U. S. DEPARTMENT OF AGRICULTURE.
DIVISION OF ENTOMOLOGY.
BULLETIN No. 20.

THE ROOT-KNOT DISEASE OF THE PEACH, ORANGE, AND OTHER PLANTS IN FLORIDA, DUE TO THE WORK OF ANGUILLULA.

PREPARED, UNDER THE DIRECTION OF THE ENTOMOLOGIST,
BY
J. C. NEAL, PH. D., M. D.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF ENTOMOLOGY,
Washington, May 10, 1889.

SIR: I have the honor to transmit for publication Bulletin No. 20 of this Division, being a report of studies and experiments made upon the Anguillula, which is the cause of the root-knot disease of the Peach and Orange in Florida, by J. C. Neal, Ph. D., M. D., of Lake City, Fla.

Respectfully,

C. V. RILEY,
Entomologist.

Hon. J. M. RUSK,
Secretary of Agriculture.

INTRODUCTORY NOTE.

For several years past complaint has been made to the Division of Entomology concerning the damage done by various species of Anguillulidæ, which affect the roots of different plants in different sections of the country, and I have frequently been urged, as Entomologist, to investigate the matter. I have always been puzzled to know what reply to make in such cases, as no American investigator has undertaken a a systematic study of these Nematodes, and they do not, in a zoölogical sense, strictly belong to the Division work. I have contented myself therefore with recording the various facts of injury to different plants that have come to me in the past twenty years, and some microscopic notes in reference to the specimens. One species seems to do considerable damage to certain plants in greenhouses in the North, while another is equally destructive to the roots of trees and plants in the South, particularly in Florida. Towards the close of the year 1887 the complaints of the damage done by the Florida root-inhabiting species were so numerous that, at the request of the Commissioner of Agriculture, I decided to conduct some investigations as a part of the Division work. The demands upon the resources of the Division arising from its more legitimate investigations have been such that but little time and small funds could be spent in this direction. Dr. J. C. Neal, then of Archer, Fla., but now Entomologist and Botanist of the Florida Agricultural Experiment Station at Lake City, a diligent observer, and associated with me in previous investigations both under the U. S. Entomological Commission and under this Division, was commissioned for five months and instructed to make as careful studies and experiments concerning this pest as it would be possible to make during the short time of his employment. His work was done between February 1 and September 1, 1888, and while I do not claim for Dr. Neal, any more than he would himself claim, special or technical knowledge in this branch of Zoölogy, his work is not without scientific interest. The investigations have been, however, from a practical stand-point, and the results more than justify the slight expenditure. The Bulletin makes no pretense to be a scientific treatise on the life history of these worms, but is in the main an effort to ascertain a suitable remedy. The general literature on the subject has not been at Dr. Neal's command, and my time is so fully occupied otherwise that I can do little or nothing at present in the way of identification of species or of comparing Dr. Neal's results with those of European investigators, which, as a matter of fact, are of little practical importance. The study of the full life history of any one of the species is attended with much difficulty, and will require much time in field and laboratory; while the technical and classificatory treatment of the subject should be undertaken by some competent helminthologist.

C. V. R.

LETTER OF SUBMITTAL.

ARCHER, FLA., *December* 2, 1888.

SIR: I have the honor to submit the following report upon the root-knot disease and its cause, the Anguillula.

These investigations, conducted under your direction, began in February, 1888, and have been continued to this date.

While not conclusive in all respects, they are at least contributions to the history of this microscopic pest, that may eventually lead to its subjection or to the mitigation of its ravages.

In conclusion, allow me to express to you my thanks for your aid and guidance during the preparation of the report.

Respectfully submitted.

J. C. NEAL, M. D.,
Special Agent.

Prof. C. V. RILEY,
Entomologist.

THE ROOT-KNOT.

DEFINITION.

An abnormal and irregular growth of the subcortical layer of roots and subterranean stems, characterized by low vitality, the result of an invasion of the tissues by a Nematode worm. (Note 1.)

HISTORY.

Since the earliest settlement of the South Atlantic and Gulf States by white people this diseased condition of the roots of trees and plants has been recognized. (Note 2.)

A very slight inspection has shown the decaying enlargements of roots, but the cause has usually been attributed to a lack in the soil of some important fertilizing ingredient, or careless cultivation, rather than some potent exterior influence.

I have carefully examined all sources of information at my command, and can find no mention of the root-knot in any agricultural paper or book prior to the year 1857.

That year Hon. P. J. Berckmans established a nursery at Augusta, Ga., and soon found this disease prevalent in many varieties of trees and plants, and in 1881 Prof. C. V. Riley being at Augusta was shown the effect of the disease by Mr. Berckmans.

In 1869 Mr. Gilbert Onderdonk, of Nursery, Tex., noted the disease in his fig, grape, and peach stocks, especially in damp, undrained locations.

In 1876 I found the root-knot prevalent over Florida, and learned from old residents that as far back as 1805 it had been known, and from time immemorial had been dreaded as a foe to gardens and groves.

About 1874 this disease, however, sprang into prominence, owing to the influx of immigrants, the development of early-market gardens and the sudden rage for orchards of peaches, figs, and oranges.

Since that time the agricultural papers have contained numerous references to this disease. My own attention was called to this pest by repeated failures to grow certain plants in a rich, damp spot on my farm.

This led me to investigate; and sending a specimen of the knotty roots to the Agricultural Department at Washington, elicited the information that a microscopic worm was the cause of the trouble, but that little was known of the Nematoid family to which it belonged.

Beyond doubt, the disease is peculiar to the South Atlantic and Gulf coast within a limit of 150 miles from tide-water. (Note 3.)

Mr. P. J. Berckmans remarks on this score—and I know no better authority—" that it is indigenous to a large portion of the South seems undeniable, as I have seen it in places in Georgia and Alabama where neither trees nor plants had ever been introduced from other sections."

Mr. Onderdonk also states a similar opinion. Other correspondents at Mobile, Ala , and in Texas confirm these statements.

PLANTS INVADED.

I.—Uncultivated :

a. Slightly affected :

Capsella bursa-pastoris (*Shepherd's Purse*).

Rubus villosus et trivialis (*Blackberry and Dewberry*).

Eupatorium fœniculaceum (*Southern Dog Fennel*).

Quamoclit vulgaris (*Cypress Vine*).

b. Badly affected :

Portulaca oleracea (*Purslane*).

Sesuvium pentandrum (*Sand Purslane*).

Verbesina siegesbeckia et sinuata.

Artemisia caudata (*Wormwood*).

Chenopodium botrys (*Jerusalem Oak*).

Amarantus spinosus (*Careless Weed*).

The above list, no doubt, will in time, and with a careful investigation, be greatly extended; most of these are the commonest of weeds in old fields and badly cultivated grounds, and the Chenopodium alone would be an ample shelter and breeding-place for the Anguillula, independent of other wild or cultivated plants.

The Eupatorium and Chenopodium are perennials, spread rapidly, and have great vitality, and for years it has been noted that where these weeds abound the root-knot exists in the greatest degree.

The Sesuvium and Portulaca, both with fleshy roots, are very common, and are an easy prey to the worms, but my experience indicates the Amarantus spinosus as the most dreaded and destructive agent in the spread of the root-knot, its roots being apparently the favorite of the Anguillula.

In Georgia, my correspondents deem the Verbesina and Artemisia the weeds most diseased, but in Texas, Mississippi, and Alabama, the list is about the same as I have given for Florida. (Note 4.)

It will be seen that it will be impossible to determine certainly the original food-plant of this pest, as it seems to attack the roots of so many; and the inference that any tender growth not impregnated with a decided toxic principle may be invaded is a doubtful conclusion to my mind.

II.—*Cultivated.*

c. Useful.

a. Slightly affected.

Gossypium herbaceum et barbadense (*Cotton*).

Solanum tuberosum et esculentum (*Potato* and *Egg-plant*).

Capsicum annuum (*Pepper*).

Spinacia oleracea (*Spinach*).

Jatropha manihot (*Cassava*).

Zea mais (*Corn*).

b. Badly affected.

The Genus Brassica (Sinapis), (*Cabbage, Kale, etc.*).

Raphanus sativus (*Radish*).

Hibiscus esculentus (*Okra*).

Pisum sativum (*Pea*).

Arachis hypogæa (*Pea-nut*).

Dolichos catiang (*Cow Pea*).

Phaseolus vulgaris (*Bean*).

Phaseolus lunatus et nanus (*Bean*).

All of the Genus Cucurbita (*Squashes, etc.*).

All of the Genus Citrullus (*Melon*).

All of the Genus Cucumis (*Cucumber*).

Lycopersicum esculentum (*Tomato*).

Beta vulgaris, varieties (*Beet*).

d. Ornamental.

a. Slightly affected.

Hibiscus syriacus et coccinneus.

Mesembryanthemum, various species (*Ice-plant*).

Mikania scandens (*Parlor Ivy*).

Pharbitis purpurea et al. sp. (*Morning Glory*).

Nolana, sp.

Petunia, sp. (*Petunia*).

Boussingaultia basselloides.

II.—*Cultivated*—Continued.

b. Badly affected.

Koniga maritima.

Iberis umbellata.

Lagenaria vulgaris (*Gourd*).

Begonia, sp. (*Begonia*).

Dahlia variabilis.

Helianthus annuus (*Sunflower*).

Coleus, var. sp.

Achyranthes, var. sp.

Amarantus var. sp.

Shrubs and Trees.

c. Useful.

a. Slightly affected.

Citrus vulgaris (*Bitter sweet Orange*).

Citrus aurantium, var. sp. (*Orange, Lemon, etc.*).

Vitis, var. sp. (*Grape*).

Prunus myrobolanus (*Plum*).

Broussonettia papyrifera (*Paper Mulberry*).

Morus, var. sp. (*Mulberry*).

Juglans cinerea (*Walnut*).

Carya olivæformis (*Pecan*).

b. Badly affected.

Prunus domestica (*Plum*).

Prunus armeniaca (*Apricot*).

Prunus vulgaris (*Peach*).

Prunus communis (*Almond*).

Ficus carica (*Fig*).

Juglans regia (*English Walnut*).

Salix, var. sp. (*Willows*).

d. Ornamental.

Spirea sorbifolia, var. sp. (*Spirea*).

Prunus nana et lanceolata (*Flowering Almond*).

Buddleia, var. sp.

Gardenia florida (*Cape Jessamine*).

This long list embraces the greater part of our most valuable food-plants, fruit-trees, and many of the choicest flowers, and it fully justifies the inquiry now made as to the history and means to prevent the spread of the disease induced by the Anguillula.

I think it useless to endeavor to account for the apparent vagaries of the Anguillula, as, for instance, to ascertain why the roots of the Prunus vulgaris are so badly affected, while Prunus cerasus are unhurt; or why the Leguminosæ are susceptible and the Umbelliferæ are not. It is reasonably sure that rapidly growing, soft tissued roots are better subjects for invasion, expansion, and decay than those of slow growth and denser structure, and the self-evident corollary is that methods and fertilizers promoting a rapid succulent growth should be avoided in all locations infected with the root-knot.

