionally good growth at first but soon died, the death of the plants was preceded by a rotting of the roots. Now, manure is alive with myriads of bacteria, while peat contains few. An examination of the two made by Mr. Karl F. Kellerman, from samples taken from the kalmia peat and the cow manure used in these experiments, showed 2,500 bacteria per plate in the

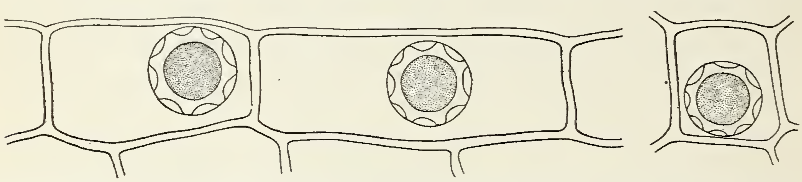


Fig. 26.—Spores of a supposedly injurious fungus in the epidermal cells of blueberry roots. (Enlarged 600 diameters.)

manure and 70 to 150 in the rotted peat, each plate representing 0.0004 of a gram of material. The bacteria in the peat were chiefly of two species, while the manure contained many. It is a reasonable supposition that the rotting of the blueberry roots may have been caused or aided by the bacteria in the manure or by some of the fungi with which manure is also abundantly charged. In mixtures like those recommended by McNab, however, containing much peat and little manure, the injurious bacteria and fungi in the manure may have been killed or held in check by the acids that exist in the peat and keep such organisms in control. If experiments show this theory to be correct, the application of manure to blueberries may then be made intelligently.

In this connection it may be well to call attention to a peculiar spore found in the roots of feeble blueberry plants grown in unfavorable soils, such as the limed peat and the clayey loam described on pages 23 and 24, and mixtures containing a large proportion of manure. In some of the epidermal cells of the rootlets were found large spherical bodies, as illustrated in figure 26. They usually occurred singly, though occasionally two and rarely three were found together in the same cell. They were 0.0007 to 0.0008 of an inch (18 to 20 $\mu$) in diameter, and in optical section showed an outer ring and an inner ring, with 6, 7, 8, 9, or 10 introrse scallops in the hyaline zone between them, the space within the inner ring being granular. These are evidently spores with a very thick wall, marked with a few large pits or depressions, and granular contents in the cell cavity. In what appeared to be later stages of development of these spores, the diameter was slightly larger, the wall was thin, the pits had disappeared, and the granular contents had become organized into minute spherical bodies, apparently incipient swarm spores, about 0.0001 of an inch (2 $\mu$) in diameter, approximately one-tenth the diameter of the spore itself. Several of these large, thin-walled spores had put out a short germination tube and lost their contents, the spore remaining entirely hyaline and empty.

It was thought at first that these might be the reproductive bodies of the mycorrhizal fungus of the blueberry, but a careful search failed to show any connection between the two. It was observed, however, that in the rootlets containing the spores the interior cells usually presented a diseased appearance, the whole rootlet sometimes showing a brown streak down its middle, due to the decomposition of the vessels and wood cells. The inquiry into the nature of the spores was not pursued further, but the conditions strongly suggested that the spores were those of a parasitic fungus occupying the interior of the roots and causing, or associated with, their death and decomposition. The spores themselves bear a strong resemblance to the resting spores of *Asterocystis radicis*, a parasitic fungus of the family Chytridiaceæ. This fungus occurs in Europe in the roots of various plants, particularly flax, in which it is the cause of a serious disease.[a]

If an explanation is sought for the injurious effect of lime on the growth of the blueberry, the observations already made indicate the propriety of a careful study of this large-spored fungus, with special reference to the effect of lime in stimulating its growth and the growth of the other organisms of decay associated with it.

### (26) Pots containing blueberry plants should be plunged in sand or other material that will furnish constant moisture and good aeration.

Although the plunging of earthen pots nearly to the rim in some moisture-holding material, such as sand, sphagnum, or peat, had been practiced for various purposes in several of the earlier cultures, and had been found essential (as stated on p. 60) for 2-inch pot cultures if rapid and uniform growth was to be secured, nevertheless the importance of applying the same practice to larger pots was not

[a] Marchal, Emile. Recherches Biologiques sur une Chytridinée Parasite du Lin. Bulletin de l'Agriculture, Brussels, vol. 16, 1900, pp. 511–554.

appreciated until the best culture from the 1908 seedlings had remained almost stagnant in 4-inch pots for over a month. The condition of the plants was first attributed to an excess of acidity in some of the peat used for potting, and next to the necessity of a period of rest from active growth. Neither of these reasons, however, it was ascertained from observation of other cultures, could account except in part for the distressed condition that these plants finally reached.

When one of the plants was knocked out of its pot it was invariably found that a large part of the roots at the sides of the earth ball were dead. It was at the period of the year, April and May, when the advent of warm sunny days made the control of temperature in the greenhouse somewhat difficult, and this, together with the previous rapid growth of the plants and the consequent increase of their water consumption, had brought about considerable irregularity in the moisture content of the pots. The conclusion was reached that the walls of the pots had become dry on one or more occasions, and that this had killed the delicate roots that came in contact with them. The roots of the blueberry, as described on page 42, are exceedingly slender, the smallest being about two-thousandths of an inch in diameter. They are very quickly killed by drying.

On the basis of this conclusion the general practice of plunging blueberry pots was adopted. If the plants are to be exposed to a very warm, dry atmosphere the plunging should be done before any considerable quantity of roots has grown through the soil to the wall of the pot. It is probably still better to do the plunging immediately after the potting, for then uniform moisture conditions can be secured throughout the soil in the pot.

Besides the avoidance of injury to the plants by the drying of their roots, the practice of plunging has another marked advantage, the maintenance of a moderate but adequate and even optimum degree of moisture in the soil with infrequent waterings. A series of pots plunged in live sphagnum in a cool greenhouse during the winter of 1908–9 frequently went for a week at a time without requiring water and then most of the water was applied between instead of in the pots. The moisture evidently moves freely in or out through the wall of the pot, which is of course not glazed, and an excess or deficiency in any one place is soon adjusted.

Sand has been found a convenient and satisfactory plunging material. The surface of the sand should come to the same level as the soil in the pot, or a little above it. A little sand on the surface of the soil does no harm, and indeed is probably advantageous. When a single pot is to be plunged it may be done by placing it within another pot of 2 inches larger diameter, the space between the walls of the two pots being then filled with sand. (See Pl. XVIII.)

The practice of plunging has proved to be of the greatest importance in securing a large growth in potted blueberry plants, as will be appreciated from the description of the development made under such conditions out of doors in the summer of 1909. (See p. 68.) In that description special attention is drawn to the superior conditions of aeration in plunged pots.

(27) PLANTS OF THE SWAMP BLUEBERRY SOMETIMES LAY DOWN FLOWERING BUDS AT THE AGE OF SEVEN MONTHS.

The laying down of flowering buds is discussed in detail on pages 71 to 73, where a description is given of the general occurrence of this phenomenon in vigorous plants one year old. The first flowering buds, however, appeared much earlier. They were observed on April 8, 1909, on plants which were 10 days less than 7 months old. At the end of the 7 months 24 plants out of 258, which constituted seven of the most advanced cultures from the seedlings of 1908, had laid down flowering buds. A small percentage of the seedlings of 1907 had also laid down flowering buds at about the same age. The phenomenon may therefore be regarded as not rare in vigorous plants of this age.

These flowering buds, which contain the rudiments of about 7 to 12 flowers each, are not adapted to development into clusters of flowers until they have been subjected to a period of cold. Most of the buds, therefore, forming just as warm weather was approaching, withered and dried on the bushes. A few flowered in 1908 and in 1909, and in this latter year one plant bore ripe fruit on August 25, at the age of a little more than 11 months.

(28) IN THE SPRING AFTER THE DANGER OF FROST WAS PAST THE PLANTS WERE REPOTTED AND PLACED OUT OF DOORS, IN HALF SHADE, PLUNGED IN SAND.

On May 19 to 22, 1909, the seedlings of 1908 were repotted in 6-inch pots, in a mixture in most cases of peat 8, sand 1, and loam 1, and placed outdoors. The plants in the principal cultures had at this time an average height of about 9 inches, with a maximum of 15 inches. The pots were plunged in sand. They were in a situation where they were exposed to sunlight from about 8 o'clock in the morning to 5 o'clock in the afternoon, and to protect them from too great heat they were partially sheltered by a slat shade. The slats were 2 inches wide, with 2-inch openings between. As the sun struck the slats somewhat diagonally and they were half an inch thick, the plants when covered by the shades received a little less than half sunlight. On clear days the shades were kept over the plants from 9 o'clock to 4 o'clock. At other hours and on cloudy days the shades were removed. On August 25 the time of shading was shortened to the period between 10 and 3 o'clock, and after September 12 the shades were left off altogether.

The plants were watered with a swift spray from a hose, the water being applied only when necessary to keep the soil from actually drying out. The sand between the pots was seldom allowed to become dry to the depth of more than half an inch. A sand mulch of about a quarter of an inch on the top of the soil in the pot was found useful in preventing the rapid drying of the soil by direct evaporation.

(29) By the use of the cultural methods already described, seedlings of the swamp blueberry have been grown into robust plants of a maximum height of twenty-seven inches at twelve months from germination.

The growth of the plants out of doors during the summer was remarkably vigorous. Hitherto experimenters with seedling blueberries have been able to produce only comparatively small plants at the end of the first season, as shown by the following citation from a publication of the best-known experimenter:[a]

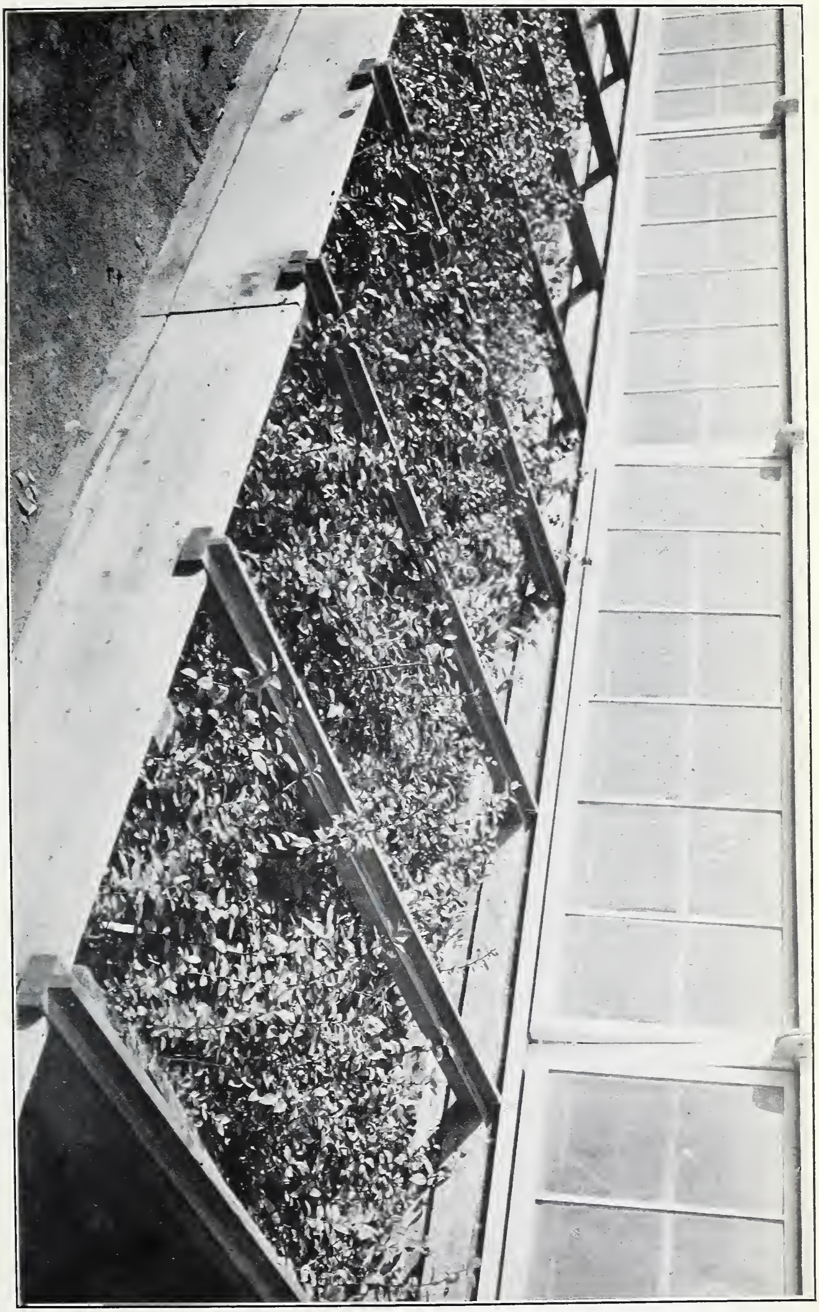
> The blueberry makes much less growth the first two years from seed than the huckleberry, but grows faster afterward. The third year I have had them make a growth of 6 to 8 inches. The low blueberry and huckleberry begin to bear at 3 or 4 years, while the high-bush blueberry requires 4 to 6 years. From 1 to 3 inches growth the first year is about all you can expect.

Under the system of treatment described in the present bulletin seedlings have been grown to a height of 27 inches at twelve months from germination. Out of the seedlings of 1908, 250 were carried through to the close of the season of 1909 in 6-inch pots. Of these, 15 were stunted plants. The remaining 235 had an average height at the end of the season of exactly 18 inches. The larger stems were often a quarter of an inch in thickness, and the main trunk, half submerged in the ground, sometimes reached a diameter of half an inch. The general appearance of these plants is shown in Plate VIII.

The principal features of cultural treatment which have contributed to this development are (*a*) the autumn germination of the seeds, (*b*) the use of suitable acid soils, (*c*) the plunging of the pots, and (*d*) the partial shading of the plants during the heat of summer, the application of these cultural methods having been guided throughout by the discovery of the existence of a mycorrhizal fungus in these plants and its treatment as essential to their nutrition. The system of germination and the character of the soils used have already been described in detail. The exact effects of the plunging and the shading remain to be considered.

It has already been shown (p. 66) that when a plant is not plunged, the minute rootlets that lie against the sides of the pot

[a] Dawson, Jackson. Cultivator and Country Gentleman, vol. 50, 1885, p. 660.



COLD FRAMES CONTAINING ONE-YEAR-OLD BLUEBERRY SEEDLINGS.

are very liable to death from dryness. When the pot is plunged in sand and the sand is kept moist these rootlets can not die from drought. They keep on growing until, in the case of vigorous plants, when the earth ball is knocked from the pot, the soil can not be seen because of the dense mat of live roots that line the pot. The same thick mass of live roots was developed in a series of 1907 seedlings carried over the winter of 1908–9 in the greenhouse in pots plunged in sphagnum. When the pot is surrounded by the moist plunging material these roots continue to luxuriate for months longer than they otherwise would. They evidently find the aeration conditions, as well as the moisture conditions, at the wall of the pot very satisfactory, for the development of roots there is far greater than within the ball itself.

The highly efficient aeration at the wall of plunged pots may explain one use of soils in which the results of the present investigations do not agree with the practice of the old heath growers. In one culture of 25 plants the soil used in the first potting was pure rotted kalmia peat rubbed through a quarter-inch screen. This first potting, in 4-inch pots, was done on March 20, 1909. The repotting, in 6-inch pots, was done on May 22, 1909, in the same kind of soil, pure coarsely sifted kalmia peat. These plants grew to be the largest of any of the seedlings of 1908, their average height at the close of the season being 20.5 inches. The three plants shown in Plate IX, all over 24 inches in height and one of them 27 inches, were from this culture.

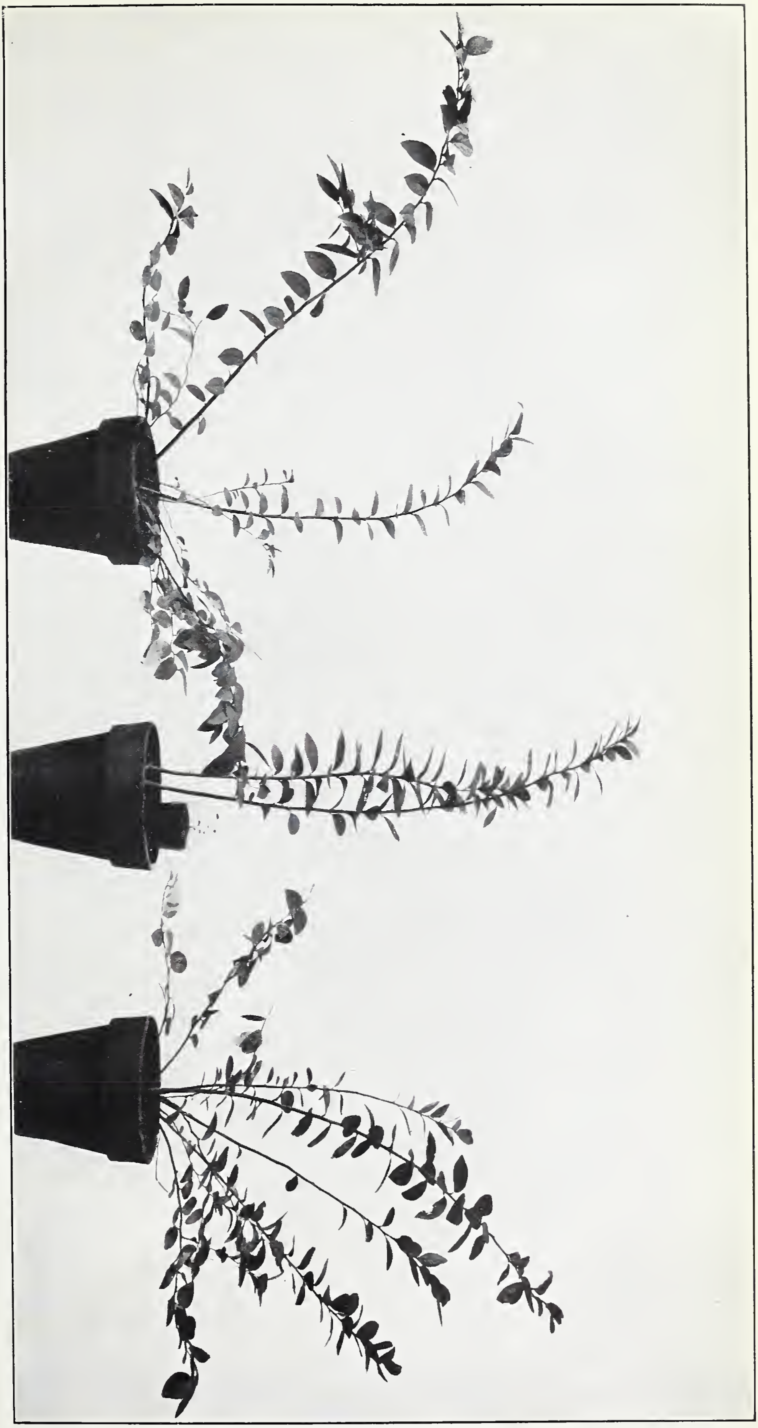
The use of pure peat was not advocated by the old heath growers. McNab recommended a mixture of 4 or 5 parts of peat, by bulk, to 1 of sand, and an even larger proportion of sand, 2 parts out of 5, has been recommended by Dawson for blueberries. When the pots are not plunged and do not therefore have the advantage of the superb aeration conditions found at the wall of the pot when surrounded by moist sand, it is probable that the presence of considerable sand in the soil is necessary to secure adequate aeration of the interior of the earth ball, for unless the pot is plunged most of the rootlets that lie against the sides of the pot will be killed and the plant must rely for its chief nourishment on the roots in the interior of the ball.

That the necessity for interior aeration in the pots is great in the case of heaths, if the plants are not plunged or are not frequently repotted, is shown by a peculiar and interesting cultural practice long tried and highly recommended by McNab. This practice is the distribution of broken crocks or pieces of sandstone through the soil at the time of repotting. He found by experience that the practice was highly advantageous to the plants, and although he did not directly explain his success in such a way, there is little doubt that his method. which may be regarded as a substitute for plunging, was advantageous because it gave large aeration surfaces about the stones in the interior of the earth ball and provided a place there for a large development of roots which could not take place at the wall of the pot. McNab's description of his method of repotting is as follows:

In shifting heaths I never reduce the old ball of earth more than by rubbing the sides and bottom with the hand, so as to loosen the outside fibers a little. I have often shifted heaths twice, and even three times, in the course of the spring and summer, with the greatest success. It is, however, quite unnecessary to shift a heath until the young fibers have come through the fresh earth given to it at its previous shifting, and begun to extend themselves round the inner edge of the pot or tub; but as soon as this takes place, they may then be shifted with advantage. This frequent shifting, however, is quite unnecessary, unless it be to encourage a favorite specimen; for in all ordinary cases, particularly when the plant is large, I consider one good shifting in two or three years quite sufficient. * * *

Besides the compost and draining which I have already mentioned, when I begin to shift heaths I have always at hand a quantity of coarse, soft freestone, broken into pieces, from an inch to 4 or 5 inches in diameter. Of these I always introduce a quantity among the fresh earth as it is put into the pot or tub, round the old ball of earth about the plant, and press them well down among fresh earth as it is put in. This I consider of great advantage to all sorts of heaths, but more particularly so to those that may have been shifted into a much larger pot or tub at once than what it had been grown in before, or in what I would call biennial or triennial shifting. These pieces of stone may be put in as large as the opening will admit between the old ball and the edge of the pot. In some of our largest tubs this opening is full 4 inches wide, and where much earth is required to be put in the bottom over the draining before the plant is put in, a quantity of these stones should be mixed with the earth also. I likewise use occasionally large pieces of soft burnt broken pots, put among the earth in the same way as the stones; but I prefer stones when I can procure them soft and free of iron. The quantity of stones which I introduce along with a large-sized heath at shifting, will, in most cases, if broken down into sand, and added to the sand previously in the soil, form about one-third part of the whole mass. When stones are introduced among the earth in the way I have recommended, heaths will never suffer so much in the summer from occasional neglect to water them as they would do if the stones were not introduced, because these stones retain the moisture longer than the earth, and in the winter they allow a freer circulation of any superabundant moisture which may be given through the mass.

The effect of the half shade used over the blueberries during the summer of 1909 was to make the growth of the plants continuous instead of confining it to a brief period in the early part of the season. In a wild state the twigs of blueberry plants stop growing in early summer, the stoppage being indicated by the withering of the uppermost leaf rudiment. The less vigorous twigs stop first, the more vigorous ones next, and the shoots last. Stoppage of growth is hastened by hot dry weather and is deferred by cloudy humid weather. In the latitude of Washington stoppage of ordinary twig growth in wild plants of *Vaccinium atrococcum* begins in May and is usually



LARGE ONE-YEAR-OLD SEEDLINGS OF THE SWAMP BLUEBERRY.

All three plants, grown in pure kalmia peat, are over 24 inches high, the one at the left 27 inches. The middle plant has been pruned. Standing on the middle pot is a small glass pot containing a seedling of the same age as the others but grown in a rich garden soil. (One-eighth natural size.)

completed, except on vigorous shoots, in June. In some of the cultivated plants which were not shaded growth was similarly stopped by the advent of hot weather. In the plants under the slat shades, however, vigorous stems did not wither their tips until their normal growth had run its course, and as new shoots were continually starting there was no general stoppage of growth until September, and many of the plants continued to grow throughout that month.

The shade was not great enough to "draw" the plants; that is, to make their growth spindling through a stretching up for light. It was merely sufficient to prevent excessive heat and destructive transpiration.

(30) THE FLOWERING BUDS OF THE BLUEBERRY ARE PRODUCED BY THE TRANSFORMATION OF DORMANT LEAF BUDS IN THE LATTER PART OF THE SEASON.

The flowers and leaves of the swamp blueberry are produced in the spring from separate buds, and these buds are formed in the preceding year. The two kinds of buds are conspicuously different, as may be seen by the accompanying illustration. (Pl. X, fig. 1.) The leaf buds occupy the lower part of the twig. They are small, conical, about 0.08 to 0.12 of an inch (2 to 3 mm.) long, with 2 to 4 external scales about equaling each other in length and each ending in a sharp point. The points only of the interior scales, which are of similar length, are visible. When a leaf bud develops in the spring it produces a leafy twig.

The flowering buds are borne along the upper part of the twig. They are fat, ovoid structures, commonly 0.15 to 0.3 of an inch (3.5 to 7 mm.) long, several times larger than the leaf buds. They show ordinarily 10 to 15 external, broad, overlapping scales. Each flowering bud contains the rudiments of a raceme of usually 7 to 12 flowers, the bud of each of these flowers lying in the axil of a bract and bearing two bractlets below the middle of its short pedicel. When a flowering bud develops it produces a raceme of flowers, but no accompanying twig or leaves.

Leaf buds are always axillary and flowering buds almost always so. The bud at the summit of a twig is in reality situated in the axil of the uppermost leaf, except in the rare cases in which the twig tip does not wither when it stops its growth. In such cases a true terminal bud is formed, surrounded by a group of lateral buds in the axils of bracts. So far as observed these buds are always flowering buds and are produced on the ends of vigorous shoots.

The manner in which the plants lay down their flowering buds, through the transformation of leaf buds, is very interesting, and it may prove to have a bearing of some importance on the method and time of pruning the bushes. The form of the leaf buds has already been described. They appear singly in the axils of the leaves almost as soon as the leaf is fully developed. After a few weeks the external scales of the bud turn brown and the bud then goes into a condition of dormancy, unless it is forced into growth through an injury to the twig or some other unusual circumstance. In most of the buds this dormant condition continues through the summer, fall, and winter. If the plant is in condition to lay down flowering buds, however, a new sort of activity appears in the late summer or autumn. One or more of the leaf buds near the end of a twig start to grow. The two brown scales are spread apart, new green scales appear between them, and a large, fat, flowering bud is formed. The bud does not, however, continue its growth at this time, but its green new scales turn brown and the condition of dormancy is again resumed before cold weather comes on.

The flowering buds thus develop out of buds which are in no way distinguishable from leaf buds. They are, in fact, leaf buds until their transformation takes place, and except for such transformation they would remain leaf buds. Furthermore, it has been found experimentally that after the formation of flowering buds has been completed, leaf buds still lower on the twig can be forced by suitable treatment to transform themselves into flowering buds. Such an experiment was made, as follows:

On August 24, 1909, at Lanham, Md., a vigorous bush of *Vaccinium atrococcum* was selected, which had already laid down its flowering buds for the succeeding year. Two branches of nearly equal size, about 16 inches long, one with 14 twigs and 53 flowering buds, the other with 16 twigs and 48 flowering buds, were chosen for the experiment. On the branch containing the 48 flowering buds each twig was cut off at a point between its lowermost flowering bud and its uppermost leaf bud, with the object of ascertaining whether any of the leaf buds on the stub of the twig would transform themselves into flowering buds. The other branch was left unpruned as a check, to show whether the normal laying down of flower buds had in reality been completed on August 24. On October 1, 1909, the two twigs were again examined. The pruned branch had laid down 31 new flowering buds, which in all cases were the transformed upper leaf buds on the stubs of the twigs. On the check branch only 1 new flowering bud had been laid down.

The best method of pruning the swamp blueberry is yet to be devised, but if a superficial pruning, like that of a hedge, proves to be a good method of stimulating vigorous growth, it is evident from this experiment that the most advantageous time to do the pruning, if a crop is to be secured the next year, is after the berries are gathered and about the time when the bush is forming its next year's flowering buds. It will then lay down new flowering buds on the cut stubs. If the pruning were done in late autumn, in the winter,

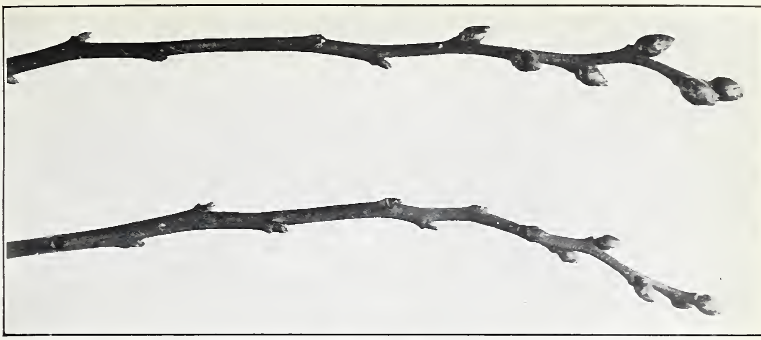


FIG. 1.—FLOWERING BUDS AND LEAF BUDS ON BLUEBERRY TWIGS.

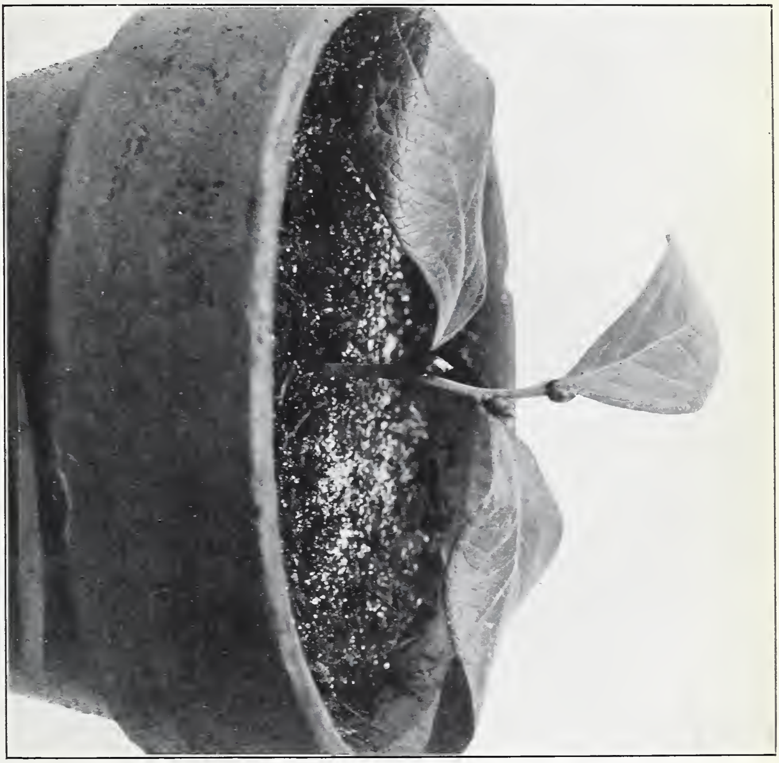


FIG. 2.—FLOWERING BUDS ON A BLUEBERRY CUTTING.

FIG. 3.—FLOWERING BUDS ON BLUEBERRY CUTTINGS.

Each twig in figure 1 shows six flowering buds. The twigs were photographed in March from plants that were 1 year old when the buds were laid down. The middle cutting in figure 3 bears only leaf buds; the two lateral ones have each transformed their uppermost leaf bud into a flowering bud. (All natural size.)

or in the spring, no new flowering buds would be formed to replace those removed by the pruning.

The time of laying down flowering buds seems to be correlated with the length of the growing season. About Washington *Vaccinium atrococcum* begins to form its flowering buds in the latter part of August, one to two months after its berries are matured. In *Vaccinium pallidum*, on the high mountain summits of North Carolina, where the growing season is short, the transformation of leaf buds into flowering buds begins as early as the last week in July while some of the berries are still green. In the cultivated plants at Washington the formation of flowering buds did not begin in 1909 until September, and it continued on some plants until cold weather stopped their growth.

The laying down of flowering buds appears to be a phenomenon local within the twig. Cuttings of the swamp blueberry made in New Hampshire on July 9, 1909, transformed their leaf buds into flowering buds in the cutting bed after reaching Washington, as shown in Plate X, figure 2, but whether the transformation in this case was made before or after the cutting had rooted was not observed. In another case, however, that of cuttings made in New Hampshire September 11, 1909, from long late shoots bearing only leaf buds, the transformation into flowering buds began to occur in the cutting bed October 12 and was completed before any roots had formed. (See Pl. X, fig. 3.)

(31) AT THE END OF THEIR FIRST YEAR SEVENTY PER CENT OF THE BLUEBERRY PLANTS HAD LAID DOWN FLOWERING BUDS FOR THE NEXT SPRING'S BLOSSOMING.

At the end of the season of 1909, 177, or 70 per cent, of the 250 seedlings of 1908 that had been put in 6-inch pots had developed flowering buds. In Plate XI is shown one of these seedlings, photographed on November 2, 1909, which had laid down 42 flowering buds. One plant produced 58 flowering buds. At the end of the preceding season, 1908, at least 25 per cent of the seedlings of 1907 that were still kept in pots had produced flowering buds. Therefore, notwithstanding the statements of earlier experimenters that the seedlings of this species do not fruit until they are several years old (p. 68), it is regarded as established that under the culture system worked out by these experiments a substantial percentage will lay down flowering buds at the end of the first year and will bear fruit the second year.

Attention has already been called (p. 67) to the occasional laying down of flowering buds when the seedlings were only 7 months old, followed rarely by flowering and fruiting at the age of less than a year.

(32) Plants of the swamp blueberry are exceedingly hardy and pass the winter in good condition outdoors when the soil is covered merely with an oak-leaf mulch, but when not exposed to outdoor conditions they do not begin their growth in spring in a normal manner.

During the fall, winter, and early spring of 1908–9 a series of blueberry seedlings of 1907 was kept outdoors on a south window sill to ascertain whether repeated freezing and thawing would kill them. Most of the plants were in thin glass 3-inch pots, covered at the sides with one thickness of gray blotting paper. One plant (to which reference is again made on pp. 75 and 76) was in a 5-inch earthen pot. None of the plants were mulched or covered in any way. They were watered whenever necessary to keep the soil from drying. In cold weather the air circulated freely about the pots and the soil was repeatedly frozen solid. On warm, sunny days the melting of the ice took place rapidly. Hard freezing followed by quick thawing was many times repeated, and the conditions of exposure were such that the plants undoubtedly were subjected to a severer test for hardiness than they would ever receive under cultural conditions.

The plants passed the winter without losing any of their twigs. The wood was plump and in excellent condition when spring came, as was evidenced further by the remarkable uniformity with which every dormant bud started to grow after the first few warm days.

For the roots of some of the plants in glass pots, however, the exposure was too severe. In some of the glass pots no root growth followed the starting of the twigs, and the plants finally died. In others the root growth at first was feeble and the plants lost some of their newly started twigs by withering. Most of the plants, however, including the one in the 5-inch earthen pot, made normal growth of both twigs and roots, notwithstanding the extraordinarily severe treatment to which they had been subjected. No difficulty is anticipated, therefore, in wintering blueberry plants successfully out of doors under any ordinary cultural conditions. The seedlings of 1908 covered with oak leaves in their outdoor plunging bed of sand passed the winter of 1909–10 in good condition.

That blueberry plants must be subjected to some sort of exposure, if they are to start satisfactorily in the spring, is indicated by the behavior of certain seedlings of 1907 which were carried through the winter of 1908–9 in a rose house, where the temperature at night was about 60° F. and during the day about 10 degrees higher. These plants, although subjected to most persistent coaxing, absolutely refused to grow during the the five months from November to March, although newly germinated seedlings grew luxuriantly under exactly the same conditions.

The comparison of these indoor plants with outdoor plants may best be made by an examination of the buds shown in the accompany-

YEARLING BLUEBERRY PLANT WITH FORTY-TWO FLOWERING BUDS.

(One-fourth natural size.)

ing illustrations, made from typical indoor and outdoor specimens. The photographs reproduced in Plate XII were made on March 27, 1909. The plant shown in figure 1 of this plate was a seedling of September, 1907, which had been kept in a greenhouse all its life at a temperature suited to the growing of roses. The plant shown in Plate XII, figure 2, was identical in history with the other until October 20, 1908, when it was placed outdoors and exposed to the severest winter conditions. It was one of the window-sill plants described on page 74. The leaves shown on the indoor plant (Pl. XII, fig. 1) are those formed in the summer of 1908, which by reason of the warm temperature of the greenhouse in which the plant was wintered had never fallen off, although the plant had made no growth later than October, 1908. Neither a flowering bud nor a leaf bud has started on this plant. On the outdoor plant (Pl. XII, fig. 2) the 4 flowering buds and 62 leaf buds which had lain dormant during the winter had begun to push a few days before the picture was taken.

Plate XIII, from photographs taken on April 24, 1909, shows the same two plants nearly a month later. The leaf buds on the outdoor plant (Pl. XIII, fig. 2) have grown into leafy twigs and the flowering buds are fully opened. Of the dormant buds on the indoor plant (Pl. XIII, fig. 1) only two have started to grow. Of these two new twigs, one on the stem to the left, in the axil of the third leaf from the top, has withered its tip and stopped developing before making a full-sized leaf. The other new twig, on the stem to the right, developed abnormally from the axil of a basal bract of a flowering bud. It later made good growth and became a very vigorous shoot. All the flowering buds on this plant dried up and produced no flowers.

The erratic starting of dormant plants which have not been subjected to the conditions necessary to bring them out of their dormancy in a normal manner is well shown also in Plate XIV. This illustration is from a photograph taken February 18, 1909. The plant was a seedling of September, 1907, which was brought into the greenhouse in early December, 1908, and remained there during the winter. The illustration shows that only one of the two flowering buds on the upper twig has started, one of the four on the lower twig, and none of the leaf buds.

There can be no question that for ordinary purposes blueberry plants should be wintered outdoors. If it is desired in experimental work to force blueberry plants to fruit in a greenhouse during their second winter, it will be necessary either to etherize them or to find out some other method of treatment by which the starch in their twigs can be transformed into other carbohydrates available for the building up of new plant tissues. The writer believes that in the hard-wooded deciduous-leaved trees and shrubs of cold countries this transformation of starch will be found to be caused normally by the changes, probably enzymatic, that follow exposure to an alternation of high and low temperatures rather than exposure to a single low temperature.

(33) Dormant plants make their early spring twig growth before new roots begin to develop

The root growth of blueberry plants in early spring is very sluggish, in strong contrast to the activity of their stems. In the plant illustrated in Plate XIII, figure 2, no new root growth had taken place up to the time the photograph was made. For their early spring growth blueberry plants seem to depend on the food stored in their twigs the year before. A microscopical examination has shown that the pith and medullary rays of winter twigs are gorged with starch.

It may be of interest to state here, as bearing on the difficulty of making stem growth exhibited by an improperly wintered blueberry, that the indoor plant shown in figure 1 of Plates XII and XIII had made considerable new root growth at the stage shown in Plate XII and abundant root growth in Plate XIII. The starting of dormant buds appears from this and many other similar cases not to be influenced by the presence or absence of new root growth.

A practical suggestion based on the late spring root development of the blueberry is that transplanting may perhaps be done up to the time of flowering with little injury to the plant.

(34) Unless pollinated by an outside agency, such as insects, the flowers produce little or no fruit.

Many blueberry plants, from seed germinated in September, 1907, were brought into flower in one of the Department greenhouses during the winter of 1908–9. When left to themselves the flowers rarely produced fruit. The greenhouse contained few pollen-carrying insects, a few ants and flies merely, no bees. It was found that the flowers were so constructed as to be unable ordinarily to pollinate themselves. The lack of fruit was evidently due to lack of pollination. When pollinated artificially the flowers usually produced fruit.

In its natural position the flower (fig. 27) is not erect but inverted, the narrow orifice of the corolla being lowermost, the nectar welling up from the surface of the disk between the base of the style and the base of the filaments. The ten stamens and the style hang downward within the corolla, the stamens being shorter than the style. The pollen when mature drops down from the two anther sacs through the two anther tubes which the stamens of these plants possess and out at the terminal pores. (See fig. 28.)

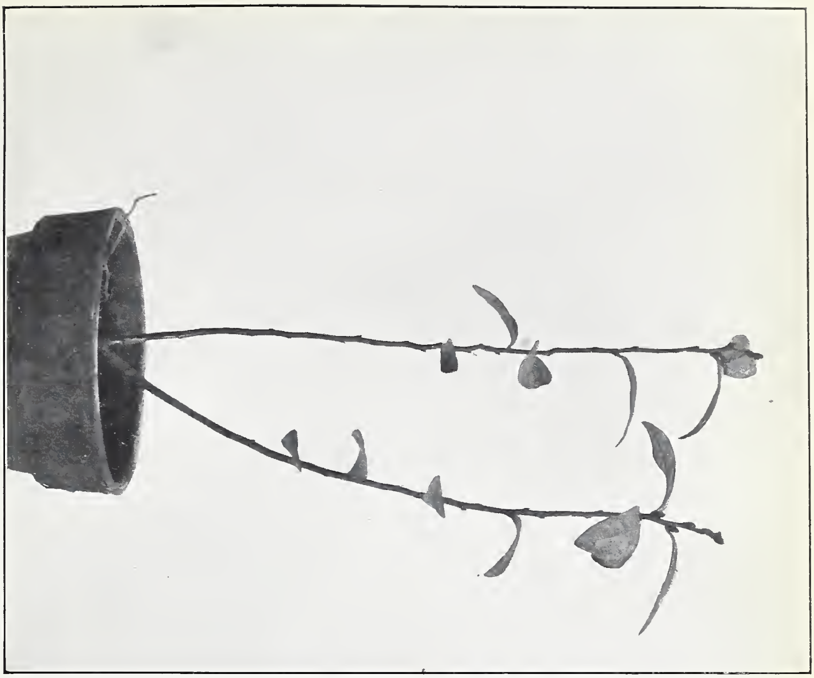


FIG. 1.—BLUEBERRY PLANT WHICH WAS WINTERED INDOORS BEGINNING GROWTH IN THE SPRING.

(Photographed March 27; one-fourth natural size.)

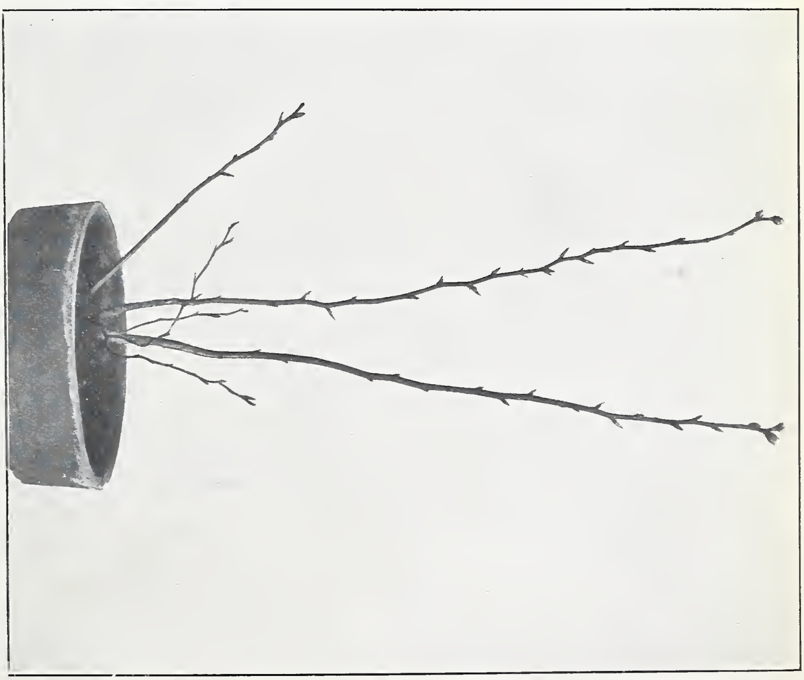


FIG. 2.—BLUEBERRY PLANT WHICH WAS WINTERED OUTDOORS BEGINNING GROWTH IN THE SPRING.

(Photographed March 27; one-fourth natural size.)

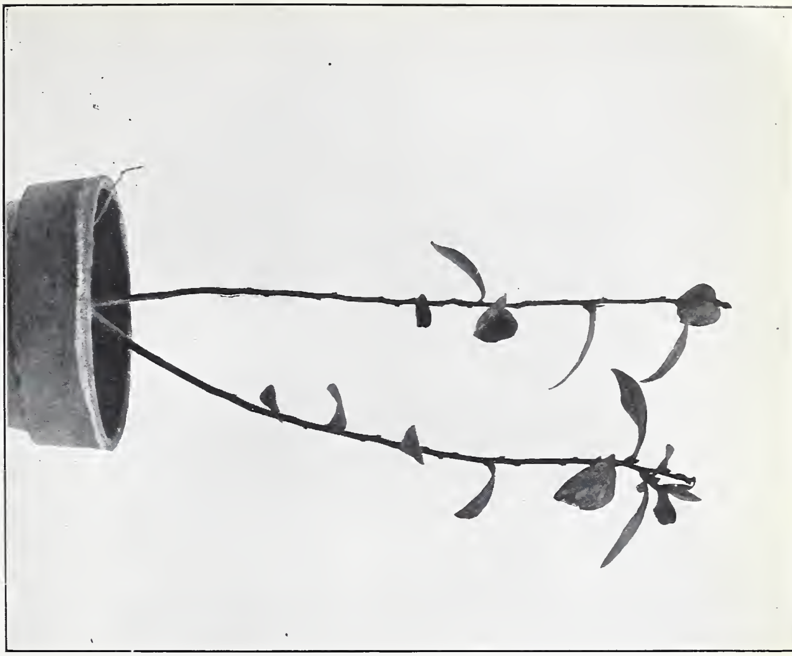


FIG. 1.—BLUEBERRY PLANT WHICH WAS WINTERED INDOORS CONTINUING GROWTH IN THE SPRING.

(Photographed April 20; one-fourth natural size.)

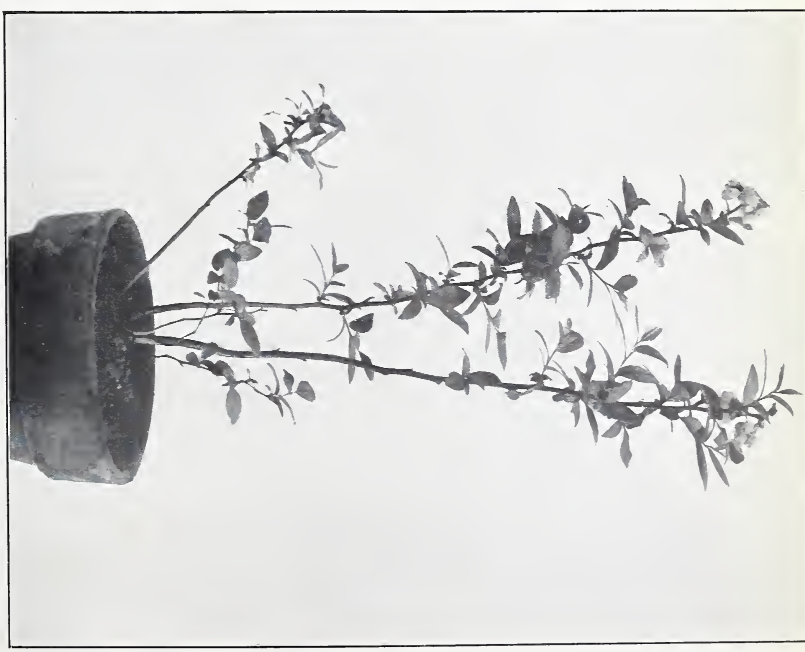


FIG. 2.—BLUEBERRY PLANT WHICH WAS WINTERED OUTDOORS CONTINUING GROWTH IN THE SPRING.

(Photographed April 20; one-fourth natural size.)

The operation of the mechanism for releasing the pollen may be observed with a high-power hand lens. The stamens hang in a close circle about the style. The filaments are broad and laced into a tight tube by the interweaving of their marginal hairs, the anther sacs press close together, and therefore the only convenient way of access to the nectar is through the slits between the anther tubes. The anther tubes are stiff and when one of them is pushed to one side the movement is communicated to the anther sac. The pollen if mature is dislodged and falls down the tube and out at the orifice.

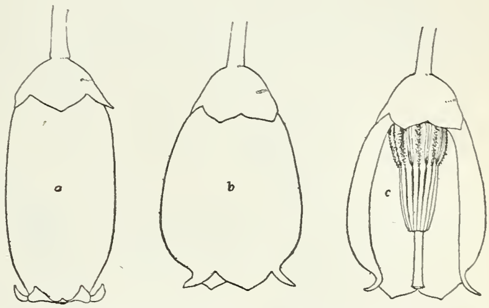


FIG. 27.—Flowers of the blueberry, from 1908 seedlings of the large-berried New Hampshire bush of *Vaccinium corymbosum: a*, Flower of the *corymbosum* type of plant; *b*, flower of the *amoenum* type of plant: *c*, same as *b*, but part of the corolla removed to show the stamens, style, and stigma. (Enlarged 3 diameters.)

The pollen does not come out of the anthers readily on a cloudy, humid day, but on a warm, sunny, dry day it accumulates in the tubes and when they are moved it runs out like grain from a grain chute. The pollen grains (fig. 29) do not stick to the sides of the parchment-like anther tubes when these are dry, but they have the faculty of adhering to hard surfaces, such as glass or the lead of a lead pencil, and they doubtless would adhere also to the hard shell of an insect whether it was covered with hairs or not.

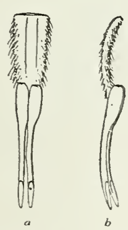


FIG. 28.—Stamens of the blueberry, from the flower shown in fig. 27, *c*: *a*, View from the inner face; *b*, side view. Both views show the broad filament with hairy margins and the anther sacs, tubes, and pores. (Enlarged 5 diameters.)

The pores of the anther tubes do not open squarely across the ends of the tubes, but they are set on a long bevel facing inward. The pollen when released would therefore fall upon the stigma were it not for a peculiarity in the structure of that organ. The sticky stigmatic surface, which the pollen must reach to effect pollination, is at the apex of the globular or top-shaped stigma, while the sides of the stigma as far up as the middle have a dry surface ending in a short collar a little wider, during the early maturity of the stigma, than the widest part of the stigmatic surface. (See fig. 30.) In the inverted position of the flower the falling pollen strikes this dry surface, like the outside of an inverted funnel, and drops off the rim or remains on it, without reaching the stigmatic surface which lies protected beneath.

Ordinarily pollination is effected by some insect which, pushing into the orifice of the corolla from beneath in search of nectar, releases the pollen, as already described. In continuing its quest for nectar the insect brushes against the stigma with some portion of its body, which is covered with pollen, either from the same flower or from some other flower previously visited.

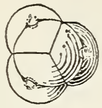


FIG. 29.—Compound pollen grain of the blueberry, consisting of four simple grains permanently cohering. (Enlarged 200 diameters.)

In pollinating the flowers by hand it was found impracticable to collect sufficient pollen to apply with a brush. The following simple and convenient method of pollination was devised: A wide opening was torn in a corolla with a pair of forceps, so that the stamens and stigma could be approached from the side. Then the lead of a lead pencil, flattened on one side and held horizontally, was brought up against the open ends of the anther tubes from below. A portion of the falling pollen was caught on the flat lead, where it could be seen easily because of the blackness of the background. Pollination was then completed by touching the stigmatic surface gently two or three times with the pollen-laden lead. A pollinated flower may be marked readily by pinching off with forceps one or more of the calyx lobes. Fruit was produced from flowers pollinated either with their own pollen or with pollen from another flower.

FIG. 30.—Pistil and calyx of the blueberry, showing the style and stigma. (Enlarged 5 diameters.)

The self-pollination of a blueberry flower, without insect aid, appears to occur, but only occasionally. On greenhouse plants fruit is rarely produced when the flowers are not artificially pollinated, and the same is true of outdoor plants protected from insects by a covering of gauze. The conditions of these observations were not such as to obviate all possibility of the accidental visit of some insect, but it is believed that real self-pollination occurred in some cases.

(35) THE FRUIT MATURES ABOUT TWO MONTHS AFTER THE FLOWERING.

A few days after pollination the corolla, with the stamens, falls off. The stigma at this time has turned brown, and within a day or

IRREGULAR FLOWERING OF A BLUEBERRY PLANT WINTERED INDOORS.

Only two of the six flowering buds have pushed, and none of the leaf buds. (Natural size. See p. 75.)

two the style also falls. The calyx remains permanently attached to the ovary and berry. About a week after the opening of the corolla, the ovary, which at first was much narrower than the expanded calyx, begins to swell and grow. This growth continues for about a month, and then for about another month the green berry makes little increase in size. A few days before the time of ripening the calyx turns purplish, next the green color of the berry takes on a translucent appearance, the next day it turns to a light purple, and the following day to a dark purple or whatever its permanent color may be. During these few days the berry makes a very rapid growth, its diameter often increasing 50 per cent. After reaching its permanent color the berry changes little in size, but for several days continues to improve in sweetness and flavor.

It is a characteristic of blueberries, important from the standpoint of picking, that after ripening they will remain on the bush a long time, often a month or more, without losing their plumpness or their flavor. This makes possible the removal of all the berries from a bush at one clean picking, unless to catch a fancy market a partial early picking is desired.

It is of interest to record that although the largest berry observed on the parent bush of the seedlings of September, 1907, was 0.46 of an inch in diameter, a berry ripened in the greenhouse on one of these seedlings measured on April 24, 1909 (Pl. XV), 0.49 of an inch in diameter, and August 2, 1909, one of the same seedlings had a ripe berry 0.5 of an inch in diameter.

(36) SO FAR AS OBSERVED THE SWAMP BLUEBERRY WHEN GROWN IN ACID SOILS IS LITTLE SUBJECT TO FUNGOUS DISEASES OR INSECT PESTS.

Like all plants grown in greenhouses, blueberry seedlings need to be watched in order to detect and stop promptly any fungous or insect pests that may appear.

With the exception of the Asterocystis-like root fungus described on page 65 as occurring on sickly plants in alkaline soils, the only parasitic fungus found on any of the plants was a mildew identified by Mrs. Flora W. Patterson as *Microsphaera alni vaccinii*, which appeared sparingly when the atmosphere of the greenhouse was too moist. This mildew is abundant on *Vaccinium vacillans*, both wild and cultivated, but the swamp blueberry is very little subject to its attacks, an important characteristic. This fungus would doubtless respond readily to the ordinary treatment for mildew with pulverized sulphur.

Among insects a green aphis sometimes threatened to damage the growing twigs, but it was easily destroyed by tobacco fumigation.

The greenhouse red spider (*Tetranychus bimaculatus*) infested some of the cultures, especially in the warmer greenhouses, occurring chiefly on the backs of the leaves, and seriously injured the plants unless promptly checked. The most satisfactory treatment was to syringe the plants once or more a day with a swift spray of water, repeating the treatment until the animals were cleared off.

A pathological condition observed in the summers of both 1908 and 1909, at first supposed to be physiological in cause, has now been traced to an insect. The young leaves of tender shoots become semi-transparent or "watery" in appearance, remain small, develop a faintly rusty color on the lower surface, tend to become slightly cockled, and sometimes turn brown and wither. It was finally observed that these leaves were infested with a very minute animal, much smaller than a red spider and when not in motion difficult to distinguish with a strong hand lens. Specimens submitted to Mr. Nathan Banks, of the Bureau of Entomology, were identified by him as a mite of the genus Tarsonemus and belonging probably to an undescribed species.

A similar and perhaps identical mite had done considerable damage to young seedlings in the greenhouse during the winter of 1908–9, its presence being indicated by the conspicuous cockling of the leaves. The difficulty had then been met by the pruning of the affected twigs. It was observed, however, in the summer of 1909 that the mite producing the watery appearance of the leaves did not occur on outdoor plants fully exposed to rain and dew, but only on plants partly or wholly protected by glass. It is suggested, therefore, that frequent syringing with water may be the proper means to control this mite.

On the whole, this species of blueberry when properly grown may be regarded as unusually free from the depredations of fungi and insects.

## IMPROVEMENT AND PROPAGATION.

(37) THE PARENT PLANT OF THE SWAMP BLUEBERRY SEEDLINGS, THE CULTURE OF WHICH HAS BEEN DESCRIBED, BORE BERRIES OVER HALF AN INCH IN DIAMETER.

The parent of the blueberry seedlings of 1908 was a bush of *Vaccinium corymbosum* selected at Greenfield, N. H., in July, 1908, after three summers of cursory observation in the mountains of southern New Hampshire and three weeks of diligent search in the summer of 1908. The bush grew at an elevation of 950 feet above the sea. It stood with many other blueberry bushes in an old, brushy, mountain pasture, in permanently moist but not swampy soil. It was about 7 feet in height, and the largest of the several stems was about 2 inches in diameter. The plant was old and somewhat decrepit, the tops on some of the stems being partially dead. Some parts of the bush, however, were in full vigor, with robust foliage and twigs. The leaves were dark green above and pale glaucous green beneath, with entire margins, and smooth on both sides except for a slight pubescence on the midrib and principal

BERRY RIPENED ON A BLUEBERRY SEEDLING AT THE AGE OF NINETEEN MONTHS.

(Natural size.)

veins of the upper surface. They were of large size, on the fruiting twigs reaching a length of 2 inches and a breadth of 1 inch and on vigorous shoots having the corresponding measurements 2.5 and 1.5 inches. The character of the leaves is mentioned in detail because of the remarkable variation shown in the leaves of the seedlings, particularly in size, toothing, color, and pubescence. The large flowers produced in the spring of 1909 were 0.4 of an inch (10 mm.) long from the base of the ovary to the tip of the corolla; the sepals were very short, and the corolla white and nearly cylindrical.

The berries were of large size, reaching a diameter of over half an inch. The color was an unusually pale blue, due to a dense bloom or glaucousness over the nearly black surface. In form the berry was not spherical, but somewhat depressed or tomato shaped. The calyx in the ripe berry (Pl. VI, fig. 1) was almost obliterated, because it was small in the beginning and because of lateral stretching of the berry in acquiring its depressed form. This smallness of calyx is of importance, because in such a berry no shelter is afforded beneath the sepals for insects, and also because the amount of "rag," or indigestible skin, is much less than in a berry with a large calyx. In flavor the berry was exceptionally good. It was sufficiently acid to be decidedly superior to the mild, sweet berry of *Vaccinium pennsylvanicum*, yet not sour like the berry of *V. canadense*. It represents one of the best types of flavor in the variable *V. corymbosum*.

The only unfavorable feature of this bush was the lateness in the maturity of its berries, a characteristic of the species to which it belongs. The earliest New England berries, which bring the fancy wholesale price of 20 cents or more per quart for the first few days, as described on page 12, are those of the dwarf *Vaccinium pennsylvanicum*, which mature about two weeks earlier than those of *V. corymbosum*.

The size of the berry is of such importance as to warrant an exact record of the measurement, not only of the largest berries but of all the berries from an average picking. On August 2, 1908, an average pint of berries was taken out of a clean picking of this bush and each berry was measured. The measuring was done by means of a metal plate containing a series of circular holes 5, 6, 7 mm., etc., in diameter. The pint of berries showed the following sizes:

| Diameter of berry. | Number of berries. |
|---|---|
| 7 to 8 mm | 2 |
| 8 to 9 mm | 50 |
| 9 to 10 mm | 191 |
| 10 to 11 mm | 278 |
| 11 to 12 mm | 137 |
| 12 to 13 mm | 10 |
| 13 to 14 mm | 3 |
| | 671 |

The largest berry measured on this bush was 14.02 mm. (0.552 of an inch) in diameter.

Three quarts of berries were picked from the bush; all those less than 10 mm. in diameter were discarded, and the remainder, about 2 quarts, were carried to Washington for seed purposes.

### (38) There is every reason to believe that the blueberry can be improved by breeding and by selection.

The swamp blueberry (*Vaccinium corymbosum*) is an exceedingly variable bush. There are three especially well-marked forms, called *V. amoenum*, *V. atrococcum*, and *V. pallidum*, by some authors regarded as distinct species, by others as forms of *V. corymbosum*. Within the limits of these forms variation is also extensive. There is great opportunity for selection among wild varieties in the size, color, flavor, and time of ripening of the berries and in the productiveness and vigor of the bushes.

That types possessing desirable qualities can be crossed there is no question. A method of pollination has already been described (see p. 78), which, supplemented by the removal of the stamens on the female parent before they have matured their pollen and also by the protection of the pollinated flowers from insects, would insure a genuine cross.

The possibility of securing valuable varieties is accentuated by the marked variation observed in the character of the offspring of the large-berried bush from which the seedlings of 1908 were grown. Besides minor variations, these seedlings show three forms which may be regarded as types. One of these, characterized by its low stature and leaves tending to be conduplicate and by its long persistence into the winter in a green state, is perhaps the result of some pathological difficulty. Two of the types, however, appear in every way to be normal. One has its leaves large, obovate-elliptical, glaucous on the back, and with entire margins, such as are possessed by the parent and are typical of true *Vaccinium corymbosum*, and it develops only a few though very robust stems, with few flowering buds. The other has smaller, narrower leaves, green on both surfaces, and with margins closely and evenly serrulate. It produces many stems smaller than those of the other, and more numerous flowering buds. It is strongly suggestive of the plant called *Vaccinium amoenum*. It is much larger and more robust than *V. pennsylvanicum*, and may possibly be a hybrid between that species and *V. corymbosum*.

The characters of bush and foliage in these two types have not yet been correlated with any differences they may show in flower and fruit. It is, however, of great interest that these same two types occur among the seedlings of 1907, as well as those of 1908, which came from a different though similar bush growing about 2 miles from the other.

(39) The swamp blueberry has been propagated by grafting, by budding, by layering, by twig cuttings, and by root cuttings.

On March 2, 1909, a few scions of the large-berried bush from New Hampshire, dormant winter twigs, were grafted on seedlings of 1907 which had been started into growth in the greenhouse. The actual work of grafting was done by Mr. Edward Goucher. All were simple splice grafts, the diagonal cut being about 0.75 of an inch in length, the diameter of stock and scion at the point of contact about 0.15 of an inch, and the length of the scion about 2.5 inches after it was cut off at the tip just below the lowest flowering bud. The splice was wrapped tightly and completely with raffia, but no wax was applied except to the cut tip of the scion. In order to prevent a possible injurious degree of evaporation from the scion, the whole graft, which was near the base of the plant, was surrounded nearly to the tip of the scion with a loose mass of sphagnum, which was kept slightly moist though well aerated.

All the scions put out new growth from their buds in about ten days. In half the grafts union did not take place, the new growth finally collapsed, and the scion died. In the others the surfaces united satisfactorily and the wrapping was removed. By the end of the season of 1909 the grafts had made a growth of 5 to 8 inches and had laid down flowering buds. (See Pl. XVI, fig. 1.)

The first experiments in budding were begun on August 13, 1909, the work being done by Mr. Henry H. Boyle. Seven seedlings of 1906 and 1907 were budded with summer leaf buds of the large-berried *Vaccinium corymbosum* bush from New Hampshire. On August 16, 6 other seedlings of 1906 and 1907 were budded with buds from large-berried plants of *V. pallidum* from North Carolina. On September 2 and 3, 1909, 26 more seedlings, of 1907 and 1908, were budded with buds from the New Hampshire bush. The buds were inserted near the base of the plant on stems 0.25 to 0.5 of an inch in diameter. The method of procedure was that used in ordinary budding, as of peaches, the same T-shaped cut being made in the bark of the stock, the bud wood cut to the length of half an inch or a little more, and the bud after insertion wrapped tightly with raffia.

The percentage of success in the budding was small. Out of the 39 plants budded only 16 retained their bud alive and in apparently good condition at the end of the season, and the following spring only 5 were alive and in condition to grow. Plate XVI, figure 2, is a reproduction of a photograph of one of the successful buds from the large-berried New Hampshire bush, taken in the winter of 1909–10 after union had taken place, the wrapping had been removed, and the stock had been cut off above the bud.

Comments on some of the features of these budding experiments may be useful to other experimenters. The growth of the stems during the portion of the season remaining after the budding was sufficient to strain the wrappings and, unless the bud wood was held tightly for its whole length, to push the bud out of place. It was found best to leave the bud tightly wrapped to the end of the season, notwithstanding the fact that the stock might become deeply creased and choked.

An examination of the buds that failed showed that in most cases bark or callus from the stock had intruded between the stock wood and the bud wood, sometimes covering the entire surface. While the bud wood in some such cases was in part still alive and green, it was of course doomed.

As late as August 30 in New Hampshire, and September 3 in Massachusetts, bushes of the swamp blueberry were found in which the bark would peel and buds could be inserted. On September 2 no wild bushes of *Vaccinium atrococcum* could be found at Washington in condition to bud. Even in Massachusetts and New Hampshire, on the dates mentioned, most of the bark on all the bushes and all of it on many bushes would not peel. Bark still in good condition occurred mostly on vigorous shoots of the season and in some cases of the preceding season. Sometimes the bark on the north side of an erect shoot would peel when that on the south side would not. Bark still green and whole would peel when near-by bark which from age and exposure had begun to turn brown and split on the surface would not peel.

Propagation by layering was carried on in 1908 and 1909. In the greenhouse experiments moist live sphagnum proved to be a more successful material than peat and sand in which to root a layered branch. When the branch laid down was one which was hardening its wood but still bearing leaves, it callused and rooted readily in the sphagnum at the point where the bark was sliced, but when a young soft-wooded branch was used it usually began to decay at the cut and finally died. Although several times tried it was never found practicable to sever a layered and rooted branch from the parent plant successfully except at the period of winter dormancy after the leaves had been shed.

### (40) The most desirable method of propagating the swamp blueberry is by cuttings.

While the surest method of propagating a selected blueberry bush is by layering, and the most rapid method of securing fruiting plants from it is by grafting, both these methods have certain objections which do not apply to the method of propagation by cuttings.

Propagation by grafting is objectionable because of the habit the blueberry plant has of continually sending up new shoots to replace the old stems. These shoots come from the root or from the base of

FIG. 1.—GRAFTED BLUEBERRY.

FIG. 2.—BLUEBERRY SEEDLING SUCCESSFULLY BUDDED.

The line of union between the stock and the scion in figure 1 is clearly shown. Two twigs had grown from the scion, a short one near the tip and a vigorous one from the lower part. In figure 2 is shown an inserted bud which has united successfully with the stock, but has not yet begun to grow. The inset figure is about three times natural size. The two main figures are natural size.

the stem just below the surface of the ground. Originating below the graft they would not bear fruit of the variety desired, and such a grafted plant would always be liable to serious depreciation in value. It is suggested, however, for the benefit of any who may desire to follow up this method of propagation, that a plant produced by root grafting would be somewhat less liable than a stem graft to the production of shoots from the stock.

Propagation by layering is not open to the objection just raised against propagation by grafting. The difficulty with layering is that only a few plants can be propagated from a parent in this way at one time. The method of layering is slow and therefore, from a commercial point of view, faulty.

Propagation by cuttings, whether of the root or the stem, is subject to neither of the objections raised to grafting and to layering. In a plant raised from a cutting the whole plant body, including the root, is of the variety desired, and alien shoots can never be produced. Furthermore, hundreds or even thousands of cuttings may be taken at one time from a valuable plant and a large stock of offspring can soon be accumulated.

The present objection to the propagation of the swamp blueberry by cuttings is the difficulty of making a high percentage of the cuttings grow. In this respect the experience of the last two years may be characterized as a series of frequent alternations of high hopes and disappointing failures. The intimate knowledge, however, acquired from these experiments regarding the behavior of cuttings under many different conditions gives ground for confidence in ultimate success; but as we are only in the middle of things in this matter a full description of the experiments with cuttings must be deferred until satisfactory results shall confirm our confidence in the methods used.

For the present it may suffice to show an illustration of a plant from a root cutting (fig. 31) and another of plants from twig cuttings (Pl. XVII) of the big-berried bush from Greenfield, N. H. In Plate XVIII is illustrated, from a photograph taken in the winter of 1909–10, a plant grown from a cutting taken on October 15, 1908, from a seedling of September, 1907. Although itself only a year old, and even then taken from a seedling only a year old, the plant after passing the winter of 1908–9 in the greenhouse and the summer of 1909 outdoors, had laid down 156 flowering buds at the time it was photographed.

While these cases show that swamp blueberry plants can be produced successfully from root cuttings and stem cuttings, the successes have been so erratically distributed that the recommendation of any particular method is hardly warranted at the present time.

It should be stated here that those species of blueberry which spread by rootstocks, such as *Vaccinium pennsylvanicum*, and other related plants having the same habit, like the deerberry (*Polycodium stamineum*) and the dwarf huckleberry (*Gaylussacia dumosa*), have

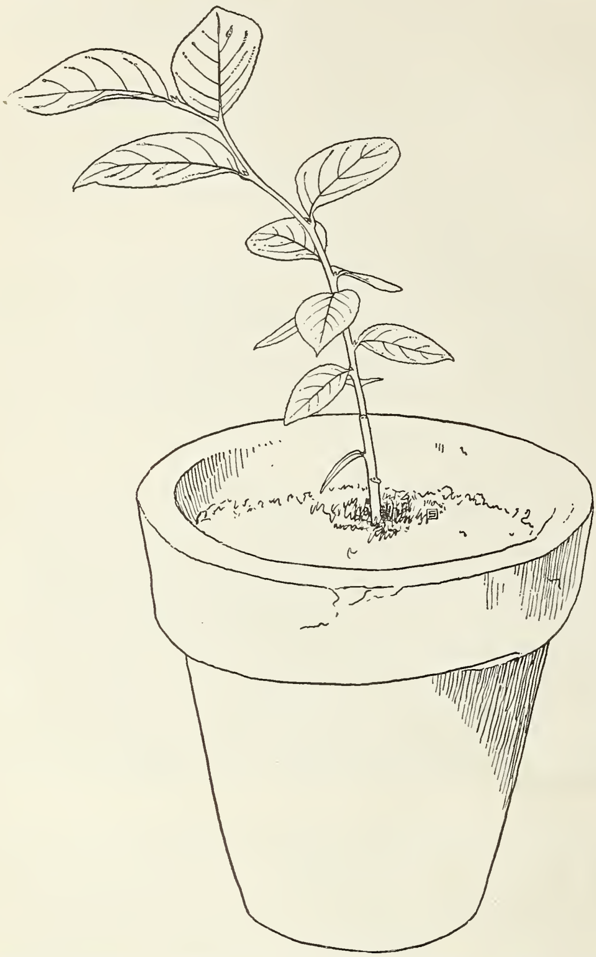


FIG. 31.—Blueberry plant grown from a root cutting. (Natural size.)

been reproduced without difficulty by rootstock cuttings. This method is not generally applicable to the swamp blueberry, however, as large plants of this species seldom produce rootstocks.

## FIELD CULTURE.

(41) EXPERIMENTS HAVE BEEN BEGUN IN THE FIELD CULTURE OF THE SWAMP BLUEBERRY.

While the results of the pot culture experiments are regarded as highly successful and satisfactory, the experimental field plantings made in 1908 and 1909 can not be said to have given more than

BLUEBERRY PLANTS FROM TWIG CUTTINGS.

(One-half natural size.)

promising results. It is true that out of one planting of 179 seedlings of 1907 made in a partially moist natural meadow at Greenfield, N. H., in early July, 1908, 97 per cent outlived the severe drought of that summer and the rigors of the following winter, and 6 per cent flowered and set fruit. The plants were not observed during the ripening season. While this record of flowering and fruiting in plants 2 years of age may be regarded as satisfactory in comparison with the several years supposed by the earlier experimenters to be required before fruiting, it nevertheless can not be regarded as satisfactory in comparison with the pot cultures from the seedlings of 1908, of which, as stated on page 73, 70 per cent were prepared to flower in 1910, their second year.

While the results of the field experiments thus far made are regarded as in no wise approaching what may confidently and reasonably be expected, they nevertheless may serve even at this early stage to convey some useful lessons.

The field planting of 179 plants already referred to contained 84 plants which had never been potted but were torn apart out of their original seed flat while in full growth and set outdoors in the place indicated. These plants after such severe treatment never grew to be robust and none of them flowered. It was among them that all but two of the deaths in the field occurred. That any of the plants should survive such rough usage is of interest experimentally, but in actual practice such a method should never of course be followed.

Most of the field plantings were made in areas where the natural soil had been chopped with a mattock to the diameter of about 18 inches and the depth of about 8 inches immediately before the planting. It is evident from the comparison of certain plantings made in 1909 that a growing plant when set out in such freshly chopped soil receives a serious setback. On June 4, 1909, 216 seedlings of 1908 were set out in new holes prepared as described above, and 48 other seedlings of 1908 were used at the same time to replace dead or feeble plants set out in the preceding year. These 48 plants therefore went into soil that had rotted for a year, although it was in part penetrated again by new roots from the surrounding native vegetation. When next examined, on June 30, the two groups of plants showed the most marked difference in growth. The plants in the new holes showed the same purpling of the leaves and cessation of growth as did plants in the greenhouse when suffering from excessive acidity due to potting in raw peat. (See p. 60.) The plants in the old holes, on the contrary, were nearly all of good color and growing well. It is inferred from this observation that blueberry plants will do better if the holes in which they are set are filled with peat or peat mixture the acidity of which has been tempered by several months of decomposition.

In all the field plantings thus far made the plants were set out while in full growth. Although most of them were in pots when transplanted, and therefore carried their entire root system with them, nevertheless it is regarded as highly probable that a better plan would be to set the plants out when dormant, in the early spring of their second year. Such a plan would offer several advantages which it is hardly necessary to recount.

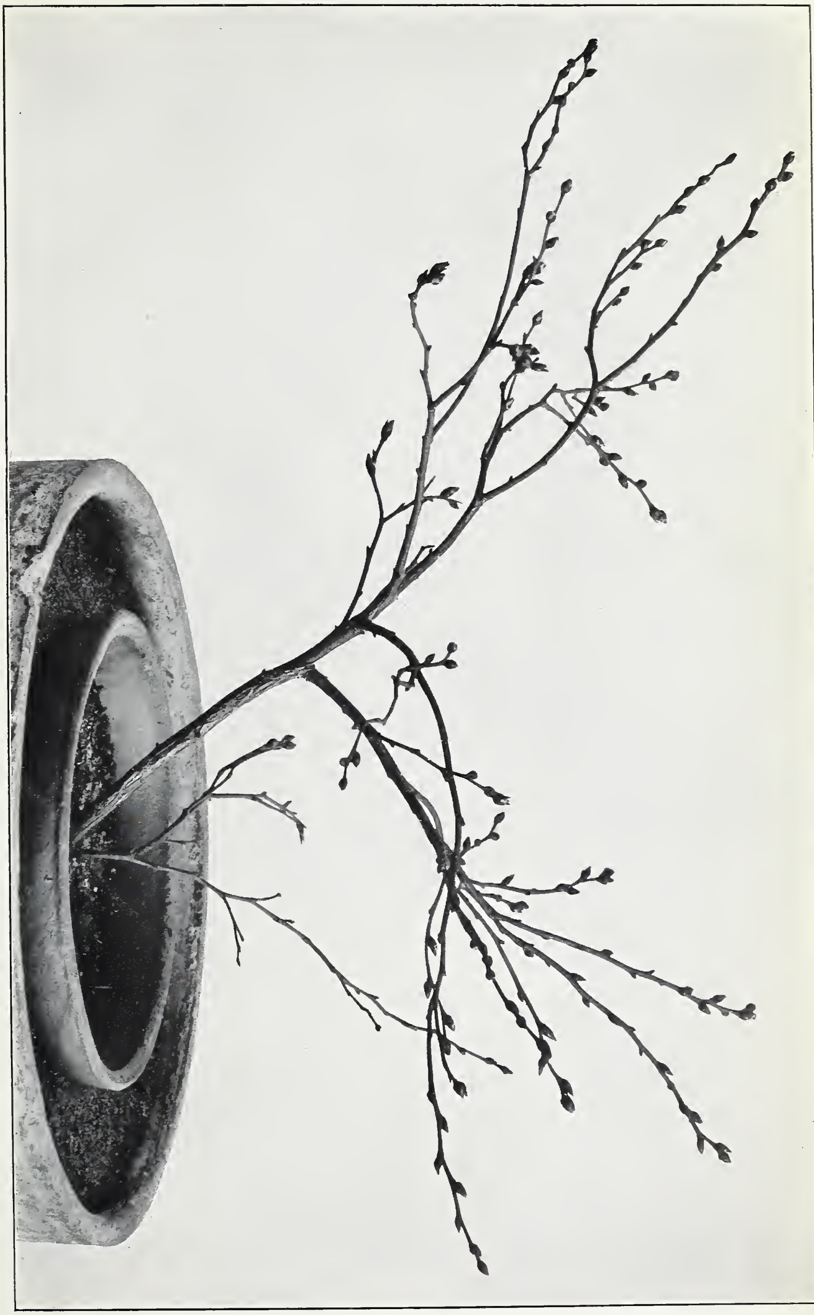
For several days after transplanting, the plants were partially shaded. Paper and the branches of various trees and bushes were tried for this purpose. Pine branches stuck in the ground on the south side of the plants were found by far the best of the shades used.

The soil about the plants was mulched in most cases with dead leaves, held in place when necessary by a little earth thrown over them.

## CONCLUSION.

In conclusion, to those desiring to experiment with the field culture of the swamp blueberry, whether with wild plants, seedlings, or plants grown from cuttings, two modes of treatment are suggested, both deduced from the experiments already made. The first method, suited to upland soils, is to set the plants in trenches or separate holes in well-rotted peat at least a foot in depth, and mulch the surface well either with leaves or with clean sand. The excavations should provide ample space for new growth of the roots, not less than a foot each way from the surface of the old root ball. The peat used may be of either the bog or upland type, as described on pages 32 to 35 of this publication, and should have been rotted for several months before using. The soil in which the holes or trenches are situated should be such as to provide good drainage, the ideal condition of the peat about the roots of the plant being one of continued moisture during the growing season, but with all the free water draining away readily so that thorough aeration of the mass of peat is assured. If the surrounding soil is sufficiently porous to insure the maintenance of such a moist and aerated condition, without the necessity of mixing sand with the peat, better growth, it is believed, will be secured than when such a mixture is used.

The second method of field culture suggested is to set out the plants in a peat bog after the bog has been drained, turfed, and deeply mulched with sand. The treatment proposed is the same as that employed in cranberry culture, except that no special provision need be made for rapid flooding of the bog for winter. The ground water in the bog may probably be kept with advantage a little lower than is usual with cranberries. This method of culture is suggested not



BLUEBERRY PLANT FROM A TWIG CUTTING.

Photographed in the winter after the plant was 1 year old. The pot is plunged in sand, in a larger pot. (One-half natural size. See p. 85.)

only because of the close botanical relationship of the swamp blueberry and the cranberry and the known similarity of their physiological requirements in the matter of peat and moisture, as well as the presence of a mycorrhizal fungus in the roots of both, but also and especially because the most robust growth in all the pot experiments occurred when the roots of the plant were feeding on pure peat and the pots were surrounded by moist sand. The important effects of these conditions are discussed on pages 68 to 71. Essentially the same effects, it is believed, are secured by the system of culture used for the cranberry.

This publication closes with no special summary of results. The numbered statements which form its framework are in themselves a sufficient summary for the general reader, and one who is led by these experiments to undertake the culture of the blueberry will find it profitable not to begin his work until he has read the whole of the publication. These plants differ in their soil requirements so fundamentally from all our common cultivated crops that it is useless to expect to succeed with their culture without a thorough understanding of the principles governing their growth.

Those desiring to look into the work of earlier experimenters can find a key to the literature in F. W. Card's book entitled "Bush Fruits," or in the article by W. M. Munson on Vaccinium, in Bailey's Cyclopedia of American Horticulture.

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