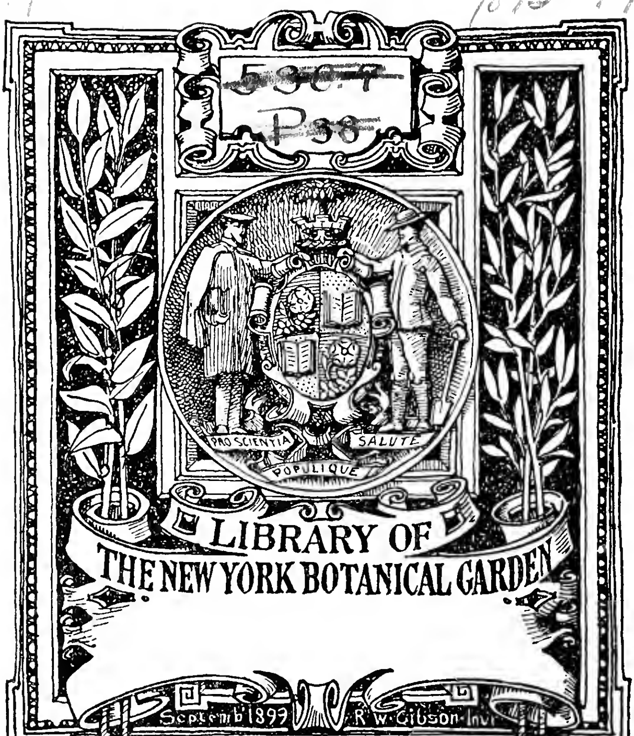
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CONTRIBUTIONS

FROM THE

BOTANICAL LABORATORY

OF THE

UNIVERSITY OF PENNSYLVANIA.

PHILADELPHIA
UNIVERSITY OF PENNSYLVANIA PRESS
1892

Contents of Vol. I, No. 1.

PUBLICATIONS OF THE
UNIVERSITY OF PENNSYLVANIA.

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A Monstrous Specimen of Rudbeckia hirta, L.

By J. T. Rothrock, B. S., M. D.

(*WITH PLATES I, II, AND III.*)

THROUGH the kindness of Mr. Francis Windle, of West Chester, Pa., a most remarkable illustration of proliferation and floral modification in the above-named plant has come to my knowledge.

There were two specimens, taken from a field which had been previously mowed. He removed them from the ground and planted them in a flower-pot near his home, where he had them under observation. We may fairly assume that if the stems had not already produced flowers that season, they were well advanced toward that period when cut down. Hence they represented a weakened second-growth. In the larger of these two heads there were nineteen well-developed secondary heads and four others less well developed, but following in the course of the larger ones.

The order of development was acropetal. Hence the most of the departure from a typical condition was evinced by the ray flowers. Of the latter there was not a single normal one in the entire floral mass, which is represented in the unnumbered illustration accompanying this brief sketch.

In general, it may be stated that while the proliferation of the tubular flowers was not so marked, still instances were not wholly wanting.

The most striking fact was, that from the central part of both ray and disk flowers there were found proliferated foliar and floral axes in the position which belonged to the styles. This is none the less singular when one remembers that the ray of Rudbeckia is neutral. From these proliferated masses, in many instances, there were secondary proliferations similar to the first, except that they were smaller and less plainly differentiated.

The tendency in the stigmas of the tubular flowers to become enlarged, green, and leaf-like was very positive. Fig. b shows this. Not only so, but in that special instance the hairs were characteristic of the species, and an upper and a lower leaf-like surface could readily be observed.

One tubular flower had five stamens, which though inserted properly on the tube of the corolla, were absolutely separate as to their anthers from each other. Its stigmas had each an evident midrib bordered by a narrow wing of parenchyma.

In some instances, where the stigmatic enlargement was not great, there were traces of a normal stigmatic surface. Unfortunately examinations of the ovaries was not always made, but in a few, ovules, probably unfertilized, were seen. It should also be stated that in one tubular flower, whose stigmas were green and decidedly enlarged, a well developed ovule was found. It could not have been fertilized.

It is, of course, hard to admit that these proliferated styles and stigmas represent axial structures; but it appears equally difficult to avoid that conclusion, if one may reason from a single, or from a few monstrous specimens.

It is not clear, however, that Linnæus had not some suspicion that such cases were of an axial nature, *in other than the aggregatæ*. It is not easy to see how he could, with his views, have excluded this Rudbeckia,[1] with its enlarged, leaf-like stigmas. There is another question raised by this specimen, *i. e.*, whether after all the Rudbeckia is not to be regarded as reducing to an absurdity that form of morphological reasoning which relies so implicitly upon a few monstrous specimens to furnish a clue to the essential nature of normal structures. In other words, is it a safe concession to allow that, in science, an exception proves the rule?

My attention has recently been called to some monstrous flowers of Digitalis, which, appearing at the summit of the stem, had resulted in the production of an unusual number of stamens.

[1] See Phil. Bot. 124.

The Digitalis and the Rudbeckia seem to support the view that such departures from the type are most likely to occur in individuals which are exhausted, or are from some cause in a condition of reduced vitality. The last energy of the plant is extended in the line of self-perpetuation. This energy, however, is often wasted in the faulty attempt to multiply the reproductive organs inordinately, rather than to perfect a few. Zoologists long since recognized the fact that multiplication of similar parts was an indication of a lower place in the scale of animal life.

The illustrations probably will explain the structural peculiarities better than any lengthened descriptions, and a brief explanation is appended.

The large unnumbered figure represents the whole head of the Rudbeckia, enlarged two diameters.

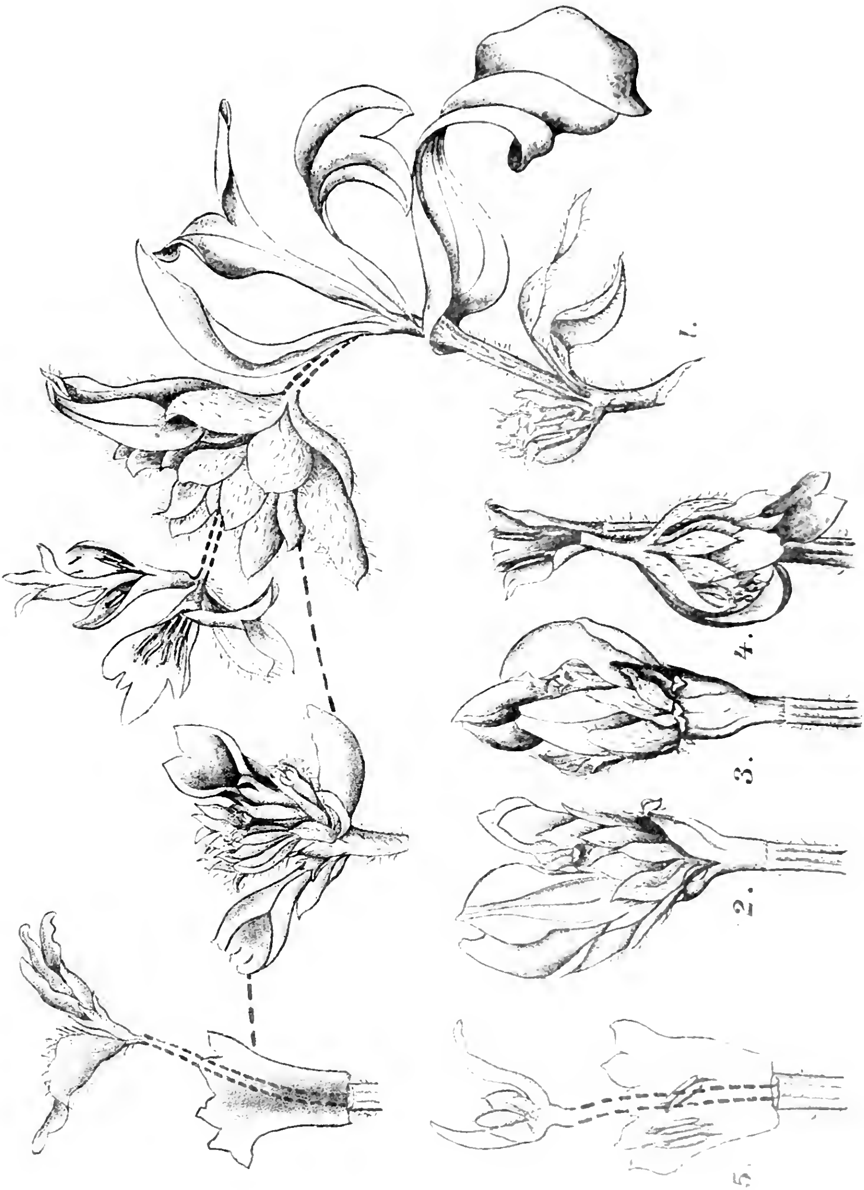
Fig. 1 shows, on the left, a cluster of tubular flowers from the side of the head. Outside this are two involucral bracts. Between the tubular flowers and the bracts rises the tube of a ray flower, out of which three attempted ray flowers spring. From the uppermost one of these is an attempted secondary head of flowers. The dotted lines on the upper side of this secondary head indicate the point from which two flowers arise. The upper of these flowers is tubular, and contains two distinct stamens and a three-cleft stigma, with two of the lobes again parted. These stigmas grow from the top of the rudimentary ovary below. The lower flower shows four distinct stamens and a much enlarged and thickened style and stigmas, the latter being distinctly green and leaf-like.

The lower dotted branch (Fig. 1) shows the point of origin of the cluster of imperfect ray and tubular flowers with which it is connected, and the extreme terminal, enlarged illustration shows more plainly the character of one of the flowers of the last clump. The artist, however, has in that, and in Fig. 5, failed to show the rudimentary ovary which appeared in each case.

Figs. 2, 3 and 4 show front and back views of a tubular flower and its contents.

Fig. 7 is another ray flower. Beside it and to the right one recognizes a *perfect* tubular flower. From this ray, in the centre, apparently, there arise two organs which probably represent stigmas ; one of these, however, is enlarged above as though it were attempting to form another ray; the other remains thread-like. To the right of these stigmas, indicated by the dotted lines, are two smaller abortive heads. Fig. 6 shows the remarkable foliar expansion of the stigmas arising from a well-marked tubular flower.

Rothrock on Rudbeckia hirta.



Rothrock on Rudbeckia hirta.

6.

7.

Rothrock on Rudbeckia hirta

Contributions to the History of Dionæa Muscipula, Ellis.

By J. M. Macfarlane, D.Sc.

(*WITH PLATE IV.*)

IT is not surprising that a voluminous literature already exists regarding *Dionæa*. The movements and digestive action of the leaf as studied specially by Darwin and T. A. G. Balfour, coupled with the electrical conditions shown to exist by Burdon Sanderson have invested the plant with more than ordinary interest. But while Darwin harmonized the relation of the plant to others that catch and digest insects, the interest excited by this seems to have prevented his reaching some of the more striking phenomena. And similarly Burdon Sanderson, concerned mainly with electrical action, has not followed out many of the suggestive lines which he touched.

Six years ago, while examining some leaves during a warm forenoon in June, I was rather surprised to notice that apparently in all cases two touches of the sensitive hairs were needed to effect closure. This observation, often verified during subsequent years, was made in forgetfulness of Sanderson and Page's statement: "If one of the sensitive hairs of a leaf" . . . . "is carelessly touched (*i. e.*, when full open) the leaf usually closes. If, however, a hair is touched very cautiously, with the aid of a camel's hair pencil, it can be predicted with certainty that no visible effect will be produced, and a similar gentle contact may be repeated several times before the leaf begins to answer to the irritation by any movement." The writer was led, however, to a closer study of the plant, and the results now given are the outcome of that study.

The subject may best be discussed under the following heads: (1) Leaf closure; (2) Leaf structure; (3) Leaf secretion; (4) Leaf opening; while the keynote to the whole is given in the words used by Burdon Sanderson in his lecture before the Royal Institution.[1] "We have to do here not merely with contractility, but with irrito-contractility."

I. Leaf Closure.

(*a*) *By Mechanical Stimuli.*

Except for the partial limitation contained in the statement by Sanderson and Page above given, all observers have hitherto asserted that the leaf closes after a single touch. Thus Darwin says,[2] "These filaments are remarkable from their extreme sensitiveness to touch, as shown not by their own movement, but by that of the lobes." Sachs[3] says, "any ungentle touch of one of these bristles effects an instantaneous closure of the two halves of the leaf." Detmer[4] says, "Werden die Filamente, die auf der oberseite des Dionæa blattes vorhanden sind, berührt, Z. B. mit einem kleinen Holzstückchen, so schliesst sich das Blatt sofort." Drude, Batalin, Munk and others, speak in similar terms. Now we can only explain this practically universal consensus of opinion to be due to observers having supposed that after the first touch of a hair with non-closure, they imagined that the leaf was torpid, or that they had missed touching one, and repeated the touch with desired result. In any case it can now be asserted that under such conditions as the plant is normally exposed to, two touches are needed to cause closure. It matters not whether these are communicated to the same hair, or to distinct hairs on the same half, or on opposite halves of the leaf.

But though no apparent movement ensues after the first touch, if a hair on the leaf of a vigorous plant be once touched during warm weather, by steady attention one can readily see that a peculiar rhythmic wave motion traverses the leaf halves in line with the length of the blade for about five seconds

[1] Nature; Vol. X, 1874, p. 127.
[2] Insectivorous Plants, p. 287.
[3] Physiology of Plants; Eng. ed. 1887, p. 376.
[4] Pflanzen physiologische Practicum; 1888, p. 64.

after contact, so that some molecular disturbance is being propagated through the leaf substance, though not for the time producing very manifest results.

Experiments were conducted to ascertain the length of time which can intervene between first and second stimulus, before the impression of the first was lost. In other words, the memory power of the protoplasm was tested. On bright days, with temperature at 65°–72° F. in a cool house, healthy specimens were selected. A leaf hair was stimulated once but the leaf did not close. A second stimulus after ten seconds caused closure with a latent period of less than two seconds. Another leaf was once stimulated, and after an interval of thirth-five seconds a second stimulus was applied when the leaf closed rather slowly. A rather small leaf was restimulated after lapse of twenty-five seconds, and a slight degree of closure occurred. A third shock was given after thirty seconds which caused closure to about one-third of its extent. A fourth shock after twenty seconds produced further closure, and after lapse of ten seconds a fifth shock completed the process, though the movement of the halves was slow and deliberate, about fifteen seconds being required.

Three leaves were operated on by stimuli at intervals of thirty seconds, and after the third stimulus no closure-effect was observable, but when the time-interval was reduced to twenty seconds two successive shocks closed two of the leaves, and another shock after ten seconds closed the third. All of the above were smaller leaves, by about half, than the average size attained in the wild state in North Carolina, and leaves were therefore chosen nearly like the latter. A large healthy leaf was acted on as follows :

1st stimulus					....................no effect.
2d	"	after	sixty	seconds,	"
3d	"	"	"	"	"
4th	"	"	"	"	"
5th	"	"	fifty	"	extremely slight closure.
6th	"	"	"	"	decided closure to extent of about half.
7th	"	"	"	"	closed loosely, and moved in doing so for eighteen seconds.

Another leaf was acted on as follows:

1st	stimulus				no effect.
2d	"	after	sixty	seconds,	"
3d	"	"	"	"	"
4th	"	"	"	"	scarcely perceptible closure.
5th	"	"	"	"	little if any closure.
6th	"	"	"	"	no effect.
7th	"	"	"	"	"
8th	"	"	fifty	"	decided though slight closure.
9th	"	"	"	"	leaf now closed fully one-third and movement prolonged through twenty-five seconds.
10th	"	"	"	"	leaf closed after movement of sixteen seconds.

A rather small leaf was then acted on as follows:

1st	stimulus				no effect.
2d	"	after	sixty	seconds,	"
3d	"	"	"	"	"
4th	"	"	"	"	"
5th	"	"	"	"	extremely slight closure.
6th	"	"	"	"	no visible closure.
7th	"	"	"	"	" " "
8th	"	"	fifty	"	very slight closure.
9th	"	"	"	"	leaf fully half closed after movement of fourteen seconds.
10th	"	"	"	"	leaf closed after movement of thirteen seconds.

A medium-sized healthy leaf was acted on thus:

1st	stimulus				no effect.
2d	"	after	forty-five	seconds	"
3d	"	"	forty	"	"
4th	"	"	thirty-five	"	extremely slight closure.
5th	"	"	thirty	"	about half closed.
6th	"	"	twenty-five	"	entirely closed.

Another of similar size as the last behaved as follows:

1st	stimulus				no effect.
2d	"	after	sixty	seconds,	"
3d	"	"	"	"	"
4th	"	"	"	"	"
5th	"	"	fifty	"	very slight closure.
6th	"	"	"	"	leaf half closed.
7th	"	"	"	"	" closed.

A leaf of the same size as the last two was acted on thus:

1st stimulus	....			no effect.
2d	"	after forty-five seconds		"
3d	"	"	forty "	scarcely visible effect.
4th	"	"	thirty "	closed to about one-third.
5th	"	"	twenty-five "	closed slowly, the movement occupying about thirteen seconds.

Experiments were made on several large strong leaves. One was sharply stimulated by pronounced bending of a hair, and after lapse of forty seconds was restimulated when it closed, after a movement of about three seconds. Another was strongly stimulated, and restimulated after forty seconds with scarcely visible effects, but after thirty-five seconds another stimulus caused rapid closure.

The above experiments were all conducted at the Edinburgh Botanic Garden, in a temperature of 65° F. to 76° F., but from August to October of the past year the writer experimented in Washington and Philadelphia, on a liberal supply of healthy plants kindly placed at his disposal by Mr. Oliver, of the Washington Botanic Garden, and on three strong green plants similarly provided by Prof. W. P. Wilson, of the Pennsylvania University, Philadelphia. Recently, also, the writer had the pleasure of studying *Dionæa* in its native haunts. The plants were experimented on mostly at a temperature of 87° F. to 92° F. in the shade. All showed a more extended memory period. Thus the following cases may be selected as typical. A leaf was stimulated without effect, but on second stimulus, after sixty seconds, it at once closed. This was frequently verified.

A leaf was acted on as follows:

1st stimulus	....			no effect.
2d	"	after eighty seconds,		"
3d	"	"	seventy-five "	"
4th	"	"	seventy "	slight effect.
5th	"	"	sixty "	leaf half-closed, by movement extending over fourteen seconds.
6th	"	"	" "	leaf closed after movement of eighteen seconds.

Repeated experiments were made on the strong green leaves of the plants mentioned above in the laboratory greenhouse of the University of Pennsylvania during October when the temperature varied from 75° to 83° F., and these always closed after time intervals of sixty to sixty-five seconds, but when extended to eighty-five seconds and then reduced, three to six stimuli could be given, thus:

1st	stimulus				no effect.
2d	"	after	eighty-five	seconds	"
3d	"	"	eighty	"	slight effect.
4th	"	"	seventy-five	"	slight added effect.
5th	"	"	seventy	"	leaf closed.