EFFECTS OF THE INVASION OF THE ANGUILLULA.

I have found mature worms, males and non-pregnant females, in rootlets but a few days old, and under circumstances which involved the necessity of invasion from without the root. See Experiment No. 22.

These Anguillulæ were small enough to enter the "stomata" of epidermal tissues, active and strong enough to even penetrate cell-walls, or to separate cells in loosely connected tissues. Once within, they could easily pass through the Cienchymatous system of the Parenchyma to any portion of the root, and I think it not unreasonable to infer that in this manner they obtain entrance in young rootlets.

Their presence causes a rapid proliferation of cells, resulting in a soft, unnatural, irregular growth of the root, with low vitality, and a varied effect upon the plant or tree.

The Chenopodium, Eupatorium, Artemisia, Amarantus, Gossypium, Solanum, and Petunia have the enlargements usually on the sides of the main stem, near the surface. The "tap-root," descending deeply is rarely affected, and the plants seem slightly affected till the sub-cortical layer is filled with worms in all stages of growth. This checks growth, either by their absorption of the nutrition gathered by the rootlets, or obstruction of the Cienchymatous ducts, the food supply is cut off before decay is visible, the leaves wither, the stems shrivel, the plant dies. (Plate VIII, 1 *a*, 4 *b*.)

The roots of the Okra, Radish, Turnip, Cabbage, Cucumber, Melon, Cow-pea, Peanut, Tomato, and Egg Plant enlarge enormously, soon becoming little else than masses of decaying tissues. The plant stops growth, the fruit either becomes distorted or drops prematurely, the leaves change color and fall off, and the plants die so rapidly as to justify the usual expression "struck by lightning," applied to the fields of Melons, Cucumbers, Tomatoes, and Cow-peas so often badly affected by the root-knot. (Plates I, II, III, IV, and VIII.)

In nurseries of young fruit-trees the greatest mischief occurs. The soil is usually carefully prepared by heavy fertilizing and culture, and the seeds of the Peach, Orange, and English Walnut are sown for stocks. When the tender shoots first appear many wither and die at once, others grow vigorously till the end of the first season, when they are usually budded with known and valuable varieties of fruit. The next spring these buds put out tardily and make a weak growth, the leaves become spotted or yellow, then drop, the bud dies, feeble straggling shoots sprout around the stem, which maintain a sickly vitality till the first drought, when the tree dies, and an examination discloses the cause in the knotty, decaying roots, without rootlets or fibrillæ.

With older trees taken from healthy locations and set in infected soil the program varies. The Peach and Fig often grow vigorously one or two years, and bear fruit that is very prone to drop immaturely, then the tree takes on an irregular growth of stunted limbs and small leaves. The tips of these limbs die back gradually to the body of the tree. If the soil is clayey the tree will put out feeble sprouts often for several years.

With the Pecan, English Walnut, and Willow, older trees remain stationary a year or so and die with the occasion of a severe drought.

In many cases, especially in old fields, the seeds of trees and plants barely germinate, or cuttings hardly form rootlets till they are invaded and destroyed.

In all of these cases the effect is to deprive the stems and leaves of food and moisture; the knots grow, the branches do not.

The annual destruction of nursery stock is enormous, especially the Peach, Fig, Willow, Spiræa, Buddleia, Coleus, etc.

In the sketches taken from nature, attached to this report, are shown typical specimens as far as possible.

The Grape, Fig, Mulberry, and Orange are prone to circular knob-like knots on the sides of the larger roots, and an occasional enlargement at the junction of small roots. (Plates IV and VII.)

The Peach, Plum, Walnut, and Spiræa grow irregular masses, involving the whole root seemingly. (Plate V.)

The Willow, Okra, etc., enlarge, and the decay is usually visible first at the extreme tip of growth from the central stem. (Plates VI, I, and II.)

TERRITORY OCCUPIED BY THIS DISEASE.

Early in the beginning of my studies of the Anguillula, I addressed letters of inquiry to most of the leading nurserymen and horticulturists in the United States, especially those in the southern section, asking an examination of diseased trees, and inclosing samples of the root-knot for comparison.

The replies I received are conclusive that the disease is unknown beyond any point in the interior 150 miles from the coast.

It does not exist except in locations free from extreme cold, and the northern boundary is not far from the January isotherm of 50°, as shown in the No. 2, Isothermal Lines of the U. S. Signal Service, 1881.

Letters from the Peach districts of Michigan, Maryland, and New Jersey complain of the "Yellows," but investigators do not report finding the diseased roots indicative of the Anguillula.

It is not found at Denison, Tex. (Munson), only along the coast in that State, and then only in sandy, wet locations. (Onderdonk.)

The usual dry air of New Mexico, California, and regions west of the Mississippi River, with the summer parched soil of these sections, forms apparently a barrier to the growth and spread of the disease, but coming eastward it is progressively worse, till it reaches a climax in Florida, which seems to possess the requisite soil, humidity, and warmth for the proper environment of the Anguillula, and consequently its complete development for mischief in gardens and groves.

Add to this the cultivation of special food plants extremely susceptible to invasion by the worm, and there can be no wonder at its prodigious increase.

TEMPERATURE.

The question of temperature is no doubt one of great importance in determining the boundaries of this disease, perhaps more so than food-plants or soils.

The soil that is annually frozen from 6 to 10 inches is nearly disinfected from the worms, especially those existing in a free state in the soil, or inhabiting the soft roots of annual plants, and this may explain why southern Michigan, northeastern Ohio, and New Jersey, with as sandy a soil as Florida or south Georgia, still escape the plague in the Peach orchards.

The Chenopodium, Artemisia, etc., abound in these States, and no doubt are the habitat of Anguillulæ, but the continued cold reduces their number to the minimum each year, and the fibrous-rooted trees are unharmed.

Again, in some cold localities the trees kept in hot-houses are affected; those without in open ground escape.

Places favored with hot, dry summers and cold, wet winters will not likely ever suffer from the ravages of the root knot.

My experiments are conclusive that below 50° in fluid, and above that, dry, the worms are inactive, paralyzed by cold, and shriveled by dryness and heat, and the inference is plain that parties wishing best results must either choose unsusceptible stocks, for grafting or budding trees liable to infection by the Anguillula, remove to favored locations, or find some means of destroying the worms.

The arid regions of the West fill one indication, the others are still *sub judice*, but in a fair way for determination.

SOILS.

It can not be questioned but that a light, sandy soil offers least resistance to the progress of the Anguillula after its liberation from decaying roots either encysted or free.

Experiments with air-dry soil show that water penetrates sand in half the time that it will penetrate clay, and over large areas of cultivated land the proportion would still be greater in favor of the sand.

Loose soils, mixed with decaying vegetation and humus, offer still better facilities for irrigation, and this explains the fact that locations highly fertilized with composts, stable manure, or leaf-mold show the root-knot quicker in plants than compact or virgin soils, and the worst results are found in gardens planted in long cultivated, fully fertilized, and thoroughly pulverized areas.

Moisture is an essential to the vigorous growth of the Anguillula, though it withstands an enormous amount of drying.

The cysts shrivel, pregnant females become irregular in outline, mature worms stiffen and remain indefinitely with suspended vitality, but resume action with the application of sufficient moisture. (Note 5.)

A friable soil, with compact clay near the surface insuring needed dampness, presents then the typical environment for the Anguillula, and this, alas, also is regarded in this section as the most advantageous location for a garden or grove.

Another very favorable location for these worms is the boggy bank of a lake or river, where there is a mass of wet, decaying vegetation.

EXPERIMENTS.

A series of experiments, under the direction of the Entomologist of the United States Agricultural Department, was begun in February, 1888, to determine the migration and life history of the Anguillula, as well as to investigate the effect of various insecticides. That these are not complete and conclusive, is owing to the extreme difficulty of tracing any individual worm by reason of its size and its surroundings.

A quantity of both ordinary sandy soil and clay was heated several hours to a temperature of 400° F.

A number of 6-inch earthen pots were also subjected to the same heat. The earth and the pots were tested for living Anguillulæ and found sterile.

(1) Four sterile pots with $\frac{1}{10}$ cubic foot of sterile soil in each pot.
(2) Same as No. 1, using sterile clay instead of surface soil.
(3) As No. 1, using yellow subsoil from infected locations.
(4) As No. 3, using clay subsoil from infected locations.
(5) As No. 1, using infected surface soil from infected locations.

In each pot were planted four seeds of the Cow-pea (Dolichos), selected because of its ease in germinating and great susceptibility to the Anguillula.

All came up within the week and grew fairly well; at the end of each week one plant was removed and the roots examined.

In Nos. 1 and 2 no knots were visible at any stage of growth and the last plant grew to maturity.

In Nos. 3 and 4 the plants were but slightly affected, and at the end of the fourth week each remaining plant had made a fair growth, despite the terminal roots were becoming enlarged.

In No. 5 half the plants died before the appearance of the third leaf, and the remainder made a sickly, feeble growth. The roots were badly knotted, decay in every case appearing at the terminal ends of the rootlets, which turned brown and dropped off at the slightest touch.

I repeated this series of experiments, using small seedling peach trees in place of the cow-peas. The results were similar—the trees in Nos. 1

and 2 growing vigorously, with fully developed roots and leaves; in No. 3, at the end of four months the trees were living, but feebly, and the roots showed signs of decay.

In No. 4 the trees had grown somewhat better and had a brighter color, but the roots were knotty.

No. 5 showed poorly, leaves smaller, roots quite knotty, and one tree dead.

The same results followed using the Weeping Willow as the test plant.

The inferences are: That the Anguillula is destroyed by a heat of 212°; that healthy trees set in infected soil soon are invaded by the free Anguillula in the soil; that soil taken from the depth of 2 or more feet below the surface is comparatively free from the worms, and that clay subsoil is less infected than the sand.

Another series of experiments testing the effect of various chemicals, fertilizers, and insecticides was tried, using four sterilized pots in each test, the pots each containing $\frac{1}{100}$ cubic foot of infected sandy soil, and the chemical, at the rate of $\frac{1}{1000}$ of the weight of the soil (24 grains), thoroughly mixed or dissolved. In each pot was planted a seedling peach and four cow-peas.

No. 6. Tobacco dust.
7. Tobacco dust with 24 grains sulphate potash.
8. Tobacco dust with 24 grains sulphide potash.
9. Tobacco dust with 24 grains sulphite potash.
10. Tobacco dust with 24 grains muriate potash.
11. Tobacco dust with 24 grains hyposulphite soda.
12. Tobacco dust with 24 grains sulphate iron.
13. Tobacco dust with 24 grains caustic lime.
14. Tobacco dust with 24 grains unleached ashes.
15. Tobacco dust with 24 grains sulphur.
16. Bisulphide carbon.
17. Sulphate potash.
18. Muriate potash.
19. Unleached ashes.
20. Caustic lime.

These experiments were also repeated in the nursery and open field on small peach trees, using 602 grains to each tree, equivalent to $\frac{1}{1000}$ part by weight of the soil. (Note 6.)

In the pots the results in Nos. 6, 7, 10, 13, and 14 were very encouraging; the peas grew to maturity, with good color and very few enlarged roots. Nos. 8, 9, 11, and 15 made a very poor growth, and died soon after the third leaf. No. 12 died immediately after sprouting, as did No. 16. Nos. 17, 18, and 19 grew nearly as well as Nos. 6 and 7; No. 20 made a fine growth, with very few enlarged roots. The peach trees died soon in Nos. 8, 9, 11, 12, 15, and 16, made a fair growth in Nos. 6, 7, 10, 13, and 14, were killed at once in No. 16, and grew the best in Nos. 17, 18, 19, and 20.

In the field Nos. 11, 16, and 8 appeared to at once kill the trees. Nos.

9 and 15 had no effect visible. Nos. 6, 7, 10, and 14 made a better growth than Nos. 17–20. Root-knot was present on all but Nos. 13, 14, and 20.

On still larger trees, applied at the rate of 27 pounds to the tree, Nos. 6, 13, 14, 17, 18, 19, and 20 gave good results, especially 6 and 17, 6 and 18, 6 and 19. These mixtures seemed to promote a vigorous growth of healthy roots, and Nos. 6 and 20, each 27 pounds to the tree, well mixed with the surface soil, appears to be as near a preventive of the "knot" as anything I have tried.

I tried the bisulphide of carbon without any effect other than the death of the trees, some fifty or more, and the kerosene emulsion to saturation of the surface soil produced a similar result, and in view of the expense and labor involved I did not repeat the experiment. (Note 7.)

A number of the prepared artificial fertilizers were tried; those containing ammonia, guano, bone, and fish produced a rapid growth, soft and easily attacked by the Anguillulæ.

In a field near my place, heavily fertilized with a bone and potash compound, the roots of the pea nut became masses of knotty roots, the worst cases of the disease I ever saw, and peach-trees growing in that field are ruined.

I have found nothing of value when applied to old bearing fruit trees, if badly affected, as any insecticide capable of absorption by the roots invariably has killed the trees when used to the amount of $\frac{1}{100}$ the weight of the surface soil, 1 foot in depth and the area of the circle filled by the roots. Alkaline mixtures, 20 to 40 pounds to each tree, or caustic lime, kainite, muriate and sulphate potash or wood ashes, used several years in succession, have come nearest a cure, destroying no doubt many free worms, and inducing a vigorous, tough growth of roots, more difficult of penetration, and possibly rendering the sap in some way obnoxious. (Note 8.)

The addition of tobacco dust in large quantities supplies nitrogen, and makes a very vigorous growth of roots and limbs. It also seems to have considerable preventive effect on the worms. Experiments conducted by one of our market gardeners has convinced him that the mixture of tobacco dust and muriate of potash in old fields in great measure prevents the ravages of the Anguillula in Okra, Cabbage, and Egg-plant, and he has adopted this as a standard fertilizer for all his products. I have seen his use of this, and am nearly prepared to sustain his views. Kainite is no doubt fully as good, but further experimenting is necessary.

Another series of experiments was made upon plants to determine the time and degree of infection.

No. 21. Sterilized pots with $\frac{3}{100}$ cubic foot of sterile soil, in which four cow-peas were planted at various depths, one-half inch, three-fourths inch, and 1 inch, were covered 1 inch with infected earth and kept watered. The results showed infection of the roots in about the same ratio as the distance from the surface. Reversing the process, putting the infected soil below, showed the roots affected soonest in the peas planted deepest, indicating but little action in the worms outside of that produced by the percolation of water.

No. 22. Another series of pots were watered with muddy water from infected earth, and though the pots contained sterilized soil the roots of the peas were badly affected. Microscopic investigation of the percolate showed both free and encysted Anguillulæ. (Note 9.)

No. 23. Pots with sterile soil had one transplanted infected peach seedling in each, and four cow-peas.

The trees soon died, and very shortly afterward the peas showed the infection, those nearest the dead peach roots the most markedly.

In a spot of new and non-infected ground several trees, Peach and Fig, were planted. The central tree was knotty-rooted and died in a few months; the next year the roots of the nearest trees, 15 feet away, became knotty nearest the dead tree, and now, after the lapse of four years, the disease extends to the tips of the roots of all the Fig and Peach trees in a circle 120 feet distant each way from the original infected tree.

In another case, in a nursery on high pine land, clay subsoil and free from disease, a number of peach roots, badly knotted, were brought from a distance and heeled in for a week. The disease spread in all directions from this nucleus.

Again, in another peach nursery was a spot of low, damp, black soil. There was no root-knot the first year it was planted in peaches; the seedlings grew well. The second year, a few trees were found in this spot with enlarged roots and destroyed. The third year, hardly a tree escaped, the disease extending along the thickly set rows of seedlings upward and in all directions on to the higher land from the hollow spot first infected.

In another case, clean fibrous-rooted trees were heeled in a day or so and planted in non-infected ground. The next year proved the most of them diseased.

These cases prove conclusively that in areas not infected the disease can be easily introduced (1) by planting infected trees; (2) by the use of composts of muck and weeds from infected soils; (3) by the distributive action of water and air, the water carrying particles of soil and worms downward from an infected elevation, or by dry soil, fragments of dry roots, desiccated free or encysted worms carried in the air during sand-storms, whirlwinds, or the heavy currents of air preceding storms that often blow "bare" acres of plowed land and overwhelm adjacent fields with the soil thus borne on the wind; (4) soil containing these worms I have no doubt has been carried on the feet of men and animals and deposited in healthy fields, forming the nucleus of a destructive agency, months afterward made visible by its effects.

Instances are not wanting that can not be explained except by some such theory of contagion and manner of travel.

REMEDIES.

1. Drainage.

Many gardens and orchards are badly located on soils partly saturated with water, either at the margins of rivers or lakes or on rich deposits of vegetable remains both low and damp.

The reasons for this choice are generally the superior quality of the land and the rapidity of growth induced by the moisture, but in the territory infected by the Anguillula the heat and rich soil cause precisely the looseness of tissue so favorable to the spread of the worms.

A dry soil, with solid root-growth, is on the contrary unfavorable; hence in many locations drainage has entirely changed the character of the land, so that peaches and figs grow where they would not before.

Experiments in Texas confirm this fully and suggest the utility of thorough drainage of wet locations, or, better yet, the avoidance of such places for groves and gardens.

In this connection it may be remarked as one of the not expected results of the "New Agriculture" in maintaining a permanently damp soil by means of water-pipes below the surface, that when it is in vogue we will have not only a great increase of crops but a greater increase of "root-knot" in the cabbages, beets, radishes, etc., thus grown. What effect the ingestion of Anguillulæ will have upon the human economy remains to be seen; as, so far as I know, no record occurs of experiments having been tried to ascertain. (Note 10.)

2. Frost.

In many places north of 29° there is cold enough each year to at times freeze the surface a considerable depth. Where this occurs, by plowing the soil at the beginning of winter and at times during that season, it is reasonable to suppose great destruction of the free Anguillulæ will ensue.

3. Fire.

The value of heat in the destruction of the germs of the root-knot has been often demonstrated in Florida, usually unwittingly, and the lesson taught has been in a measure lost.

In clearing old fields, badly infected with the worms, as shown by the crops of cotton or peas, it is customary to burn log-heaps and stumps; if, then, peaches and figs have been planted on this burned land the result has been freedom from root-knot for a series of years.

Such trees make a vigorous growth and bear well, while adjacent trees, not on burned ground, wither and die.

It would seem practicable in this wooded section to easily build small compact heaps of chips, wood, pine knots, even dry weeds and grass, over the area of say 2 feet radius from each tree-stake prior to planting, burn the heap to ashes, excavate the soil as far as heated, and re. new the fire till the subsoil is reached and the depth of at least a foot of soil in all is thoroughly sterilized by heat.

In many cases, where wood is plenty, dead standing timber to be removed, and stumps to be burned, the plan would succeed to stake out the field and build a log-heap at each stake; but if not convenient, the annual growth of weeds and grasses, well dried, will furnish fuel enough.

4. Sterile Soils. (Note 11.)

Among the early settlers of Florida the practice prevailed, when planting trees, of digging out the soil to the depth of 2 or more feet and filling in around the tree with clay or yellow subsoil obtained from virgin land and 3 or more feet below the surface. This plan succeeded, in that it surrounded the tree with sterile soil till it formed firm roots and a hardened epidermis.

My investigations show that in infected soils the deep roots are but slightly affected in comparison with those near the surface, and that the greatest destruction prevails in young trees, nursery stock, and plants having surface roots.

If a tree acquires age and the roots reach deep subsoil, the Anguillulæ do little damage. Hence the utility of using clay or subsoil, derived from virgin forest, around newly-set trees.

This old plan deserves attention and can be recommended; but since the war, in their haste to promote the growth of groves and gardens, the later horticulturists reverse this method, imbed the young tree in surface soil, and use nitrogenous fertilizers to encourage rapid development, this certainly causes increase of the root-knot.

5. Disuse of Land.

Keeping land clean, free from all growth for two or more years, has proved of great benefit if done before trees are planted. I believe the worms require living tissues to develop in, and deprived of this they would die, probably within the limit I have given.

In many places where the soil has not been cultivated for a long series of years, and the Broom Sedge Grass has exterminated all other weeds, I have failed to find any traces of the Anguillula, and I regard this as confirmatory proof that disuse of land prevents the root-knot.

6. Disuse of Easily Infected Crops.

In most of our Southern States, where the Clovers and Buckwheat will not prosper, it has been the almost universal custom to substitute the Cow-pea as a soil-renovator. Drilled or broadcast it is the great crop for "laying by" corn, and as a second or third crop after rice, oats, or market garden. Very few groves or orchards but have annually from one to three crops of pea-vines plowed in for fertilizing.

Again, as a "first crop," after clearing off the timber, it is in general use for new land. Few plants are so sensitive to the attacks of the Anguillula, and few have roots so badly infected with these worms, and this common custom of planting the Cow-pea is mentioned only to be condemned, as, if continued, in time all groves and gardens in these sandy soils will be failures.

The Lespedeza striata (Japan Clover), Desmodium molle (Beggar Weed), and Richardsonia scabra (Mexican Clover), will prove fine substitutes for the Cow-pea as forage and fertilizer. If the Cow-pea must be grown, keep it away from garden and orchard, and at planting time use large quantities of some strong alkaline fertilizer on the soil. The economical habit of planting market gardens in orchards should be discouraged.

It is easy to see the reason and the danger from the use of ammoniacal fertilizers so necessary to induce rapid growth of vegetables, and the spread of the Anguillulæ from the roots of the Melons, Cucumbers, etc., to the trees. Many instances of this sort can be seen over the South, and should serve as warning to our horticulturists in the future.

I believe that in badly infected grounds some relief could be given by drilling the Cow-pea, and, when in bloom, cutting off the stems for forage; then to plow and carefully rake up the roots in piles for burning when dry enough. This method of destroying the infected roots of Okra, Melons, etc., and the roots of the Chenopodium, etc., would no doubt be of great value in small areas, and even in larger fields, by the aid of improved machinery for gathering the roots.

It needs only the mention that planting of trees from infected localities should be avoided; even those not liable to the disease themselves may carry soil containing Anguillulæ among the roots.

I have noted that the Peach and Fig obtained from Northern nurseries seem extremely easy to take the disease, far more so than the native stocks. I only mention the fact, but have not ascertained the reason.

7. Insect Enemies.

I have found but one, the small blackish-brown ant that inhabits rotten wood and decaying roots—very common in this section—the Solenopsis xyloni.

This, when the roots of the Okra, Pea, etc., begin to decay, burrows into the tissues and drags out the pregnant Anguillulæ for destruction.

I was puzzled at first to find the dead roots of the Okra, Melon, Peach, and Fig free from cysts or pregnant worms, though in partially rotting enlargements I found plenty of Anguillula.

Closer and extended examination showed this ant in the act of devouring the enlarged worms, and its service to the orchardist is beyond value in this respect.

Inasmuch as a dry soil is favorable to ant life, it will be readily seen how drainage is useful in aiding the propagation of this tiny destroyer.

Upon crushing a mature, pregnant worm various forms of micrococci are visible by the microscope as existing within the Anguillula, evidently not hurtful, and when seen exterior to the worm seem not prejudicial to its life; but more study is needed on this point.

8. Use of Vermicide Fertilizers.

Experiments looking to the adoption of some mixtures capable of destroying the worms while in the root tissues have not proved a success. The use of smaller quantities per acre than one-tenth of 1 per cent. of the surface soil for 1 foot in depth and 10 feet radius to each tree—about a ton to the acre—produced no perceptible effect on the disease, and a greater amount injured the trees.

The use of bisulphide carbon, kerosene emulsion, and various arsenical solutions destroyed so great a percentage of the trees that on that account, and the expense of application, it was abandoned.

Alkaline mixtures have done better, and will bear repetition, especially the sulphites and muriates.

For nursery stock, it no doubt will pay to thoroughly incorporate some of these chemicals with the soil some weeks before planting seeds, cions, or young trees, using it at the rate of at least one-tenth of 1 per cent. of the surface soil cultivated.

Alkaline fertilizers, as hard-wood ashes, muriate and sulphate of potash, kainite, or ash element produce a hard growth but little, if any, affected by the root-knot. Usually the fertilizer is applied in too small a quantity. Not less than 3,000 pounds to the acre should be used to produce the required effect, one-half in December, the remainder in May.

A fertilizer containing a small percentage of carbolic acid, carbolates, thymol-cresol, or an easily decomposed sulphite would no doubt be valuable in this infected section.

9. Non-infected Stocks.

After all, I believe the use of trees that are not susceptible to the root-knot, for stocks on which to graft or bud the susceptible varieties is the proper solution of the root-knot problem. The matter of location, soil, fertilizer, and prevention then need not worry the intending orchardist. Find the disease-proof tree and the thing is done, and most of my experiments have been directed to secure in some measure this result.

It is, perhaps, too soon to say that complete success has been realized, but the gain is perceptible.

For the Orange I can recommend the hardy bitter-sweet or sour species as nearly disease-proof and a vigorous grower.

The Citrus trifoliata and the Japanese "Unshiu," or Satsuma, both seem resistant, but the time of trial has been too short. This last is a slow grower, with dense roots, and promises to be the best of any of the

Citrus family. Its hardiness, freedom from thorns, and vigor recommend it.

Grapes of the Vinifera type as well as those of the Æstivalis group are subject to the root-knot, if grown on their own roots, but grafted into stocks of the Cordifolia or Vulpina races have made superb growths free of the disease.

I have found no stock for Fig or Mulberry that has stood the test.

For the Peach family either the seedlings of the Wild Goose Plum, the Marianna, or the recently introduced Japanese Plums, Kelsey, Satsuma, or Ogru, are valuable. Three years' test of the Marianna prove that for that time, at least, the roots resisted the Anguillula and were free from knots. When the peach died the Myrobolan was infected slightly, and even the native plums suffered with the disease. It is too soon to give an unqualified approval of this as a stock, but so far it is the very best, growing from cuttings and very rapidly, making a tree that is nearly borer-proof as well as free from the Anguillulæ.

Some seedlings of our American Plums are destined to replace the Peach as a stock, unless the Japanese varieties prove superior.

I have found nothing of value for the English Walnut as a stock, nor for the Weeping Willow.

I have indicated the probable line of action to mitigate or prevent the disease in gardens—the use of alkaline fertilizers, the exposure to frost, the gathering of diseased roots to burn, the removal of certain weeds, and the disuse of land and cow peas.

EXTENT OF DESTRUCTIVE EFFECTS OF THE DISEASE.

Within the district infected by the Anguillula it would be well nigh an impossibility to give even an approximate idea of the losses sustained each year by the farmer, the gardener, and the horticulturist from the ravages of this worm.

All over the southern section of the United States hundreds of market gardens have been planted at an immense outlay of time and money, only to have the fields of vegetables blighted from this mysterious trouble, as if scorched by fire or frost. Thousands of trees have been planted only to dwindle away and die; and, as the defect has been usually ascribed to the fertilizer or the climate, the injury has been enormous, while the real cause has not been suspected, and, as far as I know, no effort made to ascertain a remedy. The Orange is slightly affected now, but in the future, when the soil will be filled with cysts and worms, Orange trees will be as uncertain, I fear, as the Peach or Fig at the present time.

From the best testimony I can get, in the early days of the white immigration, except in damp locations, peaches grew without any disease, save the "Borer." Now, in many places, the trees that do well are the exception, and in these locations it is idle waste of time, labor, trees, and fertilizers to attempt the culture of an orchard.

In such infected spots the usual program is to apply some costly ammoniacal manure to the land, cultivate early vegetables between the trees; then, after that crop is removed, sow the land in cow-peas. The result is bewildering. Next year the unfortunate planter is discouraged to find many of the trees dying back, the vegetable crop with knotty roots and irregular fruit.

Another heavy fertilizing, another crop of peas, and that spot is done for. The disgusted farmer tries another vocation, and gives over the place to weeds and desolation.

With young, closely-set rows of trees the disease causes greatest damage, spreading rapidly from tree to tree.

In market gardens, especially the Tomato, Cucumber, Melon, and Squash, the Anguillula often either destroys the plants before fruiting or reduces the size of the fruit till it fails to pay expenses.

A number of disastrous failures with gardens, that have come to my notice, no doubt resulted from this cause.

LIFE HISTORY OF THE ANGUILLULA.

The study of this microscopic worm has been exceedingly difficult, and many points in its history are not yet fully ascertained.

The limit of its existence, periods of growth, sexual characteristics, generation, variation of form, and the precise action occasioning the abnormal growth in roots, are all undetermined questions which wiil take a long continued series of observations to solve. (Note 12.)

As first observed, a mass of cells appears within the uterine cornua, cells averaging $\frac{1}{20000}$ inch in diameter, arranged in bands from $\frac{5}{10000}$ to $\frac{8}{10000}$ inch in width, reaching across to the walls of the uterus. (Plate XX, A, B.) These bands appear at the smaller end of the uterus, beginning from $\frac{20}{10000}$ to $\frac{30}{10000}$ inch from the free extremities, extending downward $\frac{30}{10000}$ to $\frac{60}{10000}$ inch. Lower down, these cells show a tendency to aggregate into irregular masses (Plate XX, B, C), then into ovate forms, eventually becoming ovals $\frac{8}{10000}$ by $\frac{24}{10000}$ inch.

At first these cysts have no epidermis, but a thin coating appears and thickens as they approach the normal size of $\frac{36}{10000}$ inch in length and $\frac{16}{10000}$ inch in width. (Plate XX, D, 2.)

During the life of the female the cysts form rapidly, until the whole uterus becomes enormously enlarged, and contains cysts in every stage, from the primary agglomeration of cells to free Anguillulæ. (Plates XIX and XVIII.)

The decay of the environing root exposes the pregnant female to changes in weather, and with a slight increase in heat the contraction of the exterior expels the contents of the uterus and disperses them.

This in most cases appears to be through the upper segment, though often it occurs through the fissure in the head. (Plate XIX.)

The cyst at first is a solid mass of granular cells. (Plates IX, 1, and X, 1.) It divides centrally at the shorter axis (Plates IX, 2, 3; X, 2, 2б, 4); each half repeats this process till four or five segments are visible. A longitudinal fissure then appears, causing eight segments (Plates

IX, 6, 7; and X, 15, 16, 18); the walls of the segments are absorbed each side the central long fissure (Plate IX, 8, 10, 15, 16, 17, 18), which extends to the margin of the cyst in one direction, and upon separation at that end motion begins, and the Anguillula awakes to life and action. (Plates IX, 17, 18; and XI, 1.)

The growth within the cyst continues till the worm attains a length of $\frac{150}{10000}$ inch or more, and a central diameter of $\frac{5}{10000}$ inch; the cyst ruptures, the worm is free (Plate XI, 2, 3, 7), leaving the empty shell shrunken and torn. (Plate XI, 4, 4*a*.)

Up to this point I have failed to discriminate the sexes. Both appear blunt at one end, which is marked with a fissure $\frac{4}{10000}$ inch to $\frac{6}{10000}$ inch in length, often with a circular hinge-like termination (Plate XII, 3*a*, 4*a*, 6*a*, 7*a*, and XIII, 1*a*, 2*a*, 3*a*) extending into a tortuous channel $\frac{2}{10000}$ inch in diameter and averaging $\frac{40}{10000}$ inch in length; then the remainder of the worm becomes a mass of cells of various sizes to within $\frac{30}{10000}$ inch or $\frac{50}{10000}$ inch of the extremity or tail.

These cells at times appear with a sinuous channel clear from either end (Plate XII, 4), or with breaks in their continuity (Plate XII, 2, 3), or granular masses interspersed (Plates XII, 6, 7, and XIV, 1, 2), or as fine cells irregularly arranged. (Plate XIII, 1, 2, 3.) Occasionally the whole interior appears as a solid mass of cells. (Plate XII, 6.)

I have not discovered the method of impregnation, but at an early period rapid changes in shape begin in the female. (Plates XVI, 2 to 15; XVII, 1 to 9; XIV; XV; and XII, 5, 6, 7, 8.) The enlargement is preceded by the formation in both upper and lower thirds of the body of dark masses of cells that eventually unite (Plates XIV, 3, A, B; 4, 5, A, B, C, and 6; XV, 2, 3), then by the time the worm reaches the age represented in Plate XVI, 11, 12; Plate XVI, 3, 4, become changed into a bicornate ovarium or uterus, which at full term attains the length of $\frac{2000}{10000}$ inch in many coils, and contains one hundred and fifty or one hundred and sixty full-sized cysts.

The shapes and sizes of these pregnant females vary greatly, and I believe are the result of the environment. In soft tissues of the Cowpea, Radish, and the like rapidly-growing plants they attain a transverse diameter of $\frac{320}{10000}$ inch, and a length of $\frac{560}{10000}$ inch. The tail is reduced to a short spine (Plates XIV, 3; and XV, 2, 3), which disappears later on, as the worm approaches the transverse diameter of $\frac{150}{10000}$ inch. (Plate XVII, 3, 4.)

The thickness of the exterior wall varies from $\frac{3}{10000}$ inch at the lower part of the body to $\frac{1}{10000}$ inch at the vertex, and is exceedingly tough and resistant. In color it appears yellowish by transmitted light, but a brilliant white by reflected light. When fully developed, it is partly transparent, showing the coils of the uterus with its cysts. The exterior is granular or corrugated, especially near the "head" (Plates XIV, 6, and XIX), and with an apparently radiate arrangement of cells from a center near the tail, or perhaps marking the disappearance of that appendage. (Plate XXI.)

The head varies from a form like Plates XVII, 3, 4, 7, 9, and XVI, 9, 12, 13, 14, to that shown by Plates XVI, 10, 11, 15; XVII, 2, 5, 8, and XVIII, the neck from a mere contraction of the body, Plates XVII, 6, and XVI, 15, to a long tube, as in Plates XVI, 14, and XVII, 9.

The body varies from almost a globe (Plate XVI, 9, 13) to an oval (Plate XVI, 14; XVII, 9), or nearly a cylinder. (Plate XVI, 15.)

The worms found in woody tissue are usually of the forms of Plates XVI, 10, 11, and XVII, 5, 8; in soft tissues like Plates XVI, 14, and XVII, 7, 9, but I am unable to understand the reason of this variation.

In roots, as a rule, the bodies radiate from the central axis of the root with the "heads" to the axis.

When once enlargement of the body begins, the worm becomes a fixture, and remains incapable of progression in any direction; the enlargement is gradual and the cells of the root tissues become smaller by the pressure, forming a rigid wall on every side of the worm.

How long the worm exists is an unsolved problem which I hope to solve in time.

Apart from vegetable tissues, I have noted signs of life in the Anguillula after being kept air-dry six months, but have no record of any reliable experiments with the worms in the roots; but the vitality is very great.

When motion is first perceived in the cyst, the worm is an average of $\frac{140}{10000}$ inch in length and $\frac{5}{10000}$ extreme thickness; soon after it becomes free it enlarges and lengthens till it casts its skin, which it does as shown in Plate XI, 5, leaving the old skin shrunken as at 6, same plate; a fragmentary cast is seen on Plate XII, 1, but I have not determined the number of times in its life it sheds the skin, as it is rare to find a perfect cast for measurement.

Among the thousands of Anguillulæ I have examined, there are a great many variations and arrangements of cells that are not easily explainable. Plates XV, XIII, and XII, 5, 8, 7, 6, exemplify some of the most marked. Plate XIII, 2, 3, is very singular; a cyst-like form, with segments. Also at 3, a peculiar arrangement of cells, large and small; in fact, I have never found two worms exactly similar in the grouping of cells; the resemblance is general, but with wide variation of details. The examples given in the plates justify this conclusion, sketched as they were from living specimens.

The arrangement of the cysts in the uterus is generally as shown by Plates XVIII, XIX, and XX, though that often becomes changed, as indicated in Plate XXI. (Note 13.)

In mature and apparently aged worms, I have found as many as a dozen free worms within the uterus, having attained motion and liberation there.

In plates showing the changes in vegetable tissues, "A" refers to the enlargements and nests of Anguillulæ, "B" to spots of decay.

NOTES.

NOTE 1.—Owing to a lack of literature on the subject, I have provisionally named this worm *Anguillula arenaria*, but it may belong to a different genus. If an Anguillula, it is very near the A. brevispinosus, but as the spine disappears in mature forms, I have called this A. arenaria.

NOTE 2.—This information came from one of the oldest citizens, who learned of it from the Spanish residents in 1820.

NOTE 3.—Letters received from correspondents at nearly every important town gave the data.

NOTE 4.—Messrs. Berckmans, Onderdonk, Munson, and Stelle are referred to.

NOTE 5.—I kept fully developed pregnant females in a watch glass dry for six months, and when wet, they expanded, and the grown worms within the cysts in the uterus resumed motion.

NOTE 6.—The average weight of a cubic foot of ordinary sandy surface soil is 6,602,625 grains, equal to 86.08 pounds avoirdupois; this at the temperature of 70°, the soil being air-dry.

NOTE 7.—The quantity required to saturate a cubic foot was 2.3 gallons of the kerosene emulsion.

NOTE 8.—The amount of lime used was 20 pounds to the tree, forty-nine trees to the acre.

NOTE 9.—Water poured upon the pots percolated through the soil and out at the hole in the bottom of the pot. This was allowed to evaporate considerably and examined with magnifier 350 diameters, eye-piece B, objective one-half inch.

NOTE 10.—Radishes and turnips are very susceptible to the Anguillula. (See Plate III, drawn from actual specimen, natural size.)

NOTE 11.—A common practice among the "old-time" slaves, who tell me it was the rule made by the old whites as far back as 1805. The reason they gave was "the peach loves clay and yellow sand."

NOTE 12.—I could only approximate the growth and development by the use of such plants as the Cow-pea and Radish—planting seed in infected soil, and at certain dates pulling up the plants and examining the knots, making a careful sketch, drawn to scale, each time. All attempts at cultivating in fluids failed.

NOTE 13.—By softening the exterior with a solution of caustic potash, snipping off the head and gently pressing the body in fluid, with a cover glass, the uterus exuded as shown in Plate XIX.

EXPLANATIONS TO PLATES.

PLATE I.

Roots of Cow Pea, showing enlargements caused by Anguillula: A, enlargement and nests; B, spots of decay. (Original.)

PLATE II.

Roots of Okra, showing enlargements caused by Anguillula: A, enlargements and nests; B, spots of decay. (Original.)

PLATE III.

Roots of Radish, showing enlargements caused by Anguillula: A, enlargements and nests; B, spots of decay. (Original.)

PLATE IV.

Roots of Grape [Black Hamburg], showing enlargements caused by Anguillula: A, enlargements and nests; B, spots of decay. (Original.)

PLATE V.

Roots of Peach, showing enlargements caused by Anguillula. (Original.)

PLATE VI.

Roots of Weeping Willow, showing enlargements caused by Anguillula—natural size. (Original.)

PLATE VII.

Roots of Fig, showing enlargements caused by Anguillula—natural size. (Original.)

PLATE VIII.

1, section of root of Okra, showing enlargements caused by Anguillula; 2, Peach, same; 3, Grape, same—enlarged four times: 4, Weeping Willow, same—natural size: A, enlargements and nests; B, spots of decay. (Original.)

PLATE IX.

Reproductive cysts which form in the uterus of the female Anguillula: 1, first stage, solid mass of granular cells; 2, 3, segmentation or division into two parts; 4, 26, 5, 5a, 6, segmentation into four parts; 7, longitudinal fissure appearing, which causes segmentation into eight parts; 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, walls of segments absorbing each side of the central longitudinal fissure which extends to the margin of the cyst in one direction, until upon separation at that end motion begins—greatly enlarged. (Original.)

PLATE X.

Reproductive cysts (continued): 1, 1a, first stage; 2, 3, 4, 26, bi-segmentation or division into two parts; 5, 6, 7, 8, 9, segmentation into four parts; 10, 11, 12, 13, 14, 15, 16, 17, 18, segmentation into eight parts—greatly enlarged. (Original.)

PLATE XI.

Developed or free Anguillulæ within the reproductive cysts: 1, free Anguillula within cyst not yet broken; 2, 3, 7, cyst broken; 4, 4a, empty shell of cyst from which Anguillulæ have emerged; 5, young worm casting skin; 6, empty skin cast by young worm--greatly enlarged. (Original.)

PLATE XII.

Growth of Anguillulæ: 1, cast skin of young worm; 2, 3, 4, 5, 6, 7, 8, worms showing bluntness at one end, with fissure having a circular, hinge like termination at A, and granular masses of cells within—greatly enlarged. (Original.)

PLATE XIII.

Growth of Anguillulæ (continued): 1, 2, 3, worms showing masses of fine cells irregularly arranged within, and fissure at blunt end with circular, hinge-like termination at A—greatly enlarged. (Original.)

PLATE XIV.

Growth of Anguillulæ and changes within the female: 1, 2, female worms showing granular masses within; 3, 4, 5, 6, changes in shape in the female, preceded by formation in upper and lower thirds of body of dark masses of cells, A, B, C, which eventually unite—greatly enlarged. (Original.)

PLATE XV.

Changes within female Anguillulæ (continued): 1, 2, 3, enlargements in shape of the female, with formation of masses of cells at A—greatly enlarged. (Original.)

PLATE XVI.

Changes in form of female Anguillulæ: 1–15, outlines showing changes in form, from leaving the reproductive cyst until the female is herself filled with cysts, also showing changes in the form of the head and disappearance of the tail—greatly enlarged. (Original.)

PLATE XVII.

Changes in form of female Anguillulæ (continued): 1–9, outlines of changes in form of body and head, with the disappearance of the tail—greatly enlarged. (Original.)

PLATE XVIII.

Gravid female Anguillula, showing contracted head and neck as in some females, and the arrangement of cysts in the uterus—greatly enlarged. (Original.)

PLATE XIX.

Arrangement of cysts in uterus of female Anguillula and expulsion of young worms through fissure in the head—greatly enlarged. (Original.)

PLATE XX.

Arrangement of cysts in uterus of female Anguillula (continued): A–B, cysts arranged in bands reaching across to the walls of the uterus; B–C, aggregation of cells into irregular masses within the uterus; C–D, aggregations of cells arranged in two rows in the uterus; D–E, cysts that have attained the normal size and become coated with a thin epidermis—greatly enlarged. (Original.)

PLATE XXI.

A changed arrangement of cysts within the uterus of the female Anguillula which often occurs—greatly enlarged. (Original.)

PLATE I.

COW PEA.

PLATE II.

OKRA.

PLATE III.

RADISH.

PLATE IV.

GRAPE.

Vitis Vinifera — Black Hamburg.

PLATE V.

PEACH.

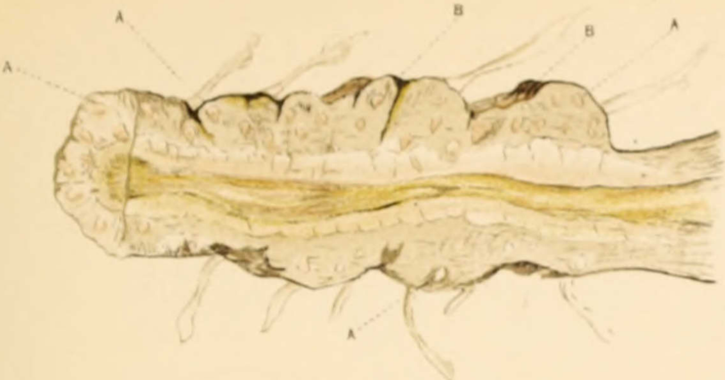
PLATE VI

WEEPING WILLOW.
Natural size.

PLATE VII.

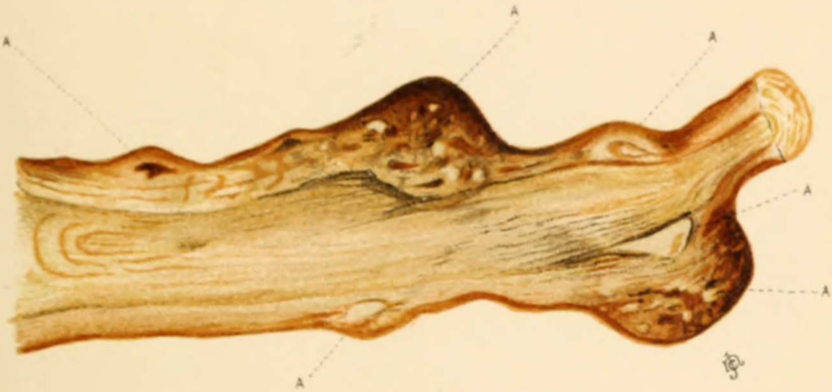
FIG.
Natural size.

PLATE VIII.



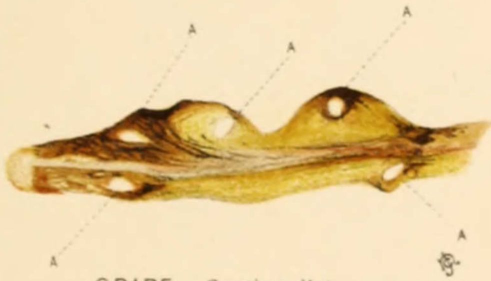
1.

OKRA. Section X 4.



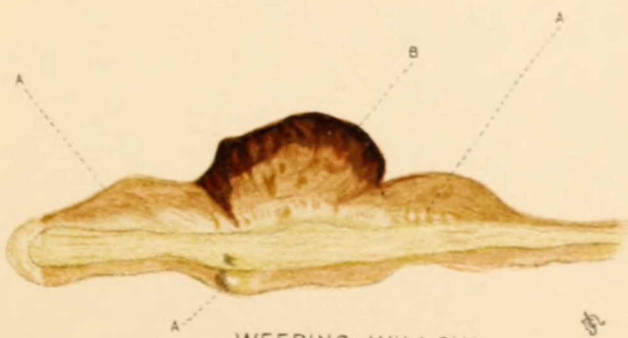
2.

PEACH. Section X 4.



3.

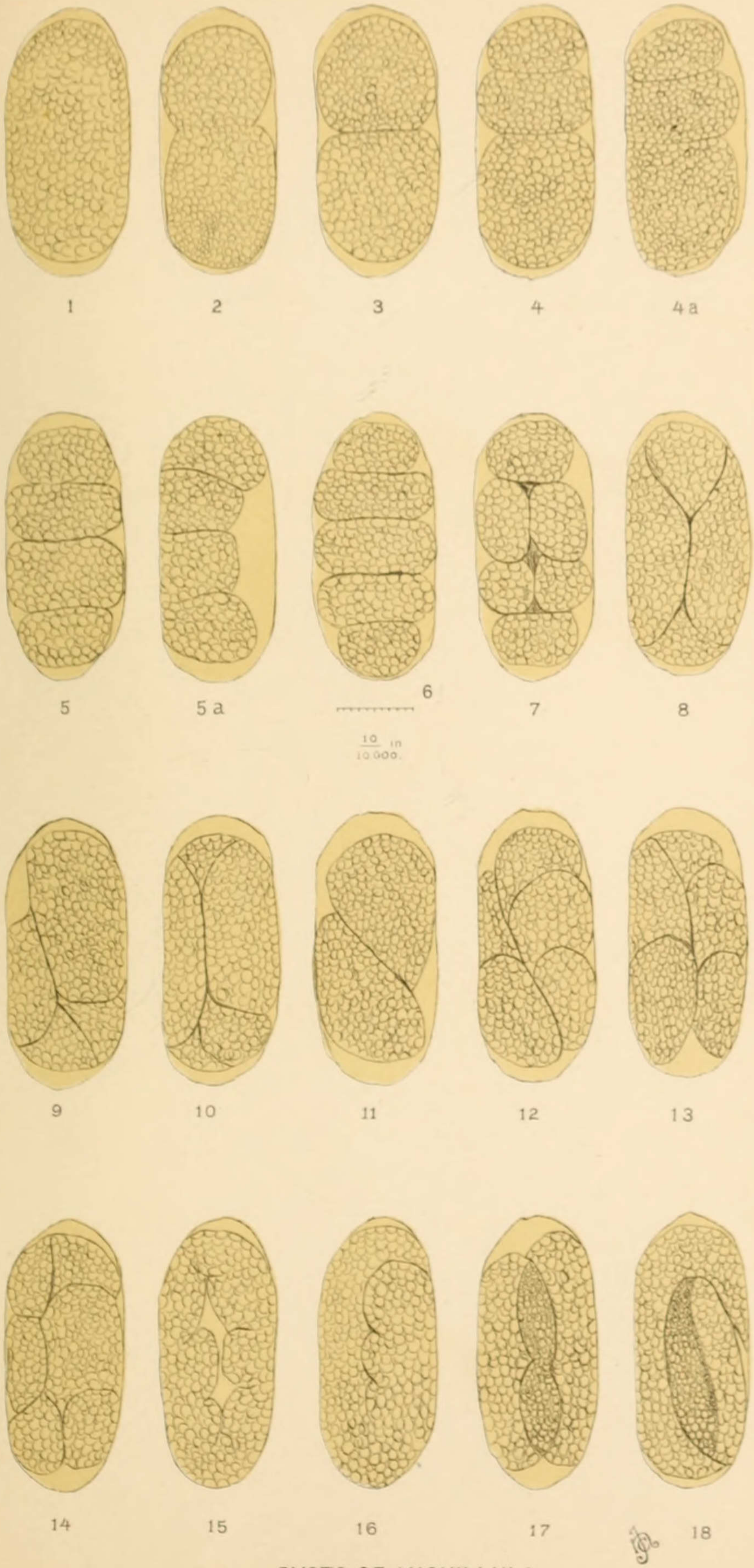
GRAPE. Section X 4.



4.

WEEPING WILLOW.
Natural size.

PLATE IX.

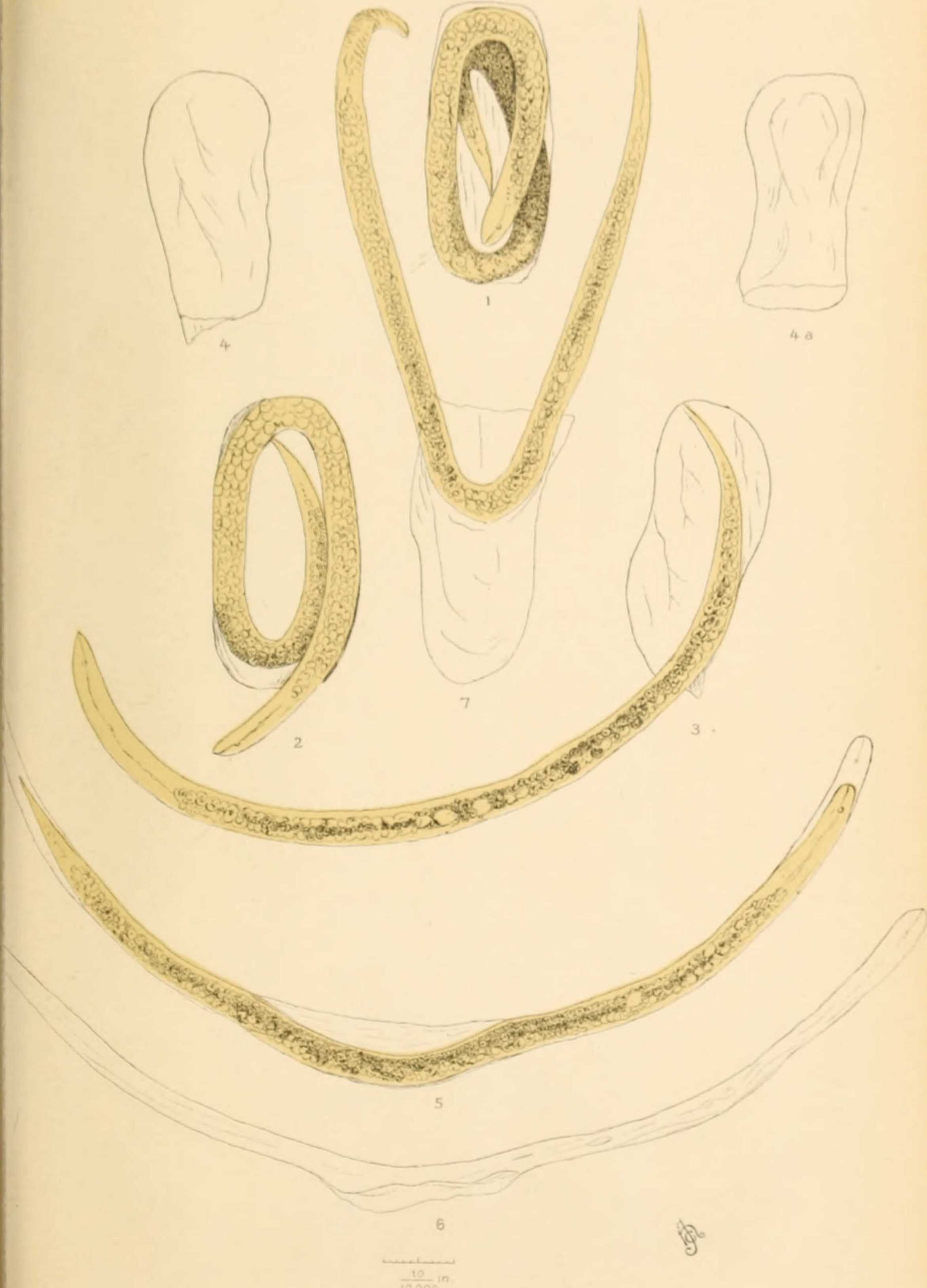


CYSTS OF ANGUILLULA.

PLATE X.

CYSTS OF ANGUILLULA.

PLATE XI.



DEVELOPMENT OF ANGUILLULA.

PLATE XII.

DEVELOPMENT OF ANGUILLULA.

PLATE XIII.

DEVELOPMENT OF ANGUILLULA.

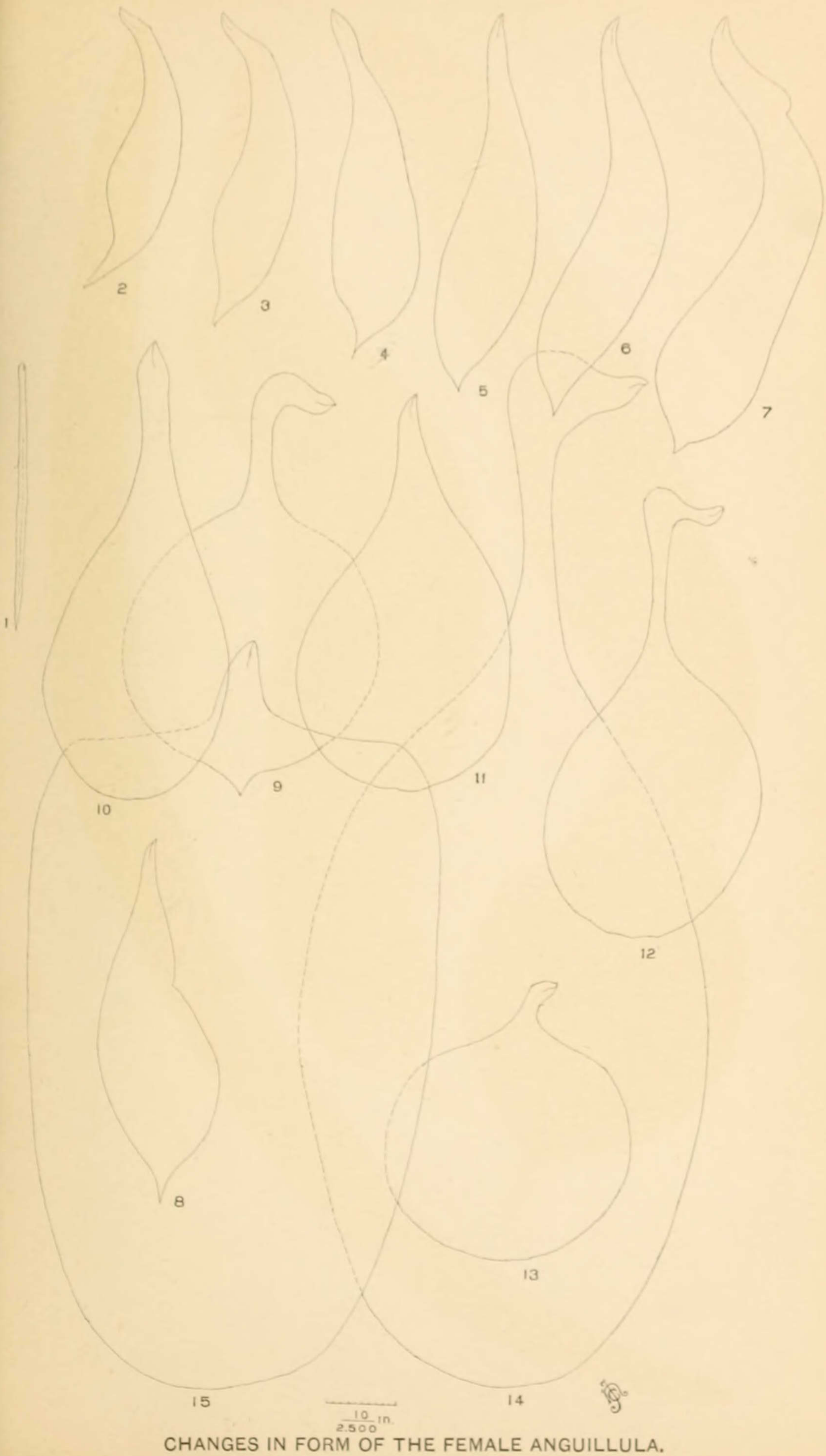
PLATE XIV.

GROWTH AND CHANGES IN THE FEMALE ANGUILLULA.

PLATE XV.

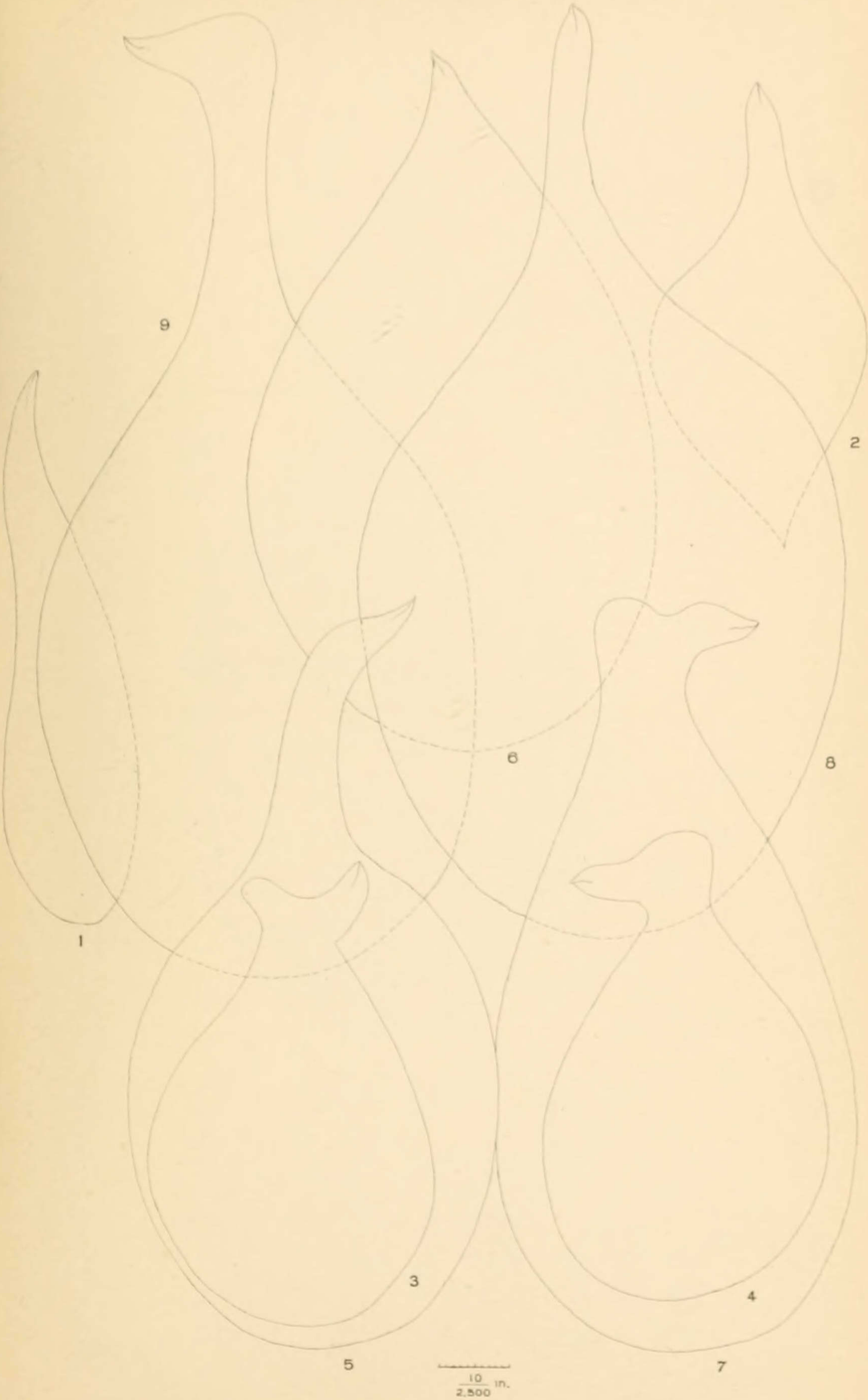
CHANGES IN THE FEMALE ANGUILLULA.

PLATE XVI.



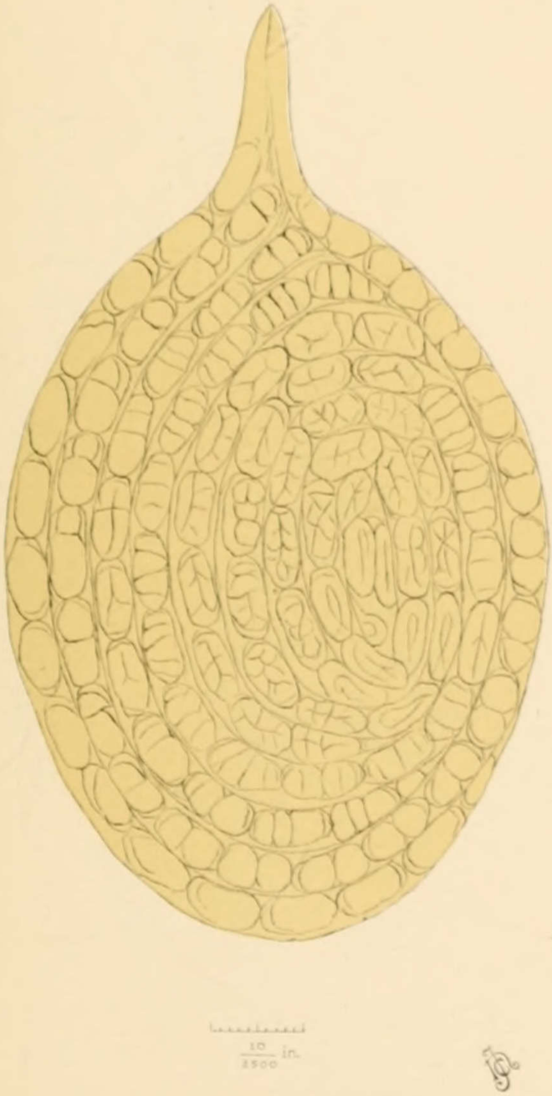
CHANGES IN FORM OF THE FEMALE ANGUILLULA.

PLATE XVII.



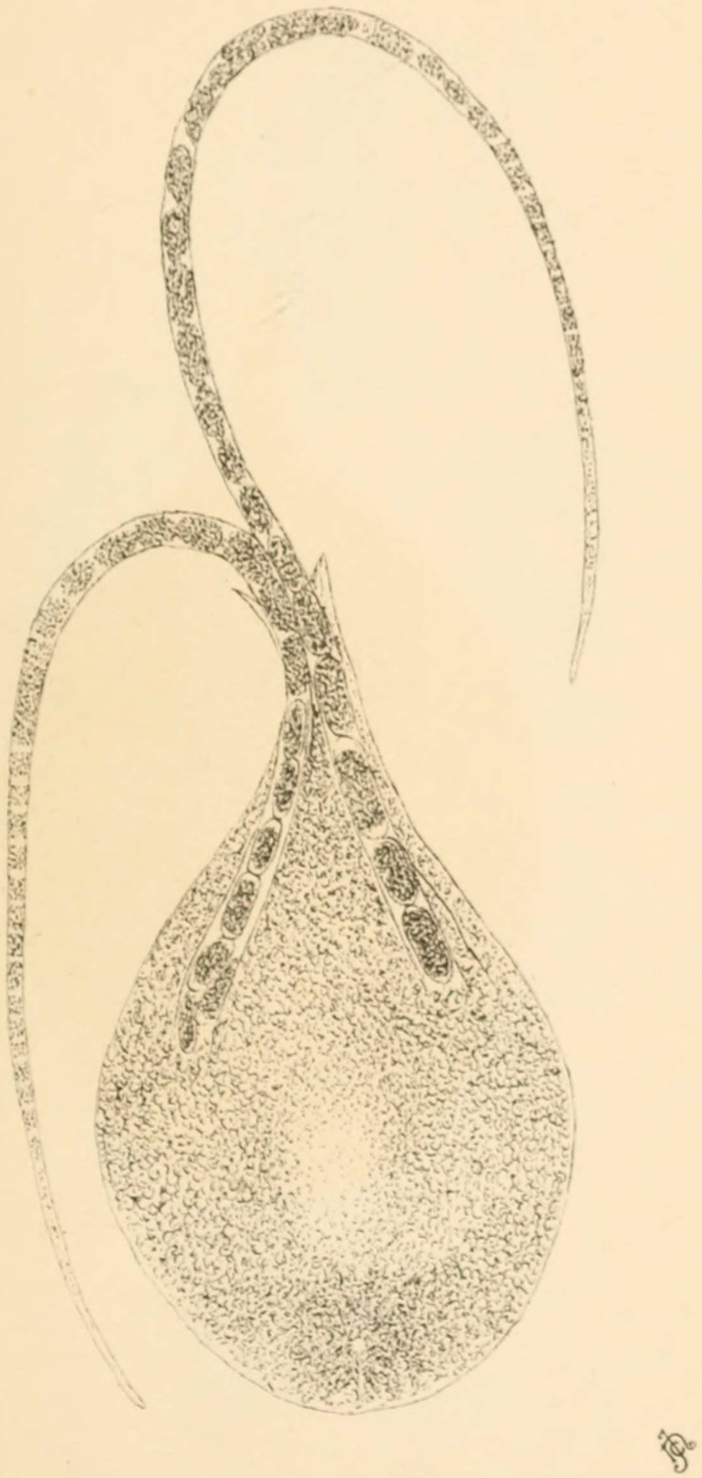
CHANGES IN FORM OF THE FEMALE ANGUILLULA.

PLATE XVIII.



GRAVID FEMALE ANGUILLULA, SHOWING CYSTS IN UTERO.

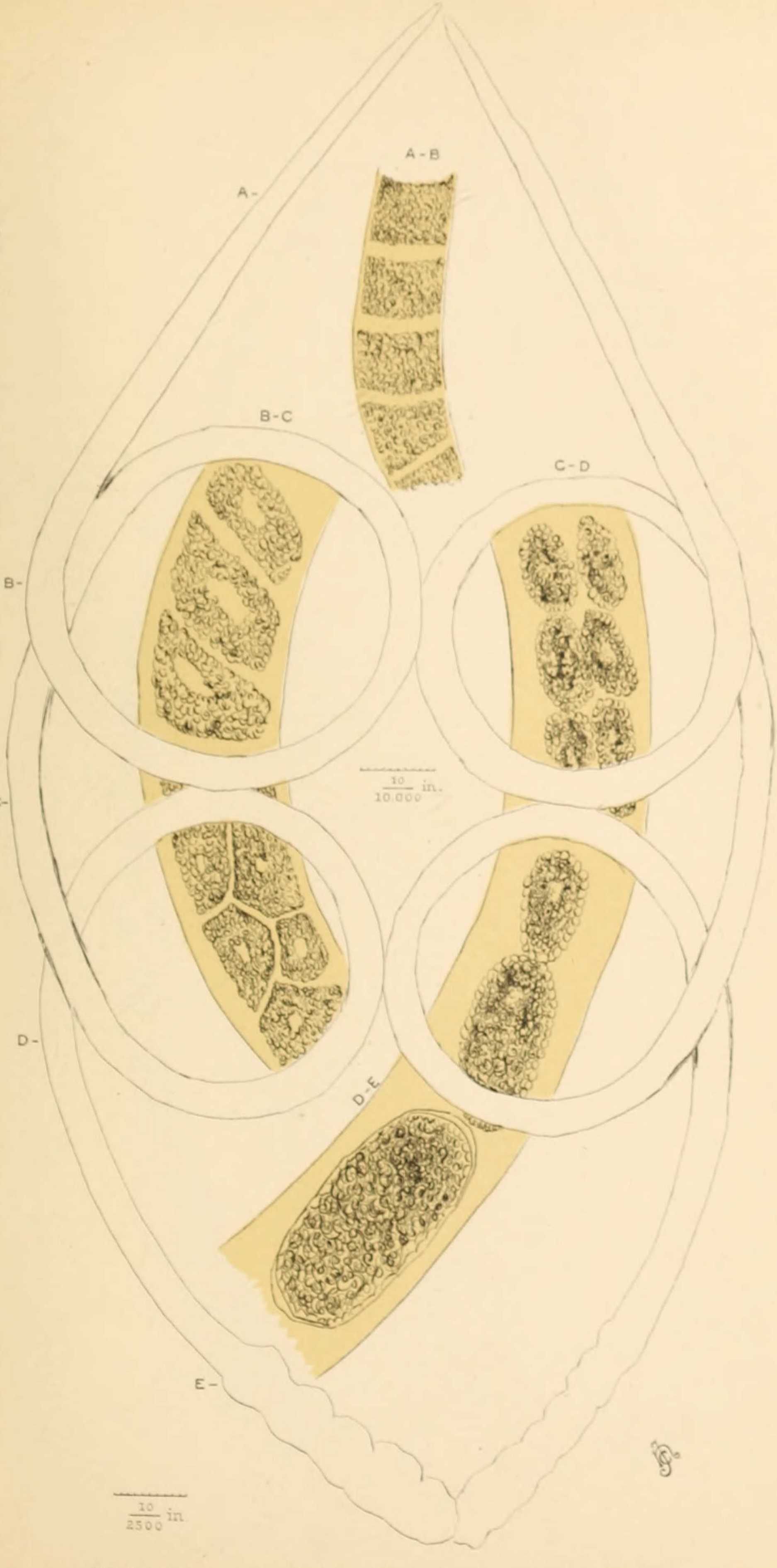
PLATE XIX.



$\frac{10}{2,500}$ in.

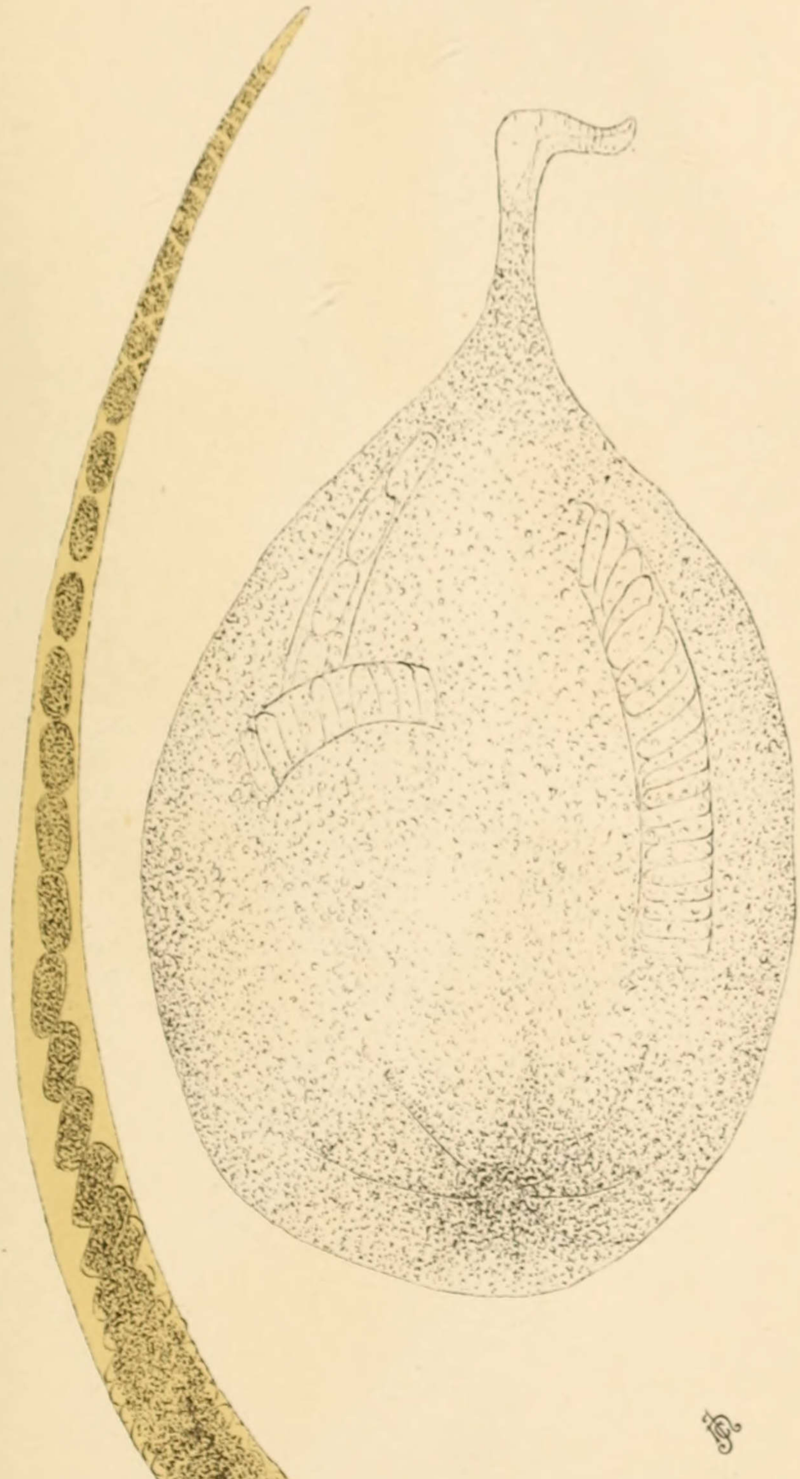
FEMALE ANGUILLULA, SHOWING EXPULSION OF YOUNG.

PLATE XX.



ARRANGEMENT OF CYSTS IN FEMALE ANGUILLULA IN UTERO.

PLATE XXI.



$\frac{10}{2.500}$ in.

ARRANGEMENT OF CYSTS IN FEMALE ANGUILLULA IN UTERO.