From tables, like the above, we conclude that in rather weak plants exposed to considerably lower temperatures than the normal—*i. e.*, from 60° to 75° F., as compared with 80° to 95° F., or 98° F. in North Carolina—sharp memory of the first stimulus is retained for from thirty to forty-five seconds; but that a decided fall is then experienced, and from fifty-five to sixty seconds the effect of the first stimulus is greatly lost. A summation of one or more stimuli, varying in number with the time-interval between these, is then needed to effect closure. That in strong plants the effect of the first stimulus is sharply retained for from fifty to seventy seconds, the variation being determined by temperature and vegetative strength of the plants.

But the very important results obtained by Sanderson and Page, supplemented by those now recorded, prove that exactly similar summations of stimuli can be recorded in the contraction of *Dionæa* leaf as in contraction of muscular tissue, except that the contracting protoplasmic substance in the former is of a greatly less specialized quality, and is to a corresponding degree more convenient and easy for demonstration. The above observers experimented on leaves by applying stimuli at intervals of two minutes, and the following table is given by them to show the result of successive mechanical excitation of the hairs at intervals of two minutes, continued until the leaf closed:

Number of excitations.	Angular measurement of effect.	Time in seconds which elapsed between contact and the first perceptible approach.
1 to 7	0	∞
8	0	∞
9	0	∞
10	¼	15.5
11	¼	10.8
12	½	7.3
13	1	5.8
14	1½	5.0
15	1¾	4.5
16	2½	5.2
17	3	2.5
18	2	7.6
19	3¼	3.8
20	3¾	3.7
21	4¾	3.3
22	5½	4.0
23	7	2.7
24	8½	2.5
25	8	not observed.
26	10	2.2
27	at 27th excitation the leaf closed.	

"From this experiment, which was repeated several times and always gave similar results, it was learned: (1) that the first half-dozen excitations were absolutely without mechanical effect; (2) that the first effectual excitation was followed by so slight a movement that if it had not been enlarged by the lever it would have been imperceptible, and (3) that after this each successive approach of the lobes in most cases exceeded its predecessor."

"The time measurements, as will be seen at a glance, stand in a remarkable relation to the mechanical effects, showing that the delay between excitations and effects diminishes as the extent of the effect increases, like facts having the same meaning, viz., that in the plant, as in certain cases well known to the animal physiologist, inadequate excitations when repeated exercise their influence by what has been termed summation, *i. e.*, that when any number of such stimulations, say *a*, *b*, *c*, *d*, *e*, etc., follow each other in succession, the effect of each is prepared for and aided by its predecessors; so that although, as in the present instance, *a, b, c, d* may seem to produce no effect whatever, each of them really produces a change in the excited structure, and each contributes when summed with its predecessors and successors to the bringing about of the visible effect which follows *e*. During the remainder of the process the operation of the same law shows itself in the gradual augmentation of the increments—the last contraction—that by which the leaf closes, being the result of the summation of the excitation which immediately preceded it with all the previous excitations. Our conception of the nature of the process may be otherwise expressed by saying, that under the influence of successive excitations the latent excitability of the leaf gradually increases, for whereas before it either made no response, or postponed its response indefinitely, it now answers to the same stimulus by a visible motion, of which the promptitude and the extent increase together."

It is noteworthy that when a leaf closes, which has been twice stimulated, with short time interval between the first and second shocks, the closing movement is a rapid one, being limited within two seconds. When a leaf closes which has received five or six shocks with a pretty wide time interval between each, the period of actual closure movement of each leaf-half may extend over ten to fifteen seconds, while one which has been frequently stimulated may even require forty-five to fifty seconds to effect final closure of half the movement limit. Now this is what we would expect from a contractile tissue which has been fatigued by repeated stimuli; a reduction of the high degree of contractility which it normally possesses.

It has hitherto been supposed that only the sensitive hairs and the triangular area between these are irritable on surface stimulation, but both outer and inner leaf surfaces exhibit a marked degree of sensitivity, though greatly inferior to that of the sensitive hairs. The latter are, therefore, localized centres of irritability, set apart in an otherwise sensitive or irritable leaf for receiving external impressions that would be of too delicate a nature to effect movement of the halves as they now exist. Ready proof of the general irritability of the leaf can be adduced by scraping or tapping the outer or inner surfaces; but the best demonstration can be given by use of ordinary steel forceps.

It can be predicted, that if one give a sharp but rather gentle forceps-snip to any part of a leaf-half, there will be no closure of the leaf; but, according apparently to the strength of the snip, a more or less pronounced propagation along it of the rhythmic undulations already referred to. If a second snip be given within fifty to seventy seconds rapid closure, within at most ten seconds after stimulus, will ensue. Every part of each leaf-half may be tested in this manner with uniform result.

Summation stimuli may similarly be communicated. A medium sized leaf was chosen and operated on as follows:

First snip stimulus					..........no effect.
Second snip stimulus after ninety seconds					..... "
Third	"	"	seventy	"	..... "
Fourth	"	"	sixty	"	.....very slight closure.
Fifth	"	"	"	"	.....slight closure.
Sixth	"	"	fifty	"	.....leaf half closed.
Seventh	"	"	forty-five	"	.....leaf closed.

A vigorous leaf behaved thus:

First snip stimulus					..........no effect.
Second snip stimulus, after three minutes					..... "
Third	"	"	two	"	..... "
Fourth	"	"	"	"	.....very slight closure.
Fifth	"	"	ninety seconds		.... " "
Sixth	"	"	"	"	.....slight closure.
Seventh	"	"	sixty	"	..... "
Eighth	"	"	"	"	.....leaf now half closed.
Ninth	"	"	forty-five	"	.....leaf closed.

These and other experiments performed at Edinburgh show what was more strikingly verified in Philadelphia, that the effect of forceps-snip stimuli was more powerfully retained than when irritation—even the most violent—was communicated through the hairs. The extremely slow closing movements of the leaf-halves was equally marked. Thus after the eighth stimulus in the last experiment, the visible range of the movement occupied twenty-one seconds.

One hair stimulus followed by a snip stimulus or *vice versa* acts equally as if two of either had been applied.

But though at least two stimuli must be communicated through the hairs, and at least two mild forceps stimuli through the lamina to effect closure, a single sharp firm stimulus usually acts similarly. The writer recently experimented on twenty-three leaves attached to plants growing wild, and eighteen of these closed after first shock when this was strong. Several of the five that did not close, as well as many of those that received a mild snip-stimulus, showed a peculiarity that had repeatedly been noticed during laboratory experiments. On application of a second stimulus, instead of almost immediate closure, as is ordinarily the case when the hairs are acted on, a latent period of from five to nine seconds elapsed previous to movement, which was then as rapid as usual. It should be noted that the leaf tissue was not ruptured.

The mechanical action of water was referred to by Darwin as follows: [1] "Drops of water, or a thin broken stream falling from a height on the filaments, did not cause the blades to close; though these filaments were afterwards proved to be highly sensitive; no doubt as in the case of *Drosera*, the plant is indifferent to the heaviest shower of rain." [2] "Although drops of water, and of a moderately-strong solution of sugar, falling on the filaments, does not excite them, yet the immersion of a leaf in pure water sometimes caused the lobes to close." We have repeatedly experimented with a thin but sharp jet of water, and the leaves have invariably closed after a short exposure to it. But the behavior of leaves that are suddenly immersed in water, at a temperature like the surrounding atmosphere of from 60° to 80° F., is more puzzling as Darwin found. Many observations that the writer has made point to the conclusion that if a leaf attached to a plant is suddenly immersed with the upper surface next the water, no change ensues, but if the process is repeated the leaf closes, *i. e.*, that the two mechanical stimuli, given by the

[1] Insectivorous Plants, p. 291.
[2] p. 292.

water, act like the two shocks communicated through the hairs or by forceps snip or otherwise. But while this is indicated by twenty-one out of twenty-nine leaves, it must still be emphasized—as showing the need for continued experiment—that leaves have repeatedly closed on first immersion in water at, or very near, the same temperature as the surrounding air. Still more puzzling is the effect of gradual immersion in water. Round Wilmington, N. C., the writer dug up thirteen plants in succession, each surrounded by large balls of soil. He carefully and slowly immersed these, in natural position, under water. Every leaf closed on all of the plants, with the exception of two which did so when the plants were gently removed from the water. This behavior led him to attempt to localize the centre of movement more exactly. Selecting twelve fine leaves, and holding them by the petiole, he slowly immersed these from the tip of the blade inwards, and invariably when the water reached the level of the first pair of opposite hairs rapid closure followed Some of these were repeatedly withdrawn when the water had reached to about one-third of a line or more from the hairs, but no change followed. Seventeen leaves were then gradually immersed obliquely, in a vessel, so that the water would first touch a single hair. Every leaf closed when the water wetted the hair. We thus learn that while rain drops or a slight water current falling on the upper leaf surface is without effect, a sharp water impact, or immersion so as to cover one or more hairs, starts contraction. But while water impact is purely mechanical, a totally different explanation is needed in the latter case. We know from Sanderson's electrical researches that the upper leaf surface is positive to the under, and that the hair region is specially sensitive in its electrical condition, so that when the leaf was immersed, the water might act as a conductor for the electricity between the upper and lower surfaces. That liquids act differently was proved by immersing in olive oil, for then no change occurred even after repeated dipping. The leaf, however, was still sensitive, for when irritated after two minutes it closed. Petroleum oil, however, set up rapid movement. At the present stage we

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cannot attempt to decide what meaning attaches to these phenomena, unless on the lines of Sanderson's work.

The above observations, coupled with Sanderson's statement, that electrical disturbance is first "appreciable by the electrometer at the external surface at about one-sixth of a second after mechanical excitation," and that "the excursion attains its maximum in one second, and that its return occupies about the same time," having satisfied us that propagation of a mechanical stimulus is comparatively slow, we determined to try whether two stimuli, very rapidly applied, with a time interval of about one-fourth second or less, might not be propagated through the protoplasm as a practically continuous impulse. Two rapid touches, with a time interval of about the fourth of a second, were given to a hair without causing visible result other than rhythmic movement of the halves. A third touch then effected closure. The above has been frequently verified with uniform results. Similarly two forceps-snips, applied very rapidly in succession, required to be followed by a third to effect closure. If, however, the interval between the first and second shocks be expanded to a third of a second or more, the two shocks are separately propagated, so that the leaf closes. The above phenomena in contraction of *Dionæa* tissues agree with those of animal muscle where a definite strength of stimulus must act for a certain time. There has not been opportunity as yet for using an apparatus which would give three, four, or more stimuli within the fourth of a second, but there is strong probability that such could be applied previous to another stimulus that would cause closure. It is evident, however, that three distinct stimuli can be given previous to leaf movement. It has not as yet been determined whether the double stimulus, propagated as a single wave, can thereby shorten the duration of a summation series when wide time intervals are allowed to intervene.

We can now refer to what may have misled observers hitherto, and given rise to the statement that one touch is sufficient to cause closure. If a hair is touched in a rather slow and deliberate manner, the leaf closes; but it must be remembered that even in the hand of a steady operator such a stimulus really resolves itself into a series of two or more delicate stimuli applied in succession.

The leaf of *Dionæa* then is truly sensitive throughout its halves to mechanical stimulation, but the capability of receiving sensation impulses is highly concentrated in the hairs. These are so modified for insect catching that the first touch is without visible effect, but prepares the leaf by summation action for a second stimulus which, when applied, causes rapid closure. The advantage of this preparatory warning to the plant is evident, for any adventitious particles blown against it will not cause useless movement. Further, like animal muscle, the contractile tissue of *Dionæa* must have a mechanical stimulus of a certain strength prolonged through a certain time to effect contraction; while a prolonged summation series can be applied, the extent of the series varying according to the time interval between each stimulus. These experiments further prove that a minimal contraction stimulus cannot be propagated through the leaf by one touch of a hair, no matter how sharp and powerful the touch is. In other words, the hair mechanism is such in relation to the contractile protoplasm that the latter is not sufficiently altered by one blow, and the minimal amount of alternation necessary for closure can only be obtained after the second stimulus.

We would here emphasize, however, the considerable difficulty one experiences in attempting to place a piece of meat or other solid on either half of a blade without due caution. Very often two or more touches are unconsciously given to the hairs.

As has been often pointed out, when a leaf is closed by mechanical irritation of the hairs, the halves interlock loosely at first by partial crossing of the marginal bristles, and then slowly firm up till the bristle-bases press against each other. But when an insect or some nitrogenous matter is enclosed, there is a gradual tightening, and the leaf margins recurve, owing to tense pressure of the halves, against a glabrous non-glandular or slightly glandular area that runs round each margin about one-sixteenth of an inch from its edge. By repeated mechanical irritation of the hairs after the leaf had closed, the same reflexing movement of the margins has occurred. Instructive results were got from a lot of plants that the writer expressed from Wilmington. Most of them during transit suffered severe concussions though the leaf substance was not ruptured. They were at once planted out, but seven-eighths of the leaves had shut tightly, and their margins were reflexed, though nothing was enclosed. A very copious viscid acid secretion, moreover, had been poured out. Other plants, whose roots had been washed clean of earth, had been placed loosely in a large preserve bottle, and at least half of the leaves were in the same condition as the last, due also to knocking against each other in transit. The above, coupled with similar behavior under chemical and electrical stimulus, points to the belief that complete tightening of the leaf is of a tetanic nature, and can only be accomplished by repeated stimulus, either of a mechanical, chemical, electrical or other kind.

Leaves that were isolated from plants in an atmosphere at 76° F. were found to retain their normal irritability from twenty to thirty minutes. Thereafter they became flaccid, and about one hour after removal did not respond to stimulus. Whole plants, from whose roots the soil had been washed away, showed irritability in their leaves for one and a half to two hours, according to the size, vigor, and root development of each. Entire plants, that had been washed clean of soil and kept in a moist, tightly-sealed glass vessel, were highly irritable on removal after six days.

Leaf Closure.

(*b*) *By Heat Stimuli.*

My experiments on the effect of dry heat have not been so extensive as to permit expression of a definite opinion, but the action of water, at different temperatures, has been tried on twenty-seven leaves.

Darwin says: "A leaf was cut off and suddenly plunged perpendicularly into boiling water. I expected that the lobes would have closed, but instead of doing so they diverged a little. I then took another fine leaf with the lobes standing at an angle of nearly 80° to each other; and on immersing it as before, the angle suddenly increased to 90°. A third leaf was torpid from having recently re-expanded after having caught a fly, so that repeated touches of the filaments caused not the least movements; nevertheless, when similarly immersed, the leaves separated a little. As these leaves were inserted perpendicularly into the boiling water, both surfaces and the filaments must have been equally affected, and I can understand the divergence of the lobes only by supposing that the cells on the lower side, owing to their state of tension, acted mechanically, and this suddenly drew the lobes a little apart, as soon as the cells on the upper surface were killed and lost their contractile power." One may best lead up to the above by considering the effect of gradually increasing temperature. All of the experiments described below were made on leaves attached to living plants.

Water was heated to 50° C., and a dropping pipette was similarly heated by immersion in the water. Three drops were then let fall on an open leaf, but produced no effect after ten seconds. A second and then a third application was made, when the leaf closed. Four other leaves behaved thus, but a sixth required four applications. Naturally, the water on exposure to the atmosphere and colder leaf surface, would lose some of its heating power, so that we may regard the actual temperature for stimulation as having ranged from 45° to 48° C.

Water at 58° C. produced no movement after ten seconds, but on a second application four leaves closed after an interval of five to eight seconds. At 65° C. six leaves were tried, and two of these closed, one after seven seconds, the other after nine, while the remaining four closed at once on a second application. At 75° C. five leaves were once treated, and all closed after intervals of six to nine seconds.

Boiling water was then used on the remaining ones, but as regards its action on the leaf substance, it should first be stated that Darwin's observations, as quoted above, had been verified by the writer some months before, and that comparison of the minute structure of the leaves then used with fresh leaves, and others preserved in various media had convinced him that immersion for even a second or two in boiling water causes coagulation of the protoplasmic substance and disorganization of the starch that is so abundantly present in many of the leaf cells. With one exception all of the leaves closed within from two to five seconds after application of the first few drops. The exception proved to be an interesting one, and such as one might scarcely have hoped to obtain. The leaf was rather small—about half the usual size—and like the others, began to close shortly after a few drops of the boiling water had been let fall on the upper surface, but just as it had half closed, movement stopped for an instant, and it then slightly relaxed to retain the heat-stiffened position for the remaining half hour, during which the plants were under observation.

As regards after-effects the last mentioned leaf was the only one which showed speedy and pronounced death changes, for next day it had a yellow flaccid aspect and in three days was dry, brown, and shrivelled. The other leaves of the same series retained their green appearance for nearly a week, except for an area about one-eighth to one-quarter inch across, marking where the water had been first applied and which soon became yellow and then brown. All of these leaves gradually became yellow, and in a fortnight were dead. Four of those acted on at from 50° to 75° C re-expanded, but as the individual leaves had not been marked in relation to water temperature we are unable to say which persisted.

The above facts prove that a gradual increase in temperature produces quickened stimulation up to a point where the contractile protoplasm and food materials are so affected that disorganization and death ensue. But the subsequent fate of most of the leaves points to a permanent injury, either local or general, to the living cell contents.

Six leaves were selected on two plants standing in a room with a temperature at 72° F. Small pieces of ice were carefully placed on each; one closed in sixteen seconds, another in twenty-five, a third in forty-two, and a fourth in ninety seconds, by which time the ice had melted. The remaining two did not close. These results were so diverse that little value could be attached to them, and the experiments were made in January, when the plants were at their worst. But, recently, in the natural haunts of the plant, the author was able to prove that "cold" stimulus is powerful in its action. On an afternoon, with the temperature at 79° in the shade, small pieces of ice were placed on twenty-three leaves. Care was taken to place these on the base or apex of the lamina, so that even the chance of wetting the hair bases might be avoided. Nineteen of the leaves closed sharply in from five to eleven seconds; three closed after sixteen to twenty-one seconds, and one closed after thirty-six seconds, by which time the ice had just melted. Small drops of ice-cold water were placed in similar positions, and these acted like the ice.

Leaf Closure.

(*c*) *By Light Stimuli.*

Darwin states[1] that concentrated light-rays are unsatisfactory in action, and the writer's experiences corroborate this so far as investigation has gone. A large leaf had the sun's rays concentrated on it in a glass house with a temperature at 96° F. After three and a quarter minutes the leaf very slowly closed to about one-third of its extent, and about half a minute later it suddenly closed completely. The leaf had expanded when visited two days after, but where exposed to the light a circular area of a yellowish color and thin in texture showed that the leaf substance in that region had been destroyed. Another leaf similarly treated, but with the light more widely diffused over the lamina, closed to about one-third of its extent, and it after expansion showed no burning effect. Three others were tried but gave negative results. Many careful studies must therefore be made before definite conclusions can be reached as to light stimulus.

[1] p. 294.

Leaf Closure.

(d) By Chemical Stimuli.

The consideration of this opens a very wide field, the border of which only we are persuaded has as yet been touched. All who have looked into the subject from Curtis and Canby onwards have noted the great differences in action which different substances possess. But Darwin and Dr. T. A. G. Balfour are the two writers to whom we are indebted for the most extended observations. I have repeated nearly all of their experiments, and have added others which suggested themselves as likely to extend the line of work. Gardiner's suggestive results have also been of use.

Balfour found that chloroform, chloride of ammonium, carbonate, sulphate, and borate of soda, sulphate of copper, meat, and various nitrogenous food stuffs, also pepper, all caused closure, though he does not state the strength of any of the solutions used. Darwin found that a moderately strong solution of sugar, chloroform, ether and nitrogenous compounds caused closure. Chloride of strontium and sulphate of iron, however, were without effect, but killed the leaf, according to Balfour; while according to Darwin hydrocyanic acid paralyzed two leaves for a time though they continued to remain open.

Though somewhat arbitrary in method substances will be treated of in the order that they appear to stimulate the leaf. At 9.30 A.M. on a clear day, three minute shreds of roasted meat were wetted and very carefully laid on as many leaves in the axil of a hair with the leaf surface. None of the leaves closed. One of them was then twice touched, when it closed and remained so for eleven days and poured out an abundant secretion. One was slightly closed at 4 P.M., the third remained unaffected. Next day at 9.15 the second leaf had closed, the latter was still open. The former remained shut for eight days, the latter never closed, and its meat particle was finally washed off in watering. Three leaves were chosen at 9 15 on another day, and on one a minute shred of meat was placed on the outer end. It showed no change at 5 P.M., but at 9.10 next day the end part of the half on which it was had slightly inflected, exactly as in a like case recorded by Darwin (p. 297). Secretion had gone on in the region next to it, and gradual digestion and absorption proceeded for five days till scarcely a trace of it remained. On the other two leaves pieces about three times as large were placed, and both had closed by 4.30 P.M., and remained thus till digestion was accomplished. But wetted pieces of meat have repeatedly been placed on leaves, and have failed to set up closure, while on three occasions, leaves with meat, that were artificially closed, did not tighten up, but continued to show the digesting meat between the bristles.

Meat, therefore, we view as a decidedly weak stimulant, and it appears likely that were a careful and exhaustive set of experiments conducted with shreds of varying size a tolerably close approximation as to the amount of a given kind of meat necessary to effect complete closure could be arrived at.

Mainly with the object in view of trying to get an unaltered leaf for microscopic study, one attached to a living plant was dipped into a one per cent. solution of chromic acid and remained unaltered for ten minutes. It was then carefully cut off and dropped into the liquid, where it showed no sign of closing for two hours; when looked at, however, after two and a half hours it had closed. This behavior seemed so remarkable that the experiment was repeated on several occasions, and with the same result; but the time between immersion and closure varied from one to two and a half hours. But the writer had forgotten at the time the behavior of some tadpoles which he placed a few years ago in the same strength of solution under the supposition that they would speedily die. On returning to the jar about one and a half hours after he was horrified to find the animals still alive and wriggling about. Several gentlemen have had like experiences.

A leaf was immersed in a one per cent. solution of chromic acid, and after five minutes cut off and allowed to lie in the solution for thirty minutes. It was then passed into a twenty-five per cent. alcohol solution and at stages lasting over an hour into increasing strengths till forty-five per cent. was reached, when it closed.

Glycerine like strong sugar solution causes contraction and like it in a rather slow manner. Strong solutions of ammonium carbonate and citrate stimulate to closure in from twenty to forty seconds, while dilute sulphuric, hydrochloric, and nitric acids act in from two to ten seconds. Three minute crystals of solid chromic acid were laid on a leaf and left for a minute without producing movement. They were then wetted by a minute drop of water, when closure occurred after eighteen seconds. A crystal about half as large as a pin's head was then arranged and wetted, when the leaf closed in five seconds. Minute fragments of potash and soda stick were arranged and dissolved, when the leaves operated on closed in from six to thirteen seconds.

Absolute alcohol, ether and chloroform are all rapid stimulants if dropped on in the liquid state, but the vapor acts according to its amount, contracting the leaf slowly but completely if abundant; contracting it only partially if less so, and rendering it insensible and powerless if the quantity be still less. But of the substances tried corrosive sublimate and one per cent. osmic acid—notably the latter—are the most powerful stimulants, and a leaf responds to their presence in one to three seconds.

Different substances, therefore, stimulate to very different degrees, and even the same stimulant can cause closure in a time ratio that is proportionate to the strength or concentration of it. These and other substances not mentioned above are exactly comparable in their action to that on muscular tissue. Now, in the case of many of the above agents there was ample time for osmotic action to be set up. But while some set up endosmotic flow, others, such as sugar solution and glycerine, would cause vigorous exosmotic flow. Though we may not be able as yet to explain fully their action on the contractile protoplasm, it seems to us that the phenomena here are identical with those of muscular tissue, and that we have to deal in the leaf substance with an organized material identical in its fundamental behavior with muscle, though greatly less sensitive in its response to stimuli.

Leaf Closure.

(c) *By Electrical Stimuli.*

After the elaborate researches of Burdon Sanderson, it is not necessary that we should do more than refer to the fact that closure follows application of this form of energy. We have not yet determined accurately whether two sharp and distinct stimuli are needed or whether one suffices, but there are grounds for believing the former to be true. In all cases the electrical terminals were delicately applied to the lower external parts of the leaf halves, after moistening of the surfaces, and closure has invariably been effected. It seems difficult to determine, from Sanderson's account, whether he, in all cases, inserted the terminals into the leaf substance, or only in connection with certain experiments, but closure by electrical stimulus from the external surface is another proof of the general sensitiveness of the leaf.

II. Leaf Structure.

Oudemans, T. A. G. Balfour, Darwin, De Candolle, Fraustadt, Kurtz, Batalin, Sanderson, Gardiner and Goebel have all described the histology of the leaf, but it is curious, indeed, that the descriptions and figures of the great centres of irritation—the hairs—are of the most general and imperfect nature. Oudemans, De Candolle, Fraustadt and Kurtz have given more attention to the general histology and development of the leaf. The two last are at variance as to the stomata on the marginal bristles, the former stating that they are present, the latter that they are absent. They *are* present in small numbers along the lower or external faces, but absent on the internal or upper, as might be expected. The brown stellate hairs referred to and figured by Oudemans, and noted by his successors, occur on the upper and lower surfaces of the expanded petiole, but only on the under surface of the blade. We would point out here that their structure and development essentially agree with those of the secreting glands on the upper leaf lamina. They further exhibit considerable variability in the mature state, and many of the deviation types approach the typical glands in showing fusion of the radiating hair processes throughout the greater part of their length. (Plate IV, Figs. 5*a*–5*d*.) Darwin experimented to ascertain whether these would show aggregation of the protoplasm, but got negative results. He institutes no comparison between them and the glands, however.

The *glands* consist, in all cases, of two elongated basal cells, with their long axes placed parallel to the course of the veins (Plate IV, Fig. 7), and these are surmounted by two tiers, the lowermost of two cells, the upper of a considerable number. The last is covered by the surface cell layer of the gland, the appearance of which has often been figured. The illustration of a gland given in side view on Plate IV, Fig. 6, conveys a slight idea of the beautiful intercellular protoplasmic connections that pass through the pores in the thickened transverse partitions of the lower cell tiers. Similar connections with the surface cell layer have not as yet been traced. Gardiner has fully described the position and relation of the nucleus in the surface cells before and after secretion has commenced. Considerable discussion has taken place on the subject of cell vacuoles and their mode of origin. Gardiner states[1] that "in each cell the protoplasm closely surrounds the cell-wall, leaving one large central vacuole filled with the usually pink cell sap." This is true of most leaves, but it is not difficult to find healthy expanded leaves whose surface gland cells enclose two to five vacuoles of varying size. Such leaves, however, are mostly of small size and of a green color, but are irritable and secrete as usual.

The *irritable hairs* are disposed in threes on each half of the blade, but Errera[2] has seen four or five, and a leaf that came under the writer's observation during 1891 had seven on one half and six on the other, and these were arranged in an irregular manner over each half. During a day's hunt even for *Dionæa*, one often encounters leaves with eight to thirteen hairs. Such facts give countenance to the view that the sensitive hairs were once more numer-

[1] Proc. Roy. Soc., Vol. 36, p. 180.
[2] Bull. Soc. Roy. de Bot. de Belgique, xviii, pt. 2, p. 53.

ous and diffuse in distribution, a condition still retained by *Drosera*.

Each hair is an emergency, and consists of three well-marked regions, the *base*, the *joint* and the *shaft*.[1] The *hair base* consists externally of four to five tiers of epidermal cells that gradually rise up from the leaf blade. Each tier is a cylinder of eighteen to twenty-two cells with thickened walls that are traversed by intercellular threads of protoplasm. These enclose loose and slightly elongated cells with rather thick, clear walls, the cells being continuous with those of the mesophyll. (Plate IV, Fig. 3.) The protoplasmic masses of all of these are connected by threads with each other, and with those of the mesophyll cells. The *joint* or special irritable centre is remarkable. It is a cylinder of elongated quadrangular epidermal cells, each three and a half to four times longer than broad. These enclose a central cylinder of mesophyll cells that are similarly elongated. In all hairs yet examined—and this applies to twenty-three—the cuticle that is strongly developed over the general epidermis gradually thins out over the basal cells, and is either quite absent over the irritable joint cells or so very delicate as to escape detection when acted upon by cuticular tests. The middle part of each epidermal joint cell is, in all hairs yet examined, creased or puckered upon itself, so that it at first gives the impression of transverse dividing walls on surface view. (Plate IV, Fig. 1.) These creasings have evidently misled observers into giving imperfect views of the hairs. The question naturally arises whether these exist in the unstimulated hair or are due to collapse of the cells, which, up to period of stimulation, are turgid. One would regard the latter as the more likely view, but so far as we have been able to bring the microscope to bear on open leaves, the joint cells appear always to be puckered. But a structural feature of some interest is the presence over the free face of each cell of minute pits which seem exactly to agree with those noticed by Gardiner[2] on the terminal hair

[1] We are unable to agree with Goebel (Bot. Schild. ii, 1891), in dividing the hair into two parts, since the relation, structure and behavior of the three areas that we have indicated prove them to be distinct alike in structure and function.

[2] Proc. Roy. Soc., Vol. XXXIX, p. 229.

cells of Drosera. His account leads one to believe that he regarded them as closed pits. Sections of *Dionæa* hair (Plate IV, Fig. 2) show that the free face of each cell is slightly thickened, but that where the pit occurs the internal thickening is absent. We cannot as yet say whether each has a pore aperture or is a closed membrane, but the knowledge we now have of intercellular connections suggests the former as a likely condition.

One naturally desires to know the use of the minute pits. In proposing an hypothesis we would refer to some of the views that have been advanced to account for leaf closure and subsequent re-expansion. Darwin suggested "that the several layers of cells that form the lower leaf surface are always in a state of tension, and that it is owing to this mechanical state, aided probably by fresh fluid being attracted into the cells that the lobes begin to separate or expand as soon as the contraction of the upper surface diminishes." Similarly, Batalin[1] regards both opening and closing of the leaf as due to a migration of liquids from one zone to another, and considers that the cells of the lower surface are always extremely turgid, but that in the expanded state those of the upper surface are even more tensely distended than the former, and he agrees with Darwin that measurements made before and after closure prove that contraction of the upper side takes place after stimulation, and he further regards the shutting as a result of disturbance of the tension equilibrium through irritation. In the setting up of this disturbance, he suggests two distinct causes: either (*a*) an active contraction of the plasmatic substance on the inner, and passive expansion of that on the outer surface, *i.e.*, molecular translocation, or (*b*), disturbance of equilibrium in the tension of the tissues resulting from expression of water through the walls. He entirely favors the latter or mechanical view, without seeming to think that a combination of the two hypotheses might explain matters.

Recognizing the difficulty of explaining such results as those of Sanderson unless the action of the living protoplasm

[1] "Flora," 1877, Nos. 3-10.

be taken account of, Sachs concluded[1] "that the condition of turgescence of the cells depends upon the protoplasmic utricle opposing the expulsion of the endosmotically absorbed water, even under high pressure," and he follows Sanderson[2] in expressing the opinion that "the extensibility of the cellulose walls plays an important part" in effecting contraction after the permeable protoplasmic utricle has permitted an escape of liquid. Gardiner's experiments further prove that plasmolysis is the important factor, and the following statement of his sums up the position: "From certain observations on *Dionæa* and *Mimosa* the author is led to believe that there also movement is made possible by the establishment of sudden and different conditions of turgidity of different cells, such differences being occasioned by the induced porosity of the protoplasm of certain of these cells. These phenomena occur perhaps in all cases of movement."

But the water that escapes after stimulation from the cells on or near the upper leaf surface must be transferred to some other region, and the amount necessary to be transferred need not be great. The presence, in large leaves especially, of loose intercellular passages between every pair of bundles suggests that liquid may escape into these. But we would suggest for further consideration the possibility that the pores on the surface of the irritable joint cells are open, and that through these the protoplasm can rapidly eject, or allow the passage of, minute quantities of liquid sufficient to disturb seriously the equilibrium; since we have indicated that the protoplasmic masses of the joint cells are connected by intercellular threads with those of the base, as are the latter again with the epidermal and gland cells. It might be imagined that minute drops escaping could readily be seen, but several difficulties stand in the way. In attempting to bring the objective of the microscope into focus on the joint cells the leaf as a rule closes; failing this the shining cell surfaces reflect light so much that excreted liquid would readily be overlooked. The experiments performed by Darwin

[1] Physiology of Plants. Eng. ed., 1887, p. 653.
[2] Roy. Instit. Lectures, "Nature," Vol. XXVI, p. 356 *et seq.*

of removing the hairs do not aid us here, as he does not state whether the leaf that had opened after removal of all the hairs was still irritable in the areas from which they had been removed. But even were such true—and Balfour's experiments favor it—it is still possible that minute drops of liquid might escape through pore apertures in the cut cell walls, just as we suppose that these escape from the pores on the unthickened areas.

The lower part of the shaft consists of three tiers of shallow, closely-packed, cells, succeeded by another tier, the cells of which are more elongated and have their upper septa more or less obliquely placed, and wedged in with the lower ends of the shaft cells above. The terminal shaft cells are elongated, thick-walled, and taper into each other. Their walls are traversed by numerous pore canals, and their cavities are filled with finely granular protoplasm, but we have not succeeded in tracing intercellular connecting threads. The internal or central cells of the shaft greatly resemble those of the epidermis in size, shape, and structure.

The *epidermal cells* of the upper leaf surface are elongated and nearly quadrangular in outline, and are covered by a thick cuticle that is in proportion to the cuticle of the lower leaf surface as 3 : 2.

Of all the plants examined by the author for intercellular protoplasmic connections *Dionæa* yields the finest results in its epidermal cells. Such are best attained, however, by a modification of the ordinary mode of treatment that was gradually arrived at during the course of the present inquiry, and is described in the footnote.[1] One readily notices then (Plate IV, Fig. 8) along each side wall eighteen to thirty protoplasmic bridges which are slightly constricted on either side of the cellulose wall, and form a central swelling at

[1] The following has been found invariably to give better results than the methods recommended by Gardiner, Keinitz-Gerloff, and others. After iodine treatment the fresh sections are placed in twenty-five per cent. sulphuric acid, and left for one to two hours. They are then removed, thrown into water, thoroughly washed in changes of it, and thereafter stained in a strong solution of watery eosin for at least an hour. Rapid washing in water then removes the stain from the swollen walls, and brings out sharply the cell protoplasm and threads of a rich crimson-red color. These show very clearly if mounted in a cell with two per cent. glacial acetic solution which fixes the stain.

the passage through the pore aperture (Plate IV, Figs. 9, 9*a*). The transverse or oblique walls are traversed by five to eight similar processes, so that the protoplasm of each epidermal cell is linked to that of neighbor cells by fifty to seventy-five fine connecting threads, and these again collectively are united with the cylinder of sensitive cells in the irritable hairs.

But the lower or internal wall surfaces of the epidermal cells have a clear shining white aspect due to colloid modification (Plate IV, Figs. 6, 7). After the most careful treatment and study, we have failed to trace a single process traversing these. On the other hand, where the lowest pair of cells of each gland unites with the sub-epidermal cells their walls are thin and traversed by protoplasmic threads. Gardiner has already mentioned[1] the occurrence of connecting threads in the mesophyll, and we have succeeded in tracing these throughout most of the cells; the threads are less abundant, however, than are those of the epidermal cells.

Taken as a whole, then, the irritable hair cells communicate by their epidermal and mesophyll portions with the leaf epidermis and mesophyll generally, while the mesophyll cells of the leaf substance appear to be cut off from the epidermis by a thickened wall, but communicate directly with the gland cells. The advantage of this is probably considerable even from a mechanical standpoint, if we remember the amount of tension to which the surface cells are exposed under the varying conditions of expansion and contraction of the leaf, as well as the secretion of the digestive liquid.

Several of the observers already mentioned have described the structure of transverse sections, but they have overlooked points that appear to be of considerable importance. When the leaf is open and undisturbed, the upper and under epidermal and subjacent three cell-layers of the mesophyll contain chloroplasts and large starch granules. But further, little patches of chlorophyll cells unite these with the bundles or are irregularly disposed in patches amongst the clear mesophyll cells, and all of them contain starch. The bast cells of

[1] Proc. Roy. Soc., Vol XXXVI, p. 181.

the bundles also show granules though of smaller size. Large quantities of starch likewise lie in the cells that make up the triangular area between the midrib bundle and its side branches. Very few granules occur in the cells along the sides of the bundle, and practically none in those beneath it. This relation the author has found to remain unchanged in non-secreting leaves even after these have been kept in the dark for several days. If now serial sections be made from the base of the blade down through the narrowed process connecting blade and winged petiole, the transition from the former to the latter is sharply marked by absence of stored starch around the bundle. As stated below, we believe that the starch is largely utilized during contraction and secretion, for then it is replaced in the bast cells by an oil and at the same time it increases greatly in amount in the upper epidermal cells, probably due to transference of the oil to the epidermal cells, and temporary storing of it previous to excretion through the glands. It is specially worthy of note that while surface pieces of epidermis become deep blue from the amount of starch they contain, not a trace of starch can at any time be detected in the gland cells.

As regards the starting of the closing movement, and the mechanism that effects closure, various views have been advanced. It is generally conceded that after stimulation the protoplasm becomes permeable to the outward flow of water, but there are grounds for believing that it is penetrated by minute pores through which the migrating water can escape. It is quite possible that these might exist, though our microscopes or methods of manipulation might be such as to fail in demonstrating them. But in examining various leaf sections very minutely under a one-ninth objective, several of the clear cells were noticed in which the protoplasm showed an evident but extremely fine striation at right angles to the leaf surface. These cells were chiefly noticed in the third and fourth layers beneath the upper epidermis. One must be careful not to confound them with very similar appearances that are shown by the cell walls when these are rather strongly illuminated, for then the membrane breaks up light in parallel waves that look greatly like the condition of the protoplasm now described. Examination of material preserved in absolute alcohol and stained in eosin caused me to express the opinion, at the 1891 meeting of the American Association of Science, that the protoplasm had delicate transverse striations, and this was also stated in abstract in the "*Gardener's Chronicle*," (Oct., 1891). Finer preparations, and the use of higher powers and additional reagents incline us to the opinion that it is due to rows of extremely minute globules or pores in the protoplasm. Each globule or pore is less deeply stained by aniline dyes, such as eosin, heliosin, and methyline blue, than is the intermediate substance; iodine solution gives to them a pale bluish-yellow aspect. We are not prepared to say whether these are pores or liquid globules, but the optical appearance they give to the cells coupled with the movements of the leaf suggest possible correlation with the structure of striped muscle. The discovery by Haycraft that many of the optical phenomena of striped muscle are due to puckering of its surface does not militate against this, for the coexistence of puckerings along with protoplasmic pores or globules is not improbable.

The nucleus of the epidermal and mesophyll cells of the blade is mostly of a fusiform shape, but by the action of swelling agents it at times assumes an oval or spherical outline. Each is bounded by a clear, highly refractive nuclear membrane, from which processes radiate out chiefly from the poles, but occasionally also from the sides. Sections of leaves that have been hardened in chromic acid and alcohol, and stained with strong solution of eosin show these processes stained, like the nuclear membrane, of a deep refractive pink hue. As they run through the protoplasmic utricle they divide up and are connected with the chloroplasts, some at least seeming to terminate in these. *Dionæa* thus presents the same relation of the nuclear threads with the starch centres that is shown by *Spirogyra*. The nucleolus is a small spherical, highly refractive body, lying inside each nucleus. Rarely there are two nucleoli. Each nucleolus encloses a minute but very sharply defined endonucleolus. Numerous minute leucoplasts exist also in the protoplasmic utricle, and their function is probably explained by the appearance of large quantities of starch during digestive secretion.

Gardiner's "rhabdoid" has been demonstrated with great clearness by directly treating surface sections with strong solution of watery eosin. They should then be fixed and examined in acetic solution. No evidence has been obtained to support Gardiner's statement that the rhabdoid decreases during secretion. A series of measurements indicate that it remains the same, or slightly increases in size, but detailed results will be given in a future communication.

III. Leaf Secretion.

Hitherto all observers have agreed in stating that if the leaf shuts through artificial mechanical stimulus, or owing to the irritation of the hairs by a dry body or inorganic substance, what we may call "non-tetanic," closure ensues; that is in such cases the marginal bristles intercross more or less, but do not subsequently become everted by reflexion of the leaf margin; and that no secretion is poured out unless nitrogenous matter is present. As regards the first point we have already shown that it is wholly due to non-continuance of stimulus, and that prolonged irritation *does* bring about reflexion of the leaf margins. But as it seemed possible that the leaf secretion might correspond in the vegetable kingdom to what is known as the waste metabolic material of animal muscle, numerous experiments were arranged to ascertain whether continued or intermittent stimuli might not cause the secretion to flow. Fresh vigorous leaves on several plants were carefully washed with water and left to dry for a day. Small glass beads, fragments of quartz and fragments of pot-crock were then laid on the leaves which were made to close. A few minutes later the hairs were repeatedly irritated by insertion of a blunt needle, and on examination an hour after, the leaves were found to be tightly closed. They were then restimulated, and the action was repeated every two hours for sixteen hours. In from eleven to fifteen hours after closure the gland surfaces were moist, and after twenty hours were secreting freely.

The secretion had all the chemical, physical, and optical characteristics of that poured out round a nitrogenous body. It at once gave a decided acid coloration to litmus test paper, had a thick mucous consistence, so that it could be drawn out into threads, and when a little was placed on a slide and treated with alcohol it coagulated and assumed under the microscope a delicate myxoid or amœboid granular areolation.

But to prevent the possibility of tissue rupture during successive irritations, a piece of glass dipping-rod was heated and shaped so that a smooth spindle-like thickening was left in the middle of two thin elongated handles. The swollen bulb of the rod was then placed on a clean dry leaf, the handles projecting from the lower and upper ends of the closed blade. After successive intervals of two hours the rod was repeatedly raised and lowered so as to irritate the hairs. When the leaf-halves were pulled slightly asunder after sixteen hours, copious secretion was going on. In this as in the above and succeeding experiments the leaves remained closed from eleven to fifteen days, and during the greater part of that time were bathed with the secretion. Strands of clean cotton thread have been inserted, and pulled back and forward at intervals of one to two hours for eleven to thirteen hours. The leaves secreted freely after fourteen to twenty hours. One that was similarly treated, but stimulated at intervals of two to four hours, began to secrete after thirty-one hours, but only poured forth copiously after three days. The secretion steadily increased till at least the fifth day. It is a mistake, therefore, to suppose that the secretion ceases after one or even two days activity. This has been verified by numerous other experiments.

With such results before us it seemed highly probable that continued electrical stimulus would also excite secretion. The terminals of a battery were slightly bent so as to accommodate themselves to the external, slightly convex, basal surfaces of a leaf after being shut. On application of the terminals to the external surface the halves closed by electrical stimulus and gradually tightened up. Three experiments were thus made and proved entirely successful. The secretion began to pour out in nine hours from one, in eleven hours from another, and in twelve from the third. In its behavior it resembled the ordinary fluid.

It thus appears that the secretion is entirely due to irritation of the protoplasm, and is poured out alike by mechanical, chemical, and electrical stimulus. Now any irritant stimulus applied to protoplasm causes rearrangement of its molecules. In the doing of this work, decomposition of its substance occurs with the setting free of decomposition products, either into the cell cavity or outside the cell. The best and most accurately investigated cases of this are derived from muscular tissue among animals, where definite decomposition products such as sarcolactic acid, carbonic acid, acid phosphate of potash and various nitrogenous compounds can be detected. But in the secretion of *Dionæa* several products, including some acid body, can be detected. Dr. T. A. G. Balfour[1] states that Prof. Dewar determined the presence of formic acid as well as various chlorides.

Gardiner states that *after absorption* various new substances can be observed, and says, "sections of leaves which were placed in alcohol thirty-six hours after feeding show that the cells contain a very large number of tufts of crystals, which are present in the cell vacuole, and adhere to the inner surface of the cell protoplasm. The tufts are formed of fine acicular crystals, which crystallize out with great regularity and radiate from a central point. The tufts are of a yellow-green color. They are insoluble in alcohol, and in one per cent. acetic acid. The formation of these crystals may be artificially produced by wetting the surface of a fresh leaf with the fluid from a leaf which has fed for a period of from thirty-six to forty-eight hours." Before perusing his account I had experimented with the secretion and found the substance described by him, but in all cases it crystallized out on addition of absolute alcohol with startling rapidity. Thus, when a secretion-drop on a slide was placed under the microscope, the secretion appeared glairy and indistinct as already described, but a few drops of alcohol caused formation of the

[1] Transactions of Botanical Society, Edinburgh, Vol. XII, p. 340.

minute needle-like crystals almost more quickly than the eye could trace.

On surface view each gland cell in the resting state, or just previous to secretion, shows one large vacuole of a reddish color, or more rarely several small ones, surrounded by finely granular protoplasm. As secretion proceeds a clear refractive viscid globule pushes or oozes out from the protoplasm into the purple vacuole, and at times divides it up. It presses against the free wall face and gradually oozes out as a surface excretion. The amount and continuity of the secretion depend largely on root absorption, as it may cease soon after first appearance if the soil becomes dry, or if reduced in amount on this account it can be again increased by watering.

As secretion proceeds the starch grains that are abundant during the resting stage in the mesophyll cells seem to change into a yellowish oil that dissolves readily in ether. This travels along the bast cells or related elements of the phloem, and is distributed radially from these. It is possible that this oil may be so acted on that it may become the source of the excreted formic acid already spoken of.

IV. Leaf-opening.

We do not attempt at present to discuss the changes subsequent to secretion, and the absorption of food materials that have been digested by the secretion. In from ten to fifteen days after closure the leaf re-expands, but remains rather torpid for several days after doing so. A remarkable peculiarity, however, has been observed in leaves that are just opening after artificial stimulation, or after secretion and digestion. When the leaf is a healthy one, and has not been greatly exhausted by repeated acts of digestion, if one or two of the marginal bristles on each leaf-half are firmly caught by forceps, the halves very gently and steadily pulled asunder and held in this position for one to two minutes, it will then be found that the leaf remains in the expanded state and can contract on stimulus. Thus, a leaf which had been mechanically irritated was slowly opening fourteen hours after, and when expanded was thrice irritated when it slowly closed.

Numerous such experiments were repeated with similar results, and others in which a series of summation stimuli were communicated behaved in the ordinary way. The only parallel case to this that we know is that termed "contraction remainder" in animal muscle, where namely as contracted muscle is relaxing a weight applied to it will cause rapid and permanent expansion.

We may now attempt to unify the results already given. We conclude that a leaf of *Dionæa*, previous to secretion, is in a state of tetanic contraction. This tetanic state results from a series of stimuli that may either be partially or entirely mechanical, thermal, luminous, chemical, or electric. Tetanic contraction of a leaf growing in the wild state, is due to two mechanical stimuli by an animal, which thereby cause leaf closure, succeeded by repeated mechanical stimuli as the captured animal struggles to escape, and continued by numerous chemical stimuli as the digested excretions of the animal act on the gland protoplasm, and through it on the general cell protoplasm of the leaf.

Rarely it may happen in the wild state, but can readily be demonstrated in the laboratory, that two rapidly applied stimuli are propagated as one shock, and a third is then needed to cause closure, the subsequent results being the same. Any form of energy, alone or conjoined with others, causes closure and tetanic contraction.

Secretion succeeds tetanic contraction, though it is not dependent on it, but the amount of secretion seems largely to depend on the amount of stimulus. Thus, in the case of leaves that secreted feebly when small cubes of roast meat were placed on them, the absorption by, and stimulation of, the protoplasm in the gland cells, through presence of nitrogenous material, might be sufficient to cause activity in the protoplasm that would set up a limited waste excretion. In tetanic closure the stimulus being correspondingly greater, the tissue waste exuding as a secretion is correspondingly greater in amount.

These phenomena are only explicable in terms of the protoplasmic activity. From a careful study of like phenomena in *Drosera*, Gardiner concludes that "the protoplasmic utricle" is traversed by pores, and that one effect of contraction "is an increased impenetrability of the primordial utricle and a consequent decrease in the size of the molecular pores." Any contraction must ultimately be referred physically to aggregation of certain molecules at the expense of others, though it does not follow in the case of *Dionæa*, that the main contraction changes can be traced to visible pores. But the writer has already stated that he believes the protoplasm of certain cells exhibits appearances which may point to such a possibility, though as yet the observations are insufficient to warrant special importance being attached to them. It has been shown further, that the protoplasm of most cells is continuous with that of neighbor cells by twenty to seventy-five intercellular processes. Proof has been adduced by Batalin, Burdon Sanderson and others, that closure is due to the inner side of each leaf, becoming less turgid than the outer, owing to migration of liquid from the former. In a *Royal Institution* Lecture Sanderson[1] further states: "It has, I trust, been made clear to you that the mechanism of plant motion is entirely different from that of animal motion. But obvious and well marked as this difference is, it is, nevertheless, not essential, for it depends not on difference of quality between the fundamental chemical processes of plant and animal protoplasm, but merely on difference of rate or intensity. Both in plants and animals, work springs out of chemical transformation of material, but in the plant the process is relatively so slow that it must necessarily store up energy, not in the form of chemical compounds, capable of producing work by their disintegration, but in the mechanical tension of their elastic membranes. The plant cell uses its material continually in tightening springs, which it has the power of letting off, at any required moment, by excitation. Animal contractile protoplasm, and particularly muscle does work only when required, and in doing so uses its material directly."

Now, it may well be asked here, does the cell wall play a specially important part, or is it not rather the case that the

[1] Nature, 1882, p. 486, *et. seq.*

living cell protoplasm is the direct and active agent? First, it is to be remembered, that since the cell walls are traversed by pores, the protoplasmic threads either must act as perfect plugs to prevent general diffusion of liquids between the cells, or the cells that are traversed by pores must be cut off in the unexcited state from the intercellular spaces, or from other cells that are not provided with pores, if such exist. Otherwise none of the walls could become tense.

It appears to be more in accordance with our present knowledge if we regard the protoplasmic utricle as the layer which can retain or give off its contents according to its molecular condition, and that the cellulose membranes are merely secondary strengthening sacs that act much like the netting bags which surround rubber bellows. Our reasons for this opinion are that the summation results, the effects of different chemical agents, and of energy in varying forms demonstrate a gradual and very exact contraction of the protoplasm, with corresponding contraction of the leaf substance.

Now, if this be accepted as a working hypothesis only, the question arises as to how the protoplasmic utricle of the cell is affected by stimuli. It is manifest that some change in the leaf cells follows stimulation of the hairs, and in view of their structure and relations this seems to be largely propagated, or distributed from the columnar cells that form the *joint* of the hair. We would suggest that on first mechanical stimulation of the leaf, or stimulation of it by chemical, thermal, or other action that the protoplasm of each cell at once rearranges localized groups of its molecules so as to form little permeable areas for the contained sap. This may constitute the change that succeeds first mechanical stimulus. But on second stimulus or continued chemical or electrical stimulus, alteration and aggregation of all the molecules causes contraction of the utricle and squeezing out of liquids through the pores or permeable areas, already established, a certain quantity being speedily expelled through the pores of the hair-joint cells, if such exist. In any case, we agree with Gardiner that the cause of movement is to be sought for in protoplasmic activity, which exhibits itself in permitting or prohibiting the passage of the sap enclosed within the protoplasmic sac of each cell.

Were animal histologists agreed as to the minute structure of muscle, and the changes that occur in it during contraction, it might be possible to make some comparison of vegetable and animal contractility. Meanwhile the facts and statements to hand, suggest that contractility, alike in the vegetable and animal kingdoms, is accompanied by migration of liquids through the protoplasmic substance, and that this is wholly determined by the molecular condition of the protoplasm irrespective of cell walls.

When one attempts to trace how such a complicated mechanism as that of *Dionæa* leaf has been evolved, difficulties appear on every side. Several definite points, however, may be referred to. From Darwin's first statement to Lindsay's recent one, the poverty of root development has arrested the attention of observers. The writer dug up a lot of plants entire, and carefully washed them. He found that the roots never branch; that from below each cluster of fresh, or recently decayed leaves, three to seven, or in strong plants, nine roots arise; that the average number is four; that the roots are from a half inch to three inches long, according to age; that the average total length of functional root-system on a plant at any one time, is eight inches, and of this only a part is covered by functional root-hairs. It is a mistake, however, to suppose, as some have done who never visited the locality, that *Dionæa* usually grows among moist *Sphagnum*. A very few plants occasionally occur in such situations, but at least seven-eighths grow in a loamy sand. It is a rather significant fact, also, that they often grow in the midst of such plants as *Seymeria tenuifolia, Gerardia purpurea and G. tenuifolia*, that are equally poor as *Dionæa* in root development, but have formed strong, parasitic root-suckers, by which they draw sap from the densely interlaced roots of ericaceous shrubs, as well as grasses and other herbs. The fly-catching capabilities of *Dionæa*, and parasitic connections of *Seymeria* and *Gerardia* are parallel physiological advantages that one can vividly see the benefit of for each, when studied in relation to natural surroundings.

The relatively large number of leaves provided with more than six hairs, that the writer has encountered, probably points to a condition when the hairs were more diffuse in their distribution; while the close similarity in development and structure between the brown stellate leaf hairs and the secreting glands, favors the view that the latter are merely specialized examples of the former.

EXPLANATION OF PLATE IV.

Illustrating Dr. J. M. MACFARLANE'S paper on *Dionæa.*

Fig. 1. Surface view of lower part of sensitive hair. *a*, base of hair; *b*, sensitive joint; *c*, shaft. The cell wall surfaces of *b* exhibit minute pit areas. × 400°.

Fig. 2. Longitudinal median section of lower part of sensitive hair; × 400°.

Fig. 3. Transverse section of hair at junction of base and joint cells; × 400°.

Fig. 4. Outline surface view of secreting gland; × 400°.

Fig. 5. *a*, *b*, *c* and *d*. Forms of hair from lower leaf surface; × 400°.

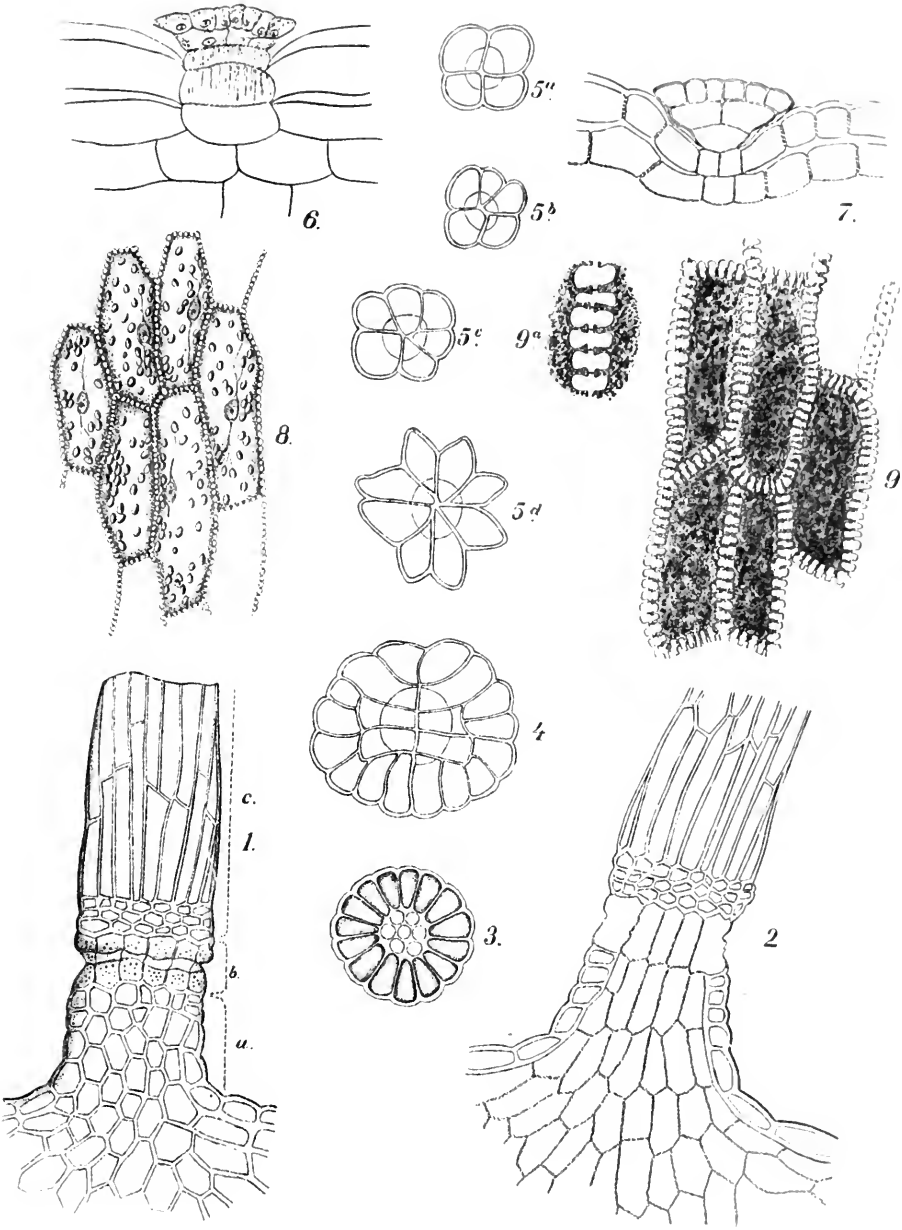
Fig. 6. Vertical section of gland parallel to secondary leaf bundles; × 400°.

Fig. 7. Vertical section of gland at right angles to the last.

Fig. 8. Surface view of epidermal cells, after slight treatment with dilute sulphuric acid and eosin staining; × °750.

Fig. 9. Surface view of epidermal cells after iodine and sulphuric solution treatment and eosin staining. The continuity of the intercellular protoplasmic threads is traceable; × 750°.

Fig. 9*a*. Portion of swollen cell wall penetrated by intercellular protoplasmic threads. The thickened areas in the three figures are rather exaggerated in amount.



Macfarlane on Dionaea.

An Abnormal Development of the Inflorescence of Dionæa.

By John W. Harshberger, A.B., B.S.

(*With Plates V and VI.*)

THE peculiarly developed plant of *Dionæa* now to be described grew in the greenhouse of the Biological Department of the University of Pennsylvania, under ordinary conditions of heat and moisture. The specimen flowered about the usual period, but the abnormal condition displayed by it was not observed till after the flowers had somewhat withered.

The scape rose as usual from the centre of the rosette of leaves and produced normal flowers at the end of the branch that is cut off and placed at the side in the illustration for sake of clearness (Plate V, Fig. 2). This branch breaks up into two main shoots, each of which divides into several flower-bearing stalks.

One of the main shoots of the scape is subtended by a long lanceolate bract, and a smaller bract is found on it a little above the insertion of the first. In the axil of the smaller bract two structures have developed, the lower being an elongated branch, the upper evidently a metamorphosed flower, (Plate V, Fig. 1, d).

The elongated branch organ has a central rhizomatic axis that produces leaves arranged in a flat spiral. Sections of the leaves when magnified show normal digestive glands, and sensitive hairs occur on the upper laminar surface. In these and all other respects, therefore, they agree with vegetative or foliage leaves. True roots (Plate V, Fig. 1, c), developed at the leaf bases, grow out from the rhizome. Sections of one of these roots reveal radially arranged bundles, in which phloem areas alternate with xylem strands.

A third bract is reached in acropetal succession from the first (Plate V, Fig. 1, g[1]), and in its axil a growth arises that corresponds in every particular with the branch-organ already described as springing from the axil of the second bract.

The axillary position of the foliar shoots and their relation to the flower-like shoot give an insight into the morphological relations of the teratological parts. In the abnormal floral branch (Plate V, Fig. 1, g) an indurated collection of nodular bodies strikingly resembles ovarian tissue. Bract G, as we have seen, subtends two branches, the lower being a vegetative shoot, the upper or superposed one resembling a flower. This condition corresponds to the superposed buds met with in such plants as *Lonicera tartarica*, which produces three to six axillary buds on some shoots; or *Juglans cinerea*, in which the primary axillary bud remains latent, and several accessory axillary buds push out, of which one elongates into a branch.

The histology of *Dionæa* has been studied and described by Kurtz,[1] C. de Candolle[2] and Fraustadt,[3] though most observers in their desire to study the specially interesting leaf traps, have to some extent neglected the anatomy of the underground parts and of the scape. The vegetative shoots above referred to seemed well suited for a study of the fibro-vascular bundle distribution.

A cross section of the scape two inches below the point of branching is illustrated in Plate VI, Fig. 4. The section shows externally an epidermis made up of large polyhedral cells. Beneath are five or six rows of loose parenchymatous elements with intercellular spaces. The phloem or soft bast of the bundle consists of sieve tubes and companion phloem cells, while a few xylem cells are intimately connected with the small phloem areas. A zone of parenchyma intervenes between the small external bundle and the larger fibro-vascular area within. The outer portion of this area is occupied by the phloem, the inner by xylem, made up of pitted vessels, also spiral and scalariform tracheids. The centre of the section consists of cellular tissue.

[1] Archiv. für anat. und Physio-wissen. Medicin, 1876.
[2] Archiv. de Sc. Physik. et Nat. Geneva, 1875-76.
[3] Cohn's Biologie der Pflanzen, Band II, pp. 50-59.

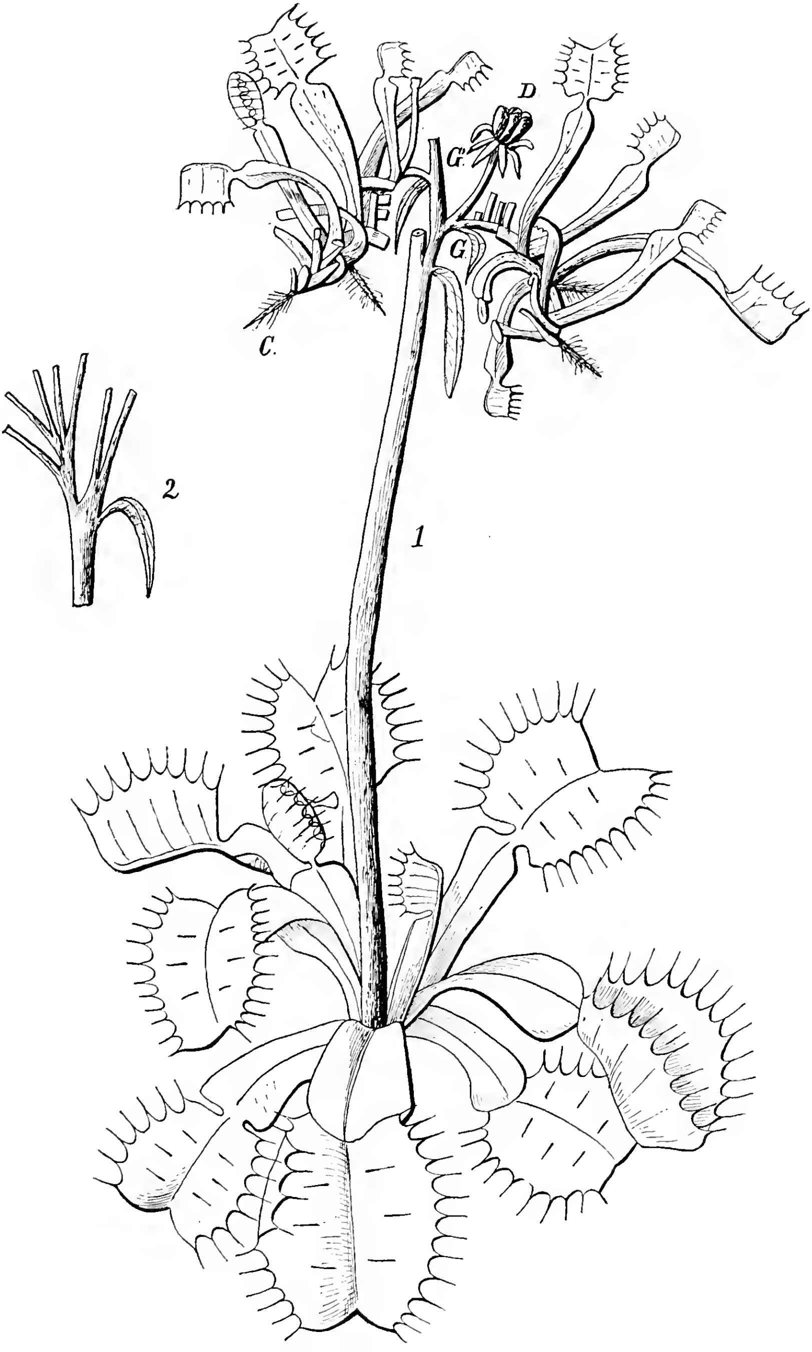
A cross section of the branch G of Plate V, made a little above its insertion into the scape, is represented in Plate VI, Fig. 5. Beneath a single layer of epidermal cells is a wide zone of fundamental tissue, succeeded by a layer of sclerenchyma interspersed by white, glistening, sclerotic cells. Internal to these is a zone of phloem tissue surrounding a central mass of xylem. The course of the bundles in the branch can now be referred to. The leaves are arranged in a flat alternate spiral (Plate VI, Fig. 3). Fraustadt (*op. cit.*) says: "The whole rhizome is short and broad, the leaves are placed on it with broad, flat insertions without internodes."

"The phyllotaxy I have not been able clearly to define, the younger leaves are apparently two-ranked; the leaves overlap one another with their foliaceous petioles." "Frequently the leaves show an open spiral arrangement." The abnormality with lengthened internodes (Plate VI, Fig. 3) is especially valuable, as it indicates more plainly the phyllotaxy and the distribution of the fibro-vascular bundles. Fraustadt, in his study of the underground short rhizome, encountered a mass of fibres. A cross section of the abnormal branch, half-way between its proximal and distal ends, appears in Plate VI, Fig. 6. Fig. 2 shows the relationship of the parts. The central tissue of the branch shows the main bundle trace (A) two leaves (C and E) come off from either side of this central area, a third leaf (O) arises above.

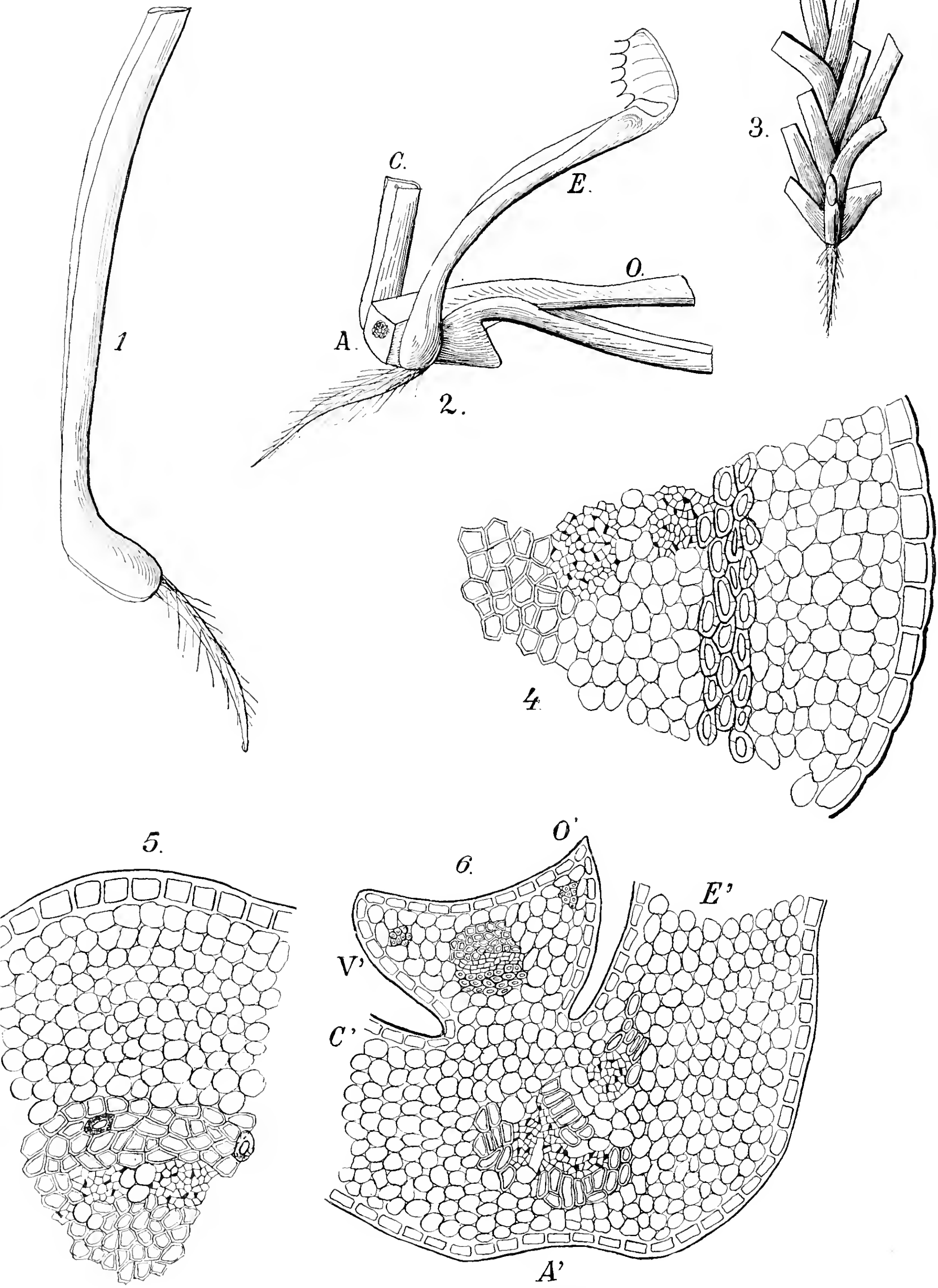
A very thin section, at this point (A, Pl. VI, Fig. 2), is magnified and shown in Fig. 6. We have in this figure the central tissue (A^1) with the two leaves arising on each side (C^1 and E^1), the third leaf O^1 arising above. A puzzling ramification of bundles here occurs, complicated by the different directions of leaf growth. The bundles at the proximal end of the rhizome are represented in Fig. 5, Pl. VI. When we reach the middle section, Figure 6, a change takes place. Before dividing into separate strands for the leaves (C^1, E^1, O^1), a twist in the stem bundles must occur for the three phloem areas come together at A^1, with the xylem circumferential. The leaves in their origin run toward the growing point a little way, then take a sharp bend, and point backward proximally. This reverses the direction of the bundles, and brings the phloem again into its true position on the lower side (V, Pl. VI, Fig. 6) of the leaves C^1, E^1, O^1. The three bundle traces must have twisted, and divided a little back of the point A^1, which thus gives the peculiar bundle anatomy at A^1 (Pl. VI, Fig. 6). We have in Fig. 6 a central rhizomatic tissue (A^1), with leaf tissues in the centre above and on each side. Each wing of tissue receives a bundle trace from the main axis cylinder. A solution can be found apparently for the curious bundle arrangement if it be considered that a twist in the fibre occurs. Fraustadt found the whole mass of parenchymatous tissue in the underground stem and leaf petioles crowded with oval starch grains. The sections of "aerial rhizome" showed the whole parenchyma densely packed with starch, which made the section somewhat opaque.

The axillary structures now referred to are clearly homologues of the buds or bulbils encountered in such plants as *Lilium Bulbiferum, and Ranunculus Ficaria*, and they suggest the possibility of vegetative or non-sexual reproduction in this particular case. It might have been possible to have grown new individuals from the axillary vegetative branches, but the suggestion of this idea came after the plant had been killed and preserved in alcohol. Authorities can only therefore be cited which seem to sustain this belief in non-sexual propagation in *Dionæa*. Miss Elizabeth H. Willis records an interesting case in point, that was noticed on a plant of *Dionæa* in her possession. "The leaves have continued to increase by sending out runners, which have taken root all around the parent plant, until now the group of independent branches (except for the creeping recumbent stem, which seems to unite them together), numbers about twenty-five."[1] A curious record is made by Hogg,[2] "that the leaves of *Dionæa*, if placed in damp moss, will take root and produce young plants on the margin." Nitschke[3] has recorded the production of adventitious plants on the leaves of *Drosera*, a near relative

[1] Botanical Gazette, Vol. X, 1885, p. 214.
[2] Nat. Hist. of the Vegetable Kingdom, 1858, p. 84.
[3] Botanische Zeitung.



HARSHBERGER ON DIONÆA.



HARSHBERGER ON DIONÆA.

of the Venus Fly Trap, while additional literature on the subject is to be found in *Annales des Science Naturelle*,[1] *Science Gossip*,[2] and *Nature*.[3]

From the above data we may conclude:

(1) That the production of individuals by bud propagation on the leaves of *Dionæa* and *Drosera* occasionally occurs.

(2) That the condition described above in *Dionæa* is a case of non-sexual reproduction supplanting the ordinary sexual process.

(3) That the bud axis may be considerably elongated, and provided with evident roots and leaves previous to separation from the parent axis.

EXPLANATION OF PLATES V AND VI,

Illustrating J. W. Harshberger's paper on *Dionæa*.

Plate V.

Fig. 1. Plant enlarged.
- G, G^1. Vegetative axillary branches.
- D. Flower-like branch.
- F. Leader figured at the side.

Fig. 2. Main leader or branch.

Plate VI.

Fig. 1. Leaf detached showing origin of the root.

Fig. 2. Ideal representation of the outgrowth half way between distal and proximal ends.
- A Central tissue.
- B Middle leaf.
- C & E Lateral leaves.

Fig. 3. Outgrowth showing phyllotaxy.

Fig. 4. Cross section of the scape.

Fig. 5. Cross section, vegetative branch at proximal end.

Fig. 6. Middle section of same branch.
- A^1 Central tissue.
- C^1, E^1, O^1 Leaves.

[1] Annales des Sci. Nat., XIV, 1840, p. 14.
[2] Science Gossip, 1873, p. 239; 1883, pp. 44 and 91.
[3] Nature, XV, p. 18.

Mangrove Tannin.

By Prof. Henry Trimble, Ph.M.

(*WITH PLATE VII.*)

[The following interesting paper by Professor Henry Trimble on Mangrove Bark needs no word of introduction from anyone. It may, however, not be out of place to call attention to the illustration of a mangrove thicket near Port Morant, Jamaica, and to add that, if the extraction of tannin from mangrove bark can be made a commercial success, the new industry so created must react most favorably upon our hemlock forests. For the hemlock trees, there are so many uses, that it seems unwise to cut them down, as has often been done solely to obtain the bark. This is especially so, when one remembers that our supply is by no means inexhaustible, and that the rate of reproduction is extremely slow. The mangrove (Rhizophora Mangle, L.) is a common inhabitant of tropical seaboards around the world, and save for the possible tannin producing capacity of its bark gives promise of no great commercial value to us.]

J. T. Rothrock.

MANGROVE bark from *Rhizophora Mangle, L.* has been frequently mentioned as a possibility in the tannin industry. Probably the first reference to it was made by Dr. James Howison[1] in 1804, when he received a gold medal from the Society of Arts, for his description, and a sample of the extract made in India from 400 pounds of the bark. The method of preparing this extract, however, was not such as to give the largest yield or the most satisfactory product, since the extraction was carried on without the aid of heat, and the resulting liquor was evaporated by exposure to the sun until quite concentrated, when it was finished by the application of heat. There must have been considerable deterioration of the product by fermentation. This sample of fifty-four pounds cost eight shillings in Bengal, and the

[1] "Preparation of Tan made in the East Indies from the Bark of the Mangrove Tree." Transactions of the Society of Arts, 22, 201.

author thought it could be prepared for ten shillings per hundred weight.

More recently, in 1846, we find a description of mangrove by W. Hamilton,[1] in which he gives an interesting account of its manner of growth and possible uses.

It appears, however, not to have come into use, except in the localities where it grows. The probable reasons for this are (1) the fact that almost all parts of the world are able to supply tanning material for home consumption, and (2) that the mangrove produces a leather of a bad color and a spongy texture. It is, therefore, of interest chiefly as a possibility, for, in the event of its being needed, the color, and spongy character which it imparts, could, no doubt, be corrected. It has been thought that an investigation of the constituents of the bark as well as a study of its peculiar tannin might be of interest. For, if not for immediate use, it would, by giving us a knowledge of the individual tannin, increase our information on the whole class of tannins, of which we at present know so little.

The material for this investigation was supplied to me by Professor J. T. Rothrock, who collected it during his southern scientific expedition in the winter of 1890–91.

The bark, after powdering, was found to contain 12.04 per cent. of moisture, and 6.10 per cent. of ash. Sodium salts predominated in the ash, chiefly as the chloride.

Only insignificant amounts of fat, wax, and compounds of that nature were found.

Stronger ether removed 0.40 per cent. of a substance insoluble in water, but which caused a green color with ferric chloride. Gallic acid was proved to be absent.

Absolute alcohol extracted 20.32 per cent. of a very astringent substance with a narcotic odor. Of this an amount equal to 13.42 per cent. of the bark was soluble in cold water, and the remainder was almost completely soluble in hot water. The alcoholic extract was found to consist largely of tannin, red coloring matter, and a small quantity of glucose.

[1] "On the medical and economic properties of the *Rhizophora Mangle*, or Mangrove Tree."
Pharmaceutical Journal and Transactions, 6, 11.

The other more important constituents were determined to be, mucilage 1.72 per cent., glucose 0.81 per cent., albumenoids 7.02 per cent., starch 4.27 per cent., and cellulose 27.49 per cent. Tannin was determined by gelatin and alum, and found to be, in the air-dry bark, 23.92 per cent. ; this was an average of three closely agreeing results. For future comparison it may be well to note that this by calculation indicates 27.19 per cent. of tannin in the absolutely dry bark.

Preparation and Purification.

A quantity of the tannin was prepared by extracting the finely powdered bark with commercial ether (specific gravity 0.750). After recovering most of the solvent, the remaining extract was distilled to dryness under reduced pressure. The residue was dissolved in ether of the same specific gravity, and the solution concentrated to dryness under reduced pressue, which had the effect to render the tannin quite porous and in a condition to be dissolved by water, which was next used. The filtered aqueous solution was carefully treated with solution of neutral lead acetate. In this operation it is to be noted that the first few drops of the reagent caused a precipitate, which on stirring disappeared. A further addition of the reagent caused a precipitate of the coloring matter, and on filtering a yellow filtrate was obtained. This filtrate was agitated successively with three portions of acetic ether, which removed the tannin. The precipitate was suspended in water and decomposed with hydrogen sulphide, the mixture filtered and the filtrate, after heating under reduced pressure to remove hydrogen sulphide, was treated with lead acetate as before and the filtrate agitated with acetic ether, which removed an additional quantity of tannin. This acetic ether solution was mixed with that from the previous agitation and the whole distilled to dryness, the residue dissolved in ether with some water, and again distilled to dryness under reduced pressure.

Properties.

The tannin obtained by the above process was in light reddish-yellow porous masses, completely and readily soluble in water, alcohol, and commercial ether. It was partly precipitated from its aqueous solution by saturation with common salt. That not precipitated was removed by agitation with acetic ether, and, although lighter in color, it was found to be identical with the darker portion precipitated by the salt.

The following are the reactions of the mangrove tannin, in one per cent. solution, with the usual reagents. There is added for comparison the behavior of a similar solution of gallo-tannic acid.

Reagent.	Mangrove-tannin.	Gallo-tannic Acid.
Sulphuric acid (1 to 9 of water),	Red deposit on cooling.	No change.
Bromine water,	Yellow ppt.	No ppt.
Ferric chloride,	Dirty-green ppt.	Blue-black ppt.
and Ammonium hydrate,	Purple ppt.	Purple ppt.
Tartar emetic,	No ppt.	White ppt.
and Ammonium chloride,	No ppt.	White ppt.
Calcium hydrate,	Pink ppt. Red on surface.	White ppt. Turning blue.
Concentrated sulphuric acid,	Deep-red color.	Yellow color.
Lead nitrate,	No ppt.	White ppt.
Cobalt acetate,	Faint cloudiness.	Flesh-colored ppt.
Uranium acetate,	Red-brown color and ppt.	Crimson color.
Potassium bichromate,	Brown ppt.	Brown ppt.
Ferric acetate,	Olive-green color and ppt.	Blue-black ppt.

These reactions agree closely with those given by Procter for the tannin of *Mimosa* or wattle bark.

A further examination of the above mangrove-tannin failed to reveal the presence of sugar. This was accomplished by precipitating a solution of 0.5 gramme of the tannin with lead oxyacetate, removing the lead from the filtrate by hydrogen sulphide, and, after removal of the latter, testing with Fehling's solution.

The Action of Heat.—By heating another portion of the tannin in glycerin to 215°, shaking out the products of de-

[1] Text-book of Tanning, p. 113.

composition with ether, and, after removing the latter, dissolving in water, and applying the usual reagents, a catechol tannin was indicated.

Hydrolysis.—0.5 gramme, after boiling for three hours with a two per cent. solution of hydrochloric acid (absolute HCl), yielded a red insoluble decomposition product, and a substance capable of reducing Fehling's solution to an extent which indicated 10.35 per cent. of glucose. The above red product was readily oxidized by nitric acid yielding a red-brown solution which rapidly faded, and which with water became paler, precipitation taking place at the same time. The original product was not completely soluble in cold or hot alcohol nor in ammonium hydrate. That which did dissolve in alcohol was not precipitated by a large quantity of water. These properties indicated the presence of gallic acid, ellagic acid and phlobaphenes.

Composition.

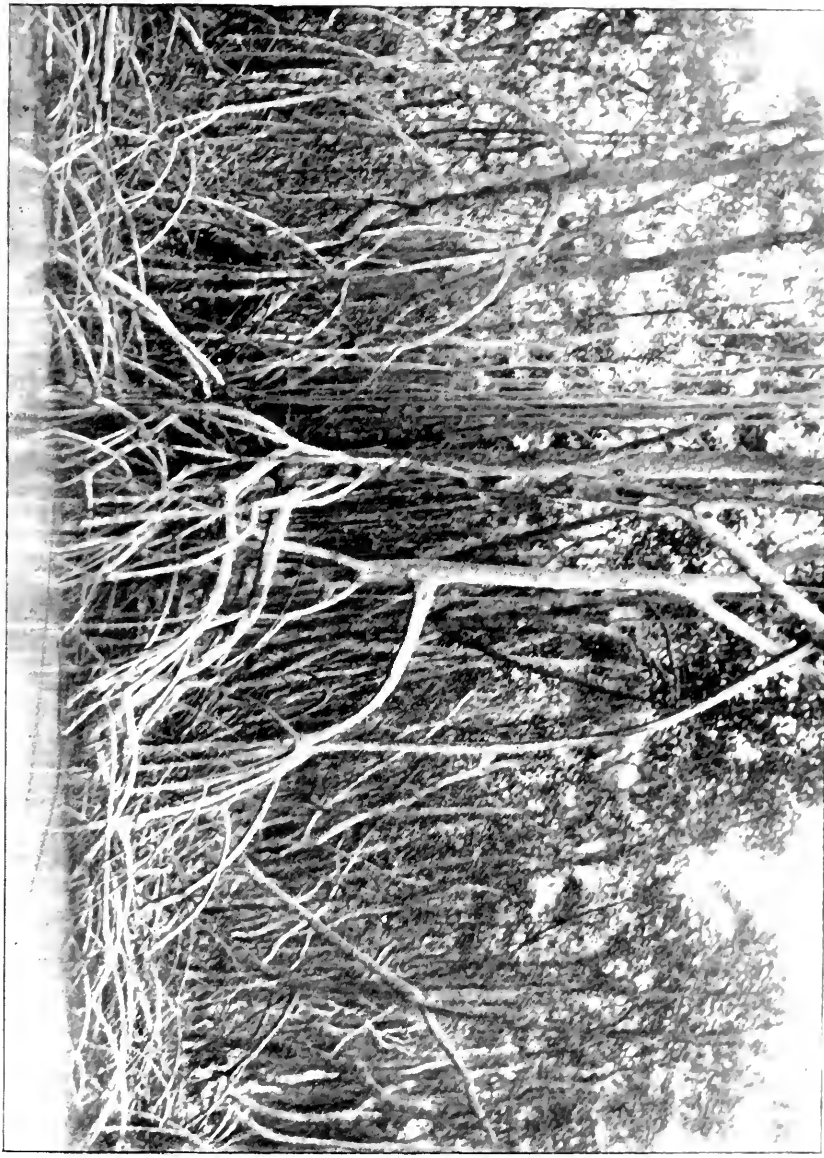
After repeated precipitation of the tannin until it was of a light reddish-yellow color, it was dried at 120° and submitted to elementary analysis with the following results:

(1) .2353 gramme gave .5188 CO_2 and .1023 H_2O.
(2) .2475 " " .5414 CO_2 and .1027 H_2O.
(3) .2556 " " .5577 CO_2 and .1070 H_2O.

indicating the following percentages:

	(1)	(2)	(3)	Average.	Calculated for $C_{25}H_{25}O_{11}$	$C_{20}H_{20}O_9$	$C_{27}H_{24}O_{11}$
C.	60.13	59.66	59.51	59.76	59.88	59.40	60.93
H.	4.83	4.61	4.65	4.69	4.99	4.95	4.68
O.	35.04	35.73	35.84	35.55	35.13	35.65	34.39

The formula $C_{25}H_{25}O_{11}$ comes the nearest to representing the average percentages obtained; the formula $C_{20}H_{20}O_9$ is that given by Dragendorff for rhatania-tannin; and the formula $C_{26}H_{24}O_{11}$ is the one given by Rochleder for horsechest-



Trimble on Mangrove Tannin.

nut-tannin, with which rhatania-tannin, according to Grabowski, and tormentil-tannin, according to Rembold, closely agree.

The conclusion naturally reached by this investigation is that we have in mangrove a tannin which is identical with those from horsechestnut, rhatany and tormentil, and possibly also with that from mimosa or wattle bark.

PHILADELPHIA, 1892.

Observations on Epigæa repens, L.

By W. P. Wilson, D.Sc.

(*WITH PLATE VIII.*)

EPIGÆA *repens* or Arbutus is one of our North American plants, which has a very wide distribution. It flowers early in the spring, in some places soon after the snow has disappeared.

Owing to its early appearance, its often beautifully tinted and sweet scented flowers, and its trailing evergreen leaves it is a great favorite wherever it grows.

In New England it passes under the name of Mayflower. As soon as it opens in the spring it is brought into Boston, tied up into little bunches, with most of its attractive leaves stripped off, and exposed for sale on the streets.

In the same way it is sold in New York, Philadelphia and other cities. It has been nearly exterminated within fifty miles of Boston. It still grows in great abundance in the Pine barrens of New Jersey, but with the small army of colored women actively engaged in pulling it up for the Philadelphia market its extermination in this locality is only a matter of time.

Its range of growth extends from Canada to Florida along the coast, and west to Minnesota, Michigan and Tennessee. In all these localities it is much sought after by lovers of flowers, and is picked and exposed for sale, or used for home decorations.

In 1796 Micheaux, while journeying in the Alleghany Mountains, picked up this little plant and made the following entry in his journal: "Le 2 Avril. Epigæa repens en pleine fleur comme les jours precedents: sur plusi. individus toutes les fleurs femelles sans rudiments d'Etamines et sur d'autres individus fleurs toutes les fleurs hermaphrodites."[1] We also find in Michaux's Flora "Flores omnes in nonnullis individuis abortivi." Michaux was therefore the first to record the different forms of this flower and to call attention to the fact, noted many years later by Gray, that all the flowers do not produce fruit.

In 1868 Meehan[2] recorded a number of observations of which the following is a brief summary:

There is much variation in the size of the corollas in different plants.

There are flowers without stamens, (Pistillate).

Some flowers have five-lobed stigmas that are widely divergent: In others the five lobes are closed. In such the stamens are present, (hermaphrodite.)

The ovaries are larger in corresponding states in the pistillate forms than in the staminate.

The pistillate forms shed their corollas first. The corollas on the hermaphrodite forms dry up without dropping.(??)

Cope communicated to Meehan at this time that the corollas of the pistillate forms are recurved and vasiform and may thus be distinguished from the hermaphrodite form.

Nearly ten years later the following facts were communicated to the Boston Society of Natural History[3] by Gray[4] and Goodale.

There are four kinds of flowers:

1. Those with long styles and perfect stigmas.
2. Those with short styles and perfect stigmas.

   Both of the above kinds with *aborted* stamens.

3. Those with long styles and imperfect stigmas.
4. Those with short styles and imperfect stigmas.

   Both of the above kinds with *perfect* stamens.

The modified stigmas on the one hand, and the aborted stamens on the other are looking toward dioecism; the differ-

[1] From the Journal of Andre Michaux, written during his travels in the United States and Canada, 1785-96, Proceedings American Philosophical Society, Vol. xxvi., 1889, No. 129, p. 138.

[2] Proceedings Philadelphia Academy Natural Sciences, Vol. xx., May, 1868, p. 133.

[3] Proceedings Boston Society Natural History, Vol. xxiii., 1876.

[4] Siliman's Journal, July, 1876.

ence in the lengths of the styles, and the differences in the lengths of the stamens are looking toward dimorphism.

It is not known whether the flowers with small stigmas are ever fertile or not.

In 1891 Halsted examined sixty flowers and came to the following conclusions:[1]

That there is only a tendency towards dimorphism:

There is no difference between the pollen grains taken from the anthers of long or of short stamens.

He finds the strong tendency to become unisexual in large part sufficient to account for the differences in length of styles and stigmas.

During the present year the writer has examined about 1,000 plants of *Epigæa repens* at the time of flowering. Most of them were from western North Carolina. A few were from localities in Canada, Massachusetts, New Jersey and Pennsylvania.

These flowers readily fall into two groups:

(1) Those having perfect pistils, with or without rudimentary stamens.

(2) Those having pollen-bearing stamens, with rudimentary pistils.

Occasionally flowers are found in the first group without a trace of a stamen. Often there are bare vestiges of filaments at the base of the corolla. In rare cases the anthers may be present, but without pollen.

In the second group the pistil is rudimentary through an undeveloped stigma only. The stigma in the first mentioned form is a five-lobed, star-shaped, terminal body, opening its lobes out nearly at right angles to the style. In the second form the stigma is five-lobed, the lobes being closely appressed into a terminal, functionless, oval enlargement.

The first form is without perfect pollen-bearing stamens, and is, therefore, pistillate. The second form, having a functionless pistil through an imperfect stigma, but bearing perfect stamens with pollen, is therefore, staminate. The

[1] Bulletin of the Torrey Botanical Club, Vol. xviii., p. 249, 1891.

two forms do not occur on the same, but on different individual plants.

Epigæa repens is therefore, not *becoming* diœcious, but is already so.

If a large number of flowers be examined in any given locality, a few will be found with long styles that carry the fertile or infertile stigma, as the case may be, considerably beyond the throat of the corolla (Plate VIII, Figs. 3, 6). In a much larger number of flowers will be found an extremely short form with stigmas only half elevated in the tubular corolla (Figs. 1, 7).

All intermediate forms may be found if one examines a sufficient number of plants (see Plate VIII, Figs. 2, 3, 4, 8). Two of the most common forms are Figs. 2, or 8 and 5. One can make out a tri-morphic condition of this plant, and quite as easily show, with a still farther examination of flowers, a polymorphic condition. In some of the flower sections on the Plate bare rudiments of stamens exist, as in Figs. 2 and 3. In Fig. 4 the anthers are present without pollen. Only one plant with flowers in this stage of development was found while examining a large mass of material from North Carolina, Pennsylvania, and New Jersey.

In Fig. 5 the stamens are short; in Fig. 7 they are long. In others they occupy an intermediate position.

Figs. 5 and 7 show the predominating forms. At the present time cross-pollination is secured with absolute certainty through diœcism.

The rudimentary stamens and pistils in the different kinds of flower show that this has not always existed, but that the flower was once perfect. In this early and perfect condition of *Epigæa* it is evident that it developed, as many other flowers have, these varying lengths of styles and stamens to aid in securing cross-pollination.[1]

There are differences between these two kinds of flower other than those which relate to the essential organs, the stamens and pistils. These differences indicate that while

[1] Any one not familiar with di-and tri-morphic flowers and the way in which they aid cross-pollination, can consult Lubbock's British Wild Flowers.

diœcism is of a later development than polymorphism, it is still of no very recent date.

The corollas of the female forms are as a rule from one-third to one-seventh smaller than those of the male. Figs. 9 and 10 show an average female and an average male flower drawn in relative proportions.

The throat is somewhat more open in the female than in the male form. In color, too, the smaller pistillate flowers seem to have gained an advantage over the staminate form, the latter often having little or no color, while the former develops beautiful shades of pink or rose color. It is not strange that the smaller and less showy female flowers should acquire a deeper hue than the larger male flowers in order to be equally conspicuous and attractive to the insects which must carry the pollen from one to the other if the seeds are to be formed.

The whole male plant, under most conditions of growth, presents a decided appearance of vigor which does not seem to belong to the female. In the male there is less color the flowers often being white, the leaves are larger, the vegetating shoots are longer and more thrifty; while in the female the color is brighter and deeper, the leaves are considerably smaller and the creeping branches much shorter. The male plant often looks thrifty in localities where the female looks dwarfed.

In examining *Epigæa* in different localities this year the writer has in several cases made a careful numerical estimate of the ratio of the sexes, to each other. The results obtained, although necessarily rather indefinite on account of varying conditions that are difficult to estimate, may be of interest to some, as touching on the question of development and persistence of sex.

Quite a number of observations and investigations made on animals seem to show that where the struggle to maintain life is a hard one, a preponderance of males are produced; while on the contrary, when food is abundant and there is no struggle, females predominate. The very few observations which have been made on plants seem to exemplify the same principle.[1]

At Blowing Rock, in the mountains of North Carolina, in a luxuriant forest, in every way the natural home of *Epigæa*, the writer made an estimate of the relative numbers of the two sexes. On a walk of four miles through the woods a cluster of flowers from every plant met with was plucked, provided the last plant picked from was not nearer then ten feet. Conditions were as nearly natural in soil, shade and surrounding vegetation as could well be imagined. In all 98 separate plants were examined; 45 of these were females and 53 males. This was not very far from an even distribution of the two sexes, there being only eight more male plants than female.

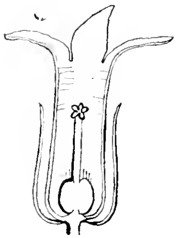
On the next day a similar estimate was made on a rocky knob, over 4,000 feet high, from which most of the trees had been cut, the bushes burned and more or less of the soil washed away. On the whole it was an unfavorable place for the growth of the plant. Only 67 clusters could be found. Of these 40 were females and 27 males. Again, on the following day an estimate was made for ten miles along a mountain road, from the sides of which much of the timber had been cut, often the bushes burned and the plants exposed to the full rays of the sun. From the adjacent forest *Epigæa* had struggled into the exposed places. The locality was not a favorable one for the plant.

Three hundred and twelve separate plants were examined. Of these 173 were females and 139 males. Here it will be seen again that the females predominate. Ten days later the last examination of this kind was made in Pennsylvania, near West Chester. Here the plants were picked mostly on the roadside and on the edge of a sunny, grassy field, where the facilities for their growth were not as good as in the open woods. One hundred and thirty-seven plants were examined. Of these 92 were females and 45 males, an excess of 47 females over the male plants.. The writer gives these notes for what they are worth, being well aware of the fact that a

[1] Dusing, Jen. Zeitsch. f. Naturw., XVII, 1883. Heyer, Ber. d. landwirthschaftl. Inst., Halle, V. 1884. Meehan, Proc. Acad. Nat. Sci., Phila., 1884.

sufficient number of localities, with character of soil and surroundings have not yet been examined to give them value. The fact has also been noted that *Epigæa*, in some localities, seldom sets seeds, the plant propagating itself largely in such places by stolons. A consideration of such habits must be taken into account in estimating the predominance of one sex over the other. Tabulated the results appear as follows:

Localities Examined.	Number of plants examined.	Number Females.	Number Males.	Number of Females in excess of Males.	Number of Males in excess of Females.	Per cent. of Females.	Per cent. of Males.
Favorable locality; rich and shady woods, without underbrush; North Carolina.	98	45	53		8	.46	.54
Unfavorable locality; Mountain Knob, 4,000 feet elevation; North Carolina.	67	40	27	13		.60	.40
Unfavorable locality; Blowing Rock to Lenoir, down a mountain road; North Carolina.	312	173	139	34		.55	.45
Unfavorable locality in Pennsylvania, near West Chester.	137	92	45	47		.67	.32



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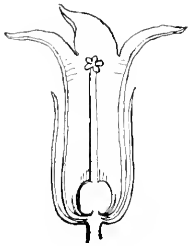

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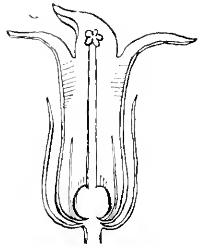

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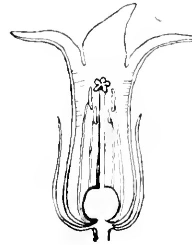

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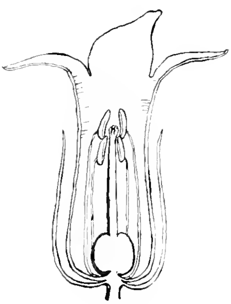

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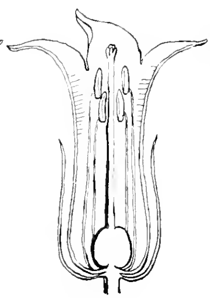

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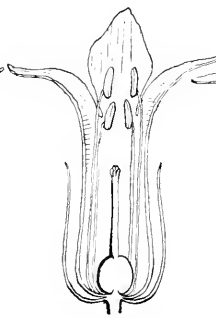

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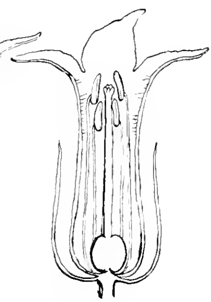

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WILSON ON EPIGÆA.

Whether this higher percentage of females under severer conditions of environment, indicates an actual production of more female forms than males; or whether an equal number of both forms are not produced in the first place, the males being reduced later by stress of surroundings, will necessitate more careful experimentaticn for determination.

Observations from any one living in localities where *E. repens* grows, are kindly asked for.

EXPLANATION OF PLATE VIII.

Illustrating Dr. W. P. WILSON'S, paper on *Epigæa repens L.*

Figs. 1, 2 and 3 show sections of pistillate flowers with varying length of styles.

Figs. 2 and 3 show rudiments of stamens.

Fig. 4 shows a vertical section of a pistillate flower with complete stamens. The anthers are, however, without pollen and shrivelled. All four figures show the star-shaped stigma of the pistillate flowers.

Figs. 5, 6, 7 and 8 represent vertical sections of staminate flowers with varying lengths of filaments and styles. They show the closed character of the stigma in the staminate form in which it never opens.

Fig. 9 represents a male flower, with its large and generally less colored corolla.

Fig. 10 represents a female flower. Figs. 9 and 10 show the relative size of the two sexes. The female is generally about one-third smaller than the male.

A Nascent Variety of Brunella vulgaris, L.

By J. T. Rothrock, B.S., M.D.

As commonly seen in the eastern United States, *Brunella vulgaris, L*, is an erect or ascending perennial herb, with its spike or head of flowers raised from five inches to a foot above the ground. More commonly the stem is erect and simple; frequently, however, one finds lateral shoots arising low down and often creeping along the ground. Both the erect and creeping shoots produce similar terminal spikes. It is important, however, to bear in mind that the erect form is with us much the more common, and that the plant is usually found in open woods or along the road sides. Within the past few years *Brunella* has invaded certain shady lawns in the eastern part of Pennsylvania, and from the fact of its rapid multiplication by rooting laterals is becoming a most serious pest. The flowering shoots in these lawn specimens have been much reduced in length, so that the flowers are seldom raised more than two inches above the ground; more frequently they are on the ground. The same peculiarity has also been noticed in the common dandelion when in similar situations.

From a consideration of all the facts, the case of *Brunella vulgaris* appeared to be an illustration of the prompt action of natural selection in producing a variety of the species which could perpetuate itself in spite of the lawn-mower.

Within a year this special form of low-flowering and low-seeding plant has been noticed in many places, and has occasioned much surprise from the striking deviation it offers from the type of the species.

But the most remarkable feature of the problem is the promptness with which it seems to have appeared. Its adaptation to the situation is most decided. The question still may be considered an open one as to whether it has developed as suddenly as it appears to have done.

Brunella vulgaris varies greatly in England in height, shape of leaves, etc. It has long been known here in meadows and open places, but nowhere, so far as my observation goes, has this low-flowering variety been found in quantity save in lawns which are frequently and closely "mowed off."

The late Dr. Darlington, who was a close observer, speaks of the plant as common in meadows, but expressly declares that it is not pernicious. The low form, however, is distinctly pernicious on the shaded lawns of eastern Pennsylvania. A point to be decided is whether it could have spread so rapidly as it has done but for the disadvantage under which the shade has placed the grass.

There is the further fact to be noticed that this variety, on the whole, produces fewer flowers and consequently fewer seeds than the typical form; and in like measure that its increase by shoots rooting from the nodes is correspondingly greater. The plants produced in this manner are so numerous as to form dense mats. This is interesting, not only because it illustrates forcibly the relation between diminished reproduction by seed and increased bud or shoot reproduction, but because it in part explains the rapidity with which the variety seems to have been developed. The chance of return to the typical form has been reduced to a minimum by growth from buds instead of from seed.

Preliminary Observations on the Movements of the Leaves of Melilotus alba, L. and other Plants.

By W. P. Wilson, D.Sc.,
assisted by
Jesse M. Greenman.

(*WITH PLATES IX, X, XI, XII AND XIII.*)

THE leaves of many plants may, under different conditions, take three distinct positions, each one of which may be assumed to give some advantage to the plant. These three positions may be designated as (1) a *normal daylight position*; (2) a *hot sun position*; and (3) a *night position*. Nearly all the genera of *Leguminosæ* furnish examples which may take any one of these positions when the surroundings are favorable. Many other widely separated families of plants furnish scattered illustrations of the same movements and changes in the position of leaves. *Oxalis*, *Pyrus* (*Americana* *Dc.*), *Sambucus*, *Rhododendron*, *Croton*, *Myriophyllum*, and *Marsilia* give examples sufficiently separated to show that family relationships have nothing to do with it. In some of these the hot sun and night positions are the same. This is illustrated in the genera *Oxalis*, *Myriophyllum* and *Marsilia*.

In the sleep of plants, or night position, the leaves are invariably so disposed or folded together as to lessen the leaf surface displayed in the daytime. Darwin came to the conclusion, supporting it with interesting experiments, that these night positions lessened the surface exposed to radiation and thus protected the plant from cold.

I wish to emphasize the fact that the hot sun positions, over 200 of which I have already examined, occurring so frequently at high altitudes, in strand vegetation, and in tropical and desert areas are special adaptations to prevent a too rapid transpiration.

In these hot sun positions the plant accomplishes the object of lessening the leaf surface in many different ways. It may be by folding the two halves of the leaves together as in *Croton glandulosum*, by rolling the leaves up as in *Rhododendron Catawbiense*, or by folding the leaflets over each other as in *Marsilia*, or by elevating all the leaflets so that their apices point directly at the sun as in *Apios*. In this last genus the leaflets become parallel with the sun's rays and thus make little or no shadow. In these different ways the leaves escape much of the heat caused by the sun's rays, and, consequently, increased transpiration which would be created thereby.

Melilotus alba (along with many other genera of *Leguminosæ*, such as *Robinia*, *Wistaria*, *Amorpha*, *Phaseolus*, *Amphicarpæa*, *Gleditschia*, *Cassia* and others), is extremely sensitive to its surroundings, and very readily puts itself, in accordance with external conditions, into any of the three positions mentioned above. (Pl. XIII, Figs. 1, 2 and 3.)

The day position may always be seen early in the morning. The leaves are spread out in a plane at right angles to the sun's rays. (Pl. XIII, Fig 1.)

The night or sleep position (Pl. XIII, Fig. 2, and Pl. IX, Fig. 1) is a very interesting one in this plant. From the normal day position the leaflets first sink down so as to make an angle of about forty-five degrees with the surface of the earth below. The terminal leaflet rotates itself on its long axis, either to the right or to the left, through an angle of ninety degrees; the lateral leaflets now each rotate on their long axis until their edges are toward the zenith. They then approach the terminal leaflet until their upper surfaces nearly or quite touch it. In this position the terminal leaflet has both its faces nearly covered, and the lateral leaflets present their under surfaces only to the external air. A little over one-third of the normal leaf surface is exposed. The torsion takes place in the pulvini of the minor leaf petioles. This night position is assumed in a different manner by nearly every genus of *Leguminosæ*. Nor do the leaves always sleep in the same manner in a given species. In the plant we are examining, the very young leaves sometimes elevate themselves on the general petiole, instead of sinking down, and then bring the apices of all three leaflets up together to the zenith until they touch each other. If the young leaf happens to be at, or near the growing bud, the leaflets will often rise up and encircle it at night. Darwin[1] has called attention to the fact that the sleep of the young leaves of certain plants resembles the sleep of the adult leaves in other genera. This may indicate relationships of descent not otherwise easily seen.

From the night position, the leaves as daylight approaches gradually change into that of the day, in which the plane of the leaves are generally so placed as to receive the rays of the sun at right angles to their surfaces. Most of the leaves are quite as low below the horizon as in their sleep positions, but their faces are turned broadly to the light.

On a cool day, with atmosphere nearly saturated with moisture, the leaves may retain this relative position to the sun's rays (Pl. IX, Fig. 2). If, however, the air and soil are dry and the sun hot, the leaves quickly take another position; the general petiole becomes slightly elevated and the leaflets rise up above the plane of the horizon. By eight o'clock in the morning we may have the position indicated in Pl. IX, Fig. 3. At nine o'clock the leaves will have still further changed. The leaflets will now be parallel with each other and also with the sun's rays. Pl. XII, Fig. 1 was photographed at nine o'clock in the morning on a hot, dry day. The leaflets have all taken a position parallel with the incident ray, and therefore cast the least possible shadow. In order to get a profile view of the angles made by the leaves with the general direction of the stem the camera was set south thirty degrees west of the plant. The leaves continue to rotate with the sun, keeping themselves parallel with its rays. At twelve o'clock the leaves will point vertically up to the zenith, as exhibited in

[1] Movements of Plants, Eng. ed., 1880, p, 345.

Pl. IX, Fig. 4. In this case the photograph was taken directly from the south. On a hot, dry day all the leaves still follow the course of the sun up to as late as six o'clock, as seen in Pl. X, Fig. 4, photographed from the north at that hour.

The preceding will show what is meant by the hot sun position of leaves. Of the many plants which may be classed with *Melilotus* in possessing this movement, not all are as extremely sensitive, for all do not possess sensitive pulvini, which render such movements easy. Not a few plants move their leaves into a single hot sun position, in which they remain during the heat of the day. Others give their leaves a position which will cause them to receive the least of the sun's rays at the hottest time of the day, and then remain rigid from this time on. (Species of *Chenopodium*, *Smilax*, *Laguncularia* and others.)

It is generally supposed by plant physiologists and those who discuss this question, that these movements are protective in character, and that they shield the chlorophyll from too intense illumination. A few experiments with *Melilotus alba* have been instituted to test this view, the author believing that loss of water is the cause of these motions and not the effect of light on the chlorophyll.

Experiment No. 1 was conducted by taking a given lot of potted plants, dividing them into two sets, giving both sets precisely the same conditions of *light* and *heat*, but watering one liberally, while the other was allowed to become quite dry. A plant from each lot was photographed from the same direction, and at the same time of day. Pl. X, Fig. 1 shows the one with insufficient water, while Pl. X, Fig. 2 shows the one plentifully watered. Although the day was not a hot one, yet the plant in dry soil has its leaves very well pointed toward the sun, while the plant in wet soil has only here and there a leaf, some of the younger ones, turned toward the sun. The results here obtained are given on a very large scale in a gravel pit behind the laboratory. Hundreds of plants are growing both on the high, dry ridges, and also in the much moister excavations below. The plants on the ridges are very active in taking the hot sun position, while at the same time those in the moister locations below place their leaves so as to receive the sun's rays much more nearly at right angles with the plane of the leaves.

Experiment No. 2.—Two vigorously growing plants were placed near together on the lawn. Over one was built a glass case, the other was left standing in the open air. The one in the case was soon in a nearly saturated atmosphere. The light was the same in each case. Pl. XI, Fig. 1 shows the one in open air; Pl. XI, Fig. 3 the one surrounded by glass. The stomata were nearly all closed in the first case, while in the latter most of them were open.

Experiment No. 3.—Three healthy plants were placed near each other on the lawn. The first was allowed to stand free in the open air; over the second was built a double glass case with two inches space between the walls, filled with alum water to absorb the heat rays of the sun; over the third was built a single glass case, which was packed with ice in the interior to keep the temperature down. On an extremely hot morning at nine o'clock all three plants were photographed. The temperature was about 8° C. lower under the alum water and in the iced box than around the plant in the open air. The conditions of light were as nearly as possible the same for all three plants. Pl. XII, Fig. 1 shows the one in open air, photographed, as are all the others, from the south thirty degrees west. The leaves are all pointing rigidly toward the sun. They make in this way the least possible shadow, or, in other words, expose the least possible surface to the sun and receive less of its heat rays. In this way transpiration becomes greatly lessened. The stomata are all closed without exception. Pl. XII, Fig. 2 shows the plant under alum water. The leaves are not nearly so elevated as in the first, many of the old ones being so disposed as to receive all the light they can get, while only the very young ones are well elevated and pointed toward the sun.

In the third one under glass and packed in ice (Pl. XII, Fig. 3) the leaves are somewhat more elevated than in the last, but not to be compared with the one in open air. The temperature was a little higher than the one under alum.

This may account for some of the difference. The stomata were well open both in the plant under alum and in the one packed in ice.

Pl. X, Fig. 3 shows a photograph of a plant taken from the west on a clear evening at six o'clock, after a shower. The lower leaflets have turned on edge, and others dropped down vertically in order to receive the sun's rays at right angles to their surfaces. It is to be compared with Pl. X, Fig. 4, taken on an excessively dry evening at the same hour. In the latter all the leaves are pointing directly west. The photograph was taken from the north.

Experiment No. 4.—Four plants were placed on the lawn and covered with red, blue, opaque or black, and white glass respectively.

The one under blue glass seemed quite as active in the movement of its leaves as the one under white glass. The one under red glass lost very soon nearly all of its directive motion from the sun, and its leaves made a slight advance toward a sleeping position. The sleep position was assumed nearly two hours earlier under the red glass than under the blue or the white. It was also found that plants under red glass put their leaves in a very different sleep position from plants under either blue or white glass. Pl. XIII, Fig. 8 shows a leaf under red glass, and Fig. 2 the normal sleep position for comparison. In the former the leaflets are passed down beyond the vertical, then twisted at the pulvini until their under surfaces are all uppermost. Pl. XII, Fig. 4 shows a complete plant photographed at twelve o'clock at night from red glass. Pl. IX, Fig. 1 was taken from white glass at the same time.

The plant under opaque or blackened glass lost in a short time its power of motion as stimulated by the sun, and soon went into a semi-sleep position and there remained with some few undulations of motion, which, however, grew less and less and soon disappeared.

Pl. XI, Figs. 2 and 4 show photographs from blue and red glass taken on a rainy afternoon at three o'clock. The plant from blue glass with leaves outstretched is trying to get all the light it can, while the one from red glass is putting itself rapidly into its sleep position. The leaves under the arrows have already tucked themselves up in the peculiar manner previously indicated in the sleep of this plant under red glass, shown in Pl. XIII, Fig. 8, and in Pl. XI, Fig. 4.

The red glass must cut off certain rays of the spectrum which serve to determine the ordinary sleep positions. No difference in the night positions could be found under the blue or white glass.

The following conclusions seem obvious from the work done and the mass of material under observation:

(1) That there are great numbers of plants which put their leaves in a special or *hot sun* position.

(2) That these *hot sun* positions have come to exist in order to protect the plants possessing them from a *too rapid transpiration.*

(3) That these *hot sun positions* are not dependent on light alone, but that the heat rays play a very important part in determining them; and also that the water supply of the plant, both in the air as well as in the soil, exercises a direct influence.

(4) That for some reason, not yet well understood, the leaves of *Melilotus alba* take a different position at night under red light from the one ordinarily assumed in the so-called sleep of this plant.

DESCRIPTION OF PLATES.

Illustrating paper by Dr. WILSON and Mr. GREENMAN.

PLATE IX.

Fig. 1. Ordinary sleep or night position of leaves of *Melilotus alba.*

Fig. 2. Day position of the leaves.

Fig. 3. Leaves slightly elevated. First state of the hot sun position.

Fig. 4. Hot sun position at twelve o'clock on an extremely hot and dry day. The leaves are pointed directly at the sun. They make the least possible shadow in this position. The transpiration caused by both *heat* and *light* is reduced to a minimum.

FIG. 1.

FIG. 3.

FIG. 2.

FIG. 4.

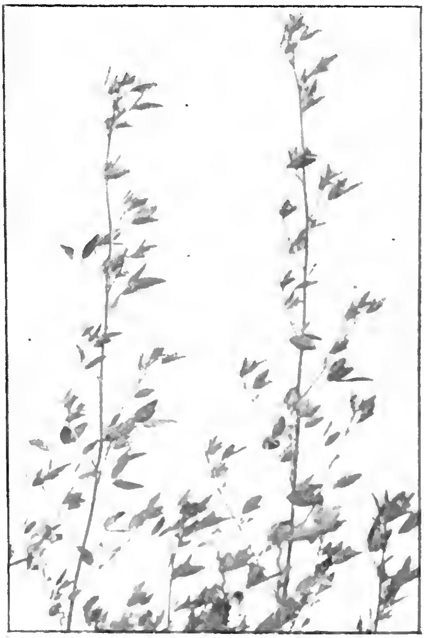
WILSON ON MELILOTUS.

Fig. 1.

Fig. 3.

Fig. 2.

Fig. 4.



Wilson on Melilotus.

Fig. 1.

Fig. 3.

Fig. 2.

Fig. 4.

Wilson on Melilotus.

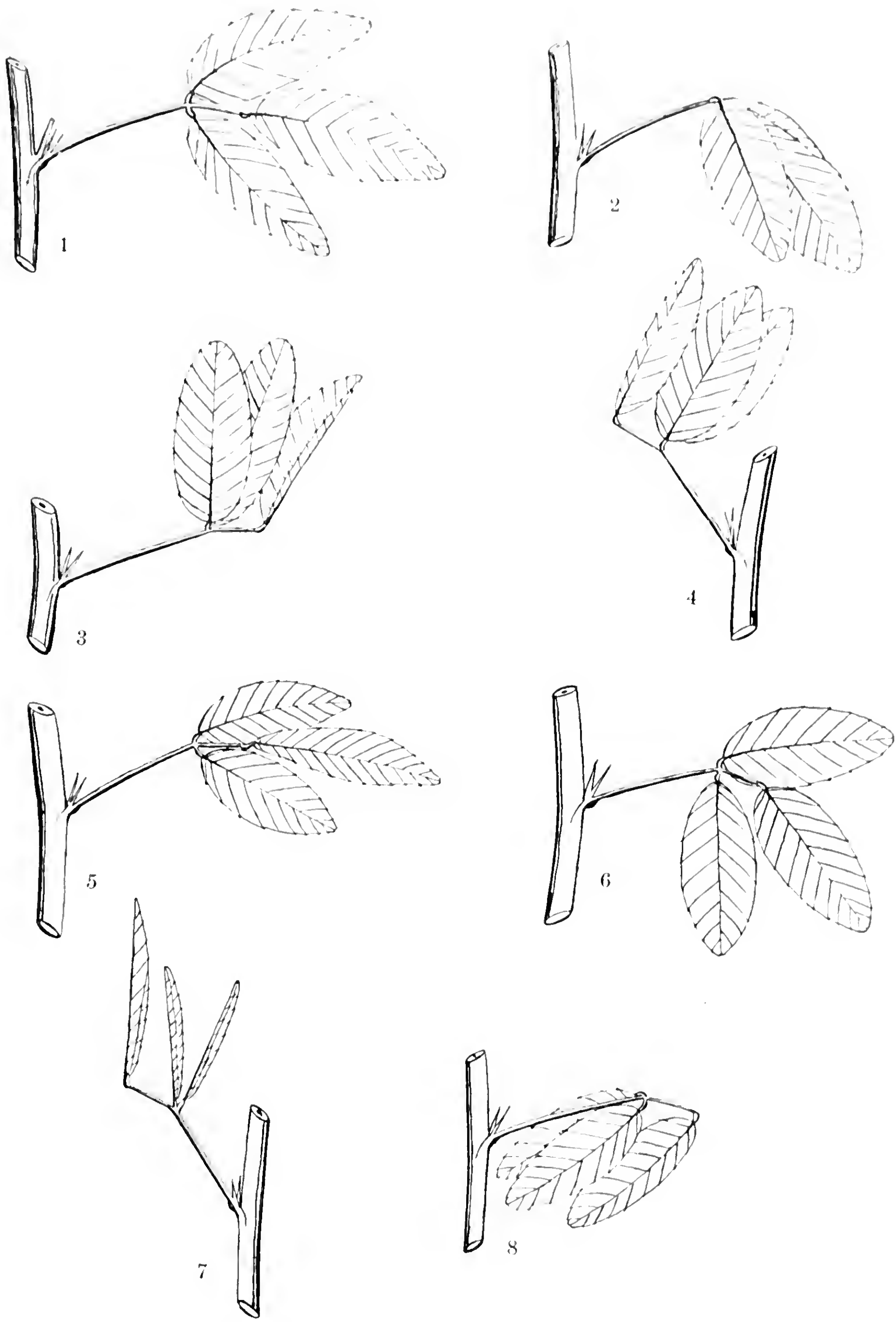
FIG. 1.

FIG. 3.

FIG. 2.

FIG. 4.

WILSON ON MELILOTUS.



WILSON ON MELILOTUS.

PLATE X.

Fig. 1. Plant of *Melilotus alba* deprived of sufficient water. To be compared with

Fig. 2. which has been liberally watered. Both photographed at the same time.

Fig. 3. Plant photographed from the *west* at six o'clock, P.M., on a bright evening after a shower. The leaves have all put themselves in position to take the sun's rays at right angles and take all the light they can get. Compare this with

Fig. 4. Plant photographed at six o'clock, P.M., on a very dry, hot day from the north. Leaves are all pointing directly at the sun. They are parallel with the sun's rays, as in Plate IX, Fig. 4.

PLATE XI.

Fig. 1. Plant in open air in sun. Observe the direction of the leaves, and compare with

Fig. 2. photographed at the same time, but under glass in a saturated atmosphere.

Fig. 3. Plant under blue glass photographed at three o'clock, P.M. Day dark.

Fig. 4. Plant under red glass photographed at the same time as Fig. 3.

PLATE XII.

Fig. 1. Plant in hot air and sun photographed at nine o'clock, A.M. Leaves all pointing toward the sun. Photograph taken from *south twenty degrees west.*

Fig. 2. Plant placed under alum water to absorb heat rays. Temperature about 10° C. less than in the open air and sun. Leaves are more horizontal

Fig. 3. Plant under glass and packed in ice to keep the temperature down. About 8° C. lower than in sun. Young leaves elevated. Older ones less influenced.

Fig. 4. *Melilotus alba* under red glass. Photograph taken at twelve o'clock, midnight. Compare this with Fig. 1 Plate IX, plant under white glass photographed at the same time.

PLATE XIII.

Fig. 1. Ordinary day position of leaves of *Melilotus alba.*

Fig. 2. Sleep, or night position.

Fig. 3. Hot sun position.

Fig. 4. Hot sun position at the same time on the other side of the plant.

Figs. 5, 6 and 7. Different positions assumed to secure light.

Fig. 8. Sleep, or position of leaves under red glass.

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CONTRIBUTIONS

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MAIZE: A BOTANICAL AND ECONOMIC STUDY.

By John W. Harshberger, Ph.D.

Maize: A Botanical and Economic Study.

By John W. Harshberger, Ph.D. (Univ. of Penna.),
Instructor in Botany, University of Pennsylvania.

(*WITH PLATES XIV, XV, XVI AND XVII.*)

CHAPTER I.

Botanical.

FOUR hundred years have passed since Columbus made his celebrated voyages, and carried back to Europe many strange plants and animals from the new world. Maize seems to have been one of the plants which the Great Navigator showed to Queen Isabella on his return to Spain. Many prominent botanists, however, assert that maize is indigenous to the Asiatic Continent and the Eastern Archipelago.

De Candolle, in his "Origin of Cultivated Plants," says: "The certainty as to the origin of maize will come rather from archæological discoveries. If a great number of monuments in all parts of America are studied, if the hieroglyphical inscriptions of some of these are deciphered, and if dates of migrations and economical events are discovered, our hypothesis [Nicaraguan origin] will be justified, modified or rejected." The following is a contribution to that end.

A. Gross Anatomy.

Culms several from the same fibrous root, ascending, branched; internodes alternately furrowed. Plant five to eight feet high.

Foliage ample; *leaves* broad, long, tapering to an acuminate point, horizontal, tip pendulous; *ligule* short, hyaline, ciliate.

FLOWERS monœcious, proterandrous, sometimes synacmic: *Male inflorescence*, a panicle of spikelets, terminal on central stalk, and its side branches,[1] branches pendulous; *male spikelets* two to four to each joint, one or more short-pedicelled, two-flowered, flowers sessile; *glumes* sub-equal, herbaceous, ciliate, sub-acuminate, concave, three- to five-nerved, bicarinate; *flowering glumes* two, hyaline; *palets* two, hyaline, concave; *lodiculæ* two, cuneate, truncated obliquely. *Female inflorescence* axillary, spicate, branched at times, with a number of perfect ears on each branch. The spikes are fasciated into a continuous spongy cob, so that the ripened ear breaks readily at any point into its several joints, each bearing two opposite pairs of kernels; *ears* two to six inches long, three-quarters of an inch broad, with two, four, eight to ten rows of kernels; *spikelets* many, imbricated on a cylindrical rhachis, spikelets paired in alveoli, strongly margined and cupulate, the margin becoming hard and corneous; female spikelets two-flowered, with outer ones neutral; *glumes* membranaceous; *palets* membranaceous, concave, glabrous; *squamulæ* and *stamens* none; *ovary* slightly stalked; *grain* white, hard, corneous, smooth, ovate, pointed, constricted at the base, three-eighths of an inch long; *style* terminal, compressed, pubescent with compound hairs, filiform, point bifid. The grain belongs to the race of soft corns (*Zea amylacea*, Sturtevant).[2]

The relation of *Zea* to nearly allied genera, in the tribe MAYDEÆ, becomes intelligible on examination of the Mexican plant collected by Professor Dugés. The plant may represent the original wild form, or may be the reverted form of an agricultural variety, but the latter supposition seems a highly improbable one. The grains in the Mexican plant are placed in alveoli, the margins of which are hard and corneous. All the genera in the tribe MAYDEÆ have the grains enclosed in a hard, stony case (*Pariana*, *Coix*, *Polytoca*, *Chionache*, *Schlerachne*, *Tripsacum*, *Euchlœna*). *Tripsacum* and *Zea* show

[1] The illustrations in Plates XIV and XV show the side branch in a compacted form the terminal tassel has not developed in the plant represented.

[2] Sturtevant, New York Agric. Exp. Stat. Rep., 1884, 124; 1886, 64.

interesting similarities. The female spikes in maize, in all probability, are fasciated into a continuous cob, and when ripe the ear has a tendency to break into joints or pieces. The spikes in *Tripsacum* are axillary and terminal, separating spontaneously at maturity into joints. The pistillate spikelets, two-flowered, with inner flower fertile, the outer flower abortive, are imbedded in an oblong joint of the thickened rhachis, occupying a boat-shaped recess, which is closed by the cartilaginous outer glume. *Zea* has two spikelets, spikelets two-flowered with inner flower fertile, the outer aborted, placed in a cucullate depression of a fleshy cob. It seems that the fleshy cob has been formed by the union of several distinct spikes; this conclusion is strengthened on comparing *Zea* with *Euchlæna* and *Tripsacum*, for in the two latter genera the joints are trapezoids, and easily disarticulated, with the fruit set in a cartilaginous capsule, forming a false fruit. A study of depauperate ears supports this view. A bifurcation of the tip frequently occurs, when the rhachis is prolonged into two axes. The tissues sometimes separate sufficiently to show the different spikes which compose the fleshy cob. The arrangement of the grains corresponds to the separate spikes of the consolidated cob. These structural and teratological arrangements point to the probable union of several spikes into a thick, fleshy axis, with grains on the circumference, each paired row limited at the side by a long, shallow furrow, a row corresponding to a single spike of *Euchlæna* or *Tripsacum*.

The branch with alternate arrangement of ears (Fig. 9, Plate XV), seems to be the more primitive, for cultivated forms with one ear enormously developed have frequently two or three ears placed in the axils of husks enclosing the larger fertile ear.[1] One ear, in the cultivation of corn for centuries, has enlarged at the expense of the others, furnishing another illustration of the law of compensation in growth.[2]

Professor Dugés found this corn called by the natives "maiz

[1] Cornell Agric. Exp. Stat., Bul. 49, Dec., 1892, p. 333 See Bibliography, end Section A.

[2] St.-Hilaire called it "correlation of growth."

de coyote," at Moro Leon (otherwise Congregacion), about four Mexican leagues north of Lake Cuitzco, on the boundary line between the States of Guanajuato and Michoacan.[1] The Dugés plant, raised at the Cambridge Botanical Garden, is probably the same as that found by Dr. Roezl, in 1869, in the State of Guerrero, and described as a plant with ears very small, in two rows, truly distichous, the grains small and hard.[2]

Wild maize must have ready means of seed dissemination. The cultivated forms would disappear, if man did not sow the kernels, for the grain is too large to be carried by the winds, and the sheathing husks prevent animals from reaching the ripened achenes. The grain is smaller than the ordinary cultivated varieties, but large and wholesome enough to attract wild beasts and birds, and in all probability this is one of the ways in which corn was distributed. The following observation is to the point:[3] "Yesterday, while at work, I saw a flock of chickadees (*Parus atricapillus* L.), one of which I saw had something in its mouth, which upon inspection proved to be a kernel of sweet corn. He was on an apple tree when I first saw him, apparently trying to find a storehouse, but failing flew to a board fence, and running along found a split, where he deposited it." Several birds have taken their names from their liking for corn. An American blackbird, of the family Icteridæ, one of the marsh blackbirds, is fond of Indian-corn, and devours it greedily. P. L. Sclater calls *Pseudoleistes virescens* the South American maize bird, and Wilson designates *Agalæus phœniceus* the maize thief. The Indians may have learned the use of maize from the wild animals, for Professor Otis T. Mason refers to the fact that half-starved Indians robbed the stores of nuts and corn hoarded by the animals.

The original form, in the wild state, was propagated probably by lateral offshoots. All the cultivated forms produce suckers. "The [Mexican] plants began to grow vigorously

[1] Watson, Proc. Amer. Acad. Arts and Sci., XXVI, 158.
[2] Brewer, New York Agric. Soc., 1877–1882.
[3] American Entomologist and Botanist, II, 370.

and to send off numerous offshoots from the base. These suckers grew as rapidly as the main stem, so that the plants, which had been placed fortunately some feet apart, had the appearance of two hills, one of the two having nine and the other twelve stalks ascending from a common base." [1]

The production of suckers on annual plants in the north, was probably a perennial habit in a more southern latitude, so that in the semi-tropics the non-sexual development of suckers was the ordinary method of propagation, the vigor of the stock being rejuvenated by an occasional distribution of seed by birds.

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3. *Ascherson*, Bemerkungen über ästigen Maiskolben. Sitz. d. Prov. Brand., XXI, 133.
4. *Reibisch*, Ueber Maiskolben mehrfach entwickelt. Isis, 1875, 29.

B. Histology.

Maize is easily grown in all its stages, and it serves, therefore, as a type specimen with which other monocotyledons can be compared. A complete histological description is desirable.

Root.—Janczewski, in his classification of angiospermous roots, places the root of *Zea* in his second category defined by the general tissue differentiation: "Sharply marked plerome cylinder and calyptrogen layer. Between the two, at the apex of the *punctum vegetationis*, is an initial group only one layer of cells thick, which splits immediately behind the apex into periblem and dermatogen (*i.e.*, cortex and epidermis)." Most monocotyledons which have been investigated agree in this.[2] A longitudinal section of the root apex shows the following arrangement of tissues. The root

[1] Watson, Proc. Amer. Acad. Arts and Sci., XXVI, 158.

[2] De Bary, Comparative Anatomy, 10, Fig. 3.

cap of loose dead cells is constantly renewed from active layers within, so that the cap can be divided into two portions, the outer dead, the inner active layers. The dermatogen, continuous with the epidermis or piliferous layer of the root above, is covered near the apex by the actively dividing calyptrogen. The periblem occupies an intermediate position between the dermatogen or proto-epidermis and the plerome cylinder inside. The three meristematic layers, dermatogen, periblem and plerome, take part in the construction of the root, while the root cap is added as a fourth protective element at the growing point. The central bundles are formed from the plerome; the calyptra is formed from the calyptrogen.

A cross section of the primary root shows the tissues in a different aspect. Two regions are defined as the central axis cylinder and the encircling parenchymatous tissue. The cylinder's centre is occupied by woody elements with radiating arms reaching the pericycle; the phlöem portions alternating with the xylem wings. The bundle system is a radial one. Large dotted or scalariform ducts are prominent elements, readily identified. Spiral tracheids are found between the large ducts and the smaller external annular tracheids. The sieve portion of the phlöem is obscure, except when the wood elements are reduced to a minimum. The cell walls of the pericycle show scleroid thickenings. The endodermis is distinguished by its position on the circumference of the axis cylinder. The remaining parenchyma is irregular with large intercellular air cavities. The primary root soon disappears, as in monocotyledons generally, and is replaced functionally by the secondary roots, which differ in the arrangement of some of the more important elements.

The layers in the secondary root are arranged as follows (Fig. 1, Plate XVI): The large vessels of the bundle are uniform in size; the annular ducts and spiral tracheids have increased until they occupy a large part of the space between the pericycle and the wide dotted vessels; the phlöem areas are small (Fig. 1, P); the pericycle is formed of irregular elliptical cells with long diameter anticlinal; the endodermis differs somewhat from that of the primary root in having the rear walls of the cells crescentically thickened. The parenchyma is in regular rows outside, but near the epidermis it becomes irregular and consists of loose cells.

The secondary roots arise from the stem, and in their later origin are aerial. They appear at first as nodules, which grow larger until the epidermis is finally ruptured by the emergence of the rounded tip of the root. The root is positively geotropic, and grows downward into the soil. Before entering the soil, however, gum is formed in large quantity on the tip, and is of thick, treacle-like consistency. In the aerial roots of palms, similar gummy matter is formed by a breaking down and enormous swelling of the external cell walls. Cell walls which have undergone this mucilaginous modification take, when placed in water, the consistency of gelatin, and when warmed appear to dissolve, forming thick mucilage. It is apparent by analogy that the secondary roots in *Zea* form a mucilaginous covering by a change in their external cell walls. The formation of these roots is as follows:

Fig. 2, Plate XVI, shows the developing secondary root before the point breaks through the epidermis and hypodermis. Three superimposed hollow cones are found immediately beneath the two outer protective layers, the outer and middle cones being separated by a cushion of parenchyma. The outer cone is composed of actively growing cells with the nucleus and nucleolus plainly visible. It corresponds evidently to the calyptrogen layer of Janczewski. The inner cones correspond to the periblem and plerome cylinders with the outer layer of the periblem as the dermatogen or protoepidermis. The cells of the plerome, destined to form the central vascular system, are much longer than broad, the long axis anticlinal.

Stem.—Comparison of an upper and a lower internode of the stem shows the following differences:[1] The upper internodes have a larger number of small peripheral bundles than the lower, and the epidermal layers have comparatively

[1] Strasburger, Botanische Prakticum, 109.

thicker cell walls. The bundles of the stem run parallel along the internodes without intercrossing. A typical central bundle is chosen in describing the closed collateral bundle of maize, because at the surface the bundle elements are reduced to a minimum, and because here a union frequently occurs between two or three bundles. The surrounding layers of the bundle consist of strongly thickened sclerenchyma, the external and internal cells having thicker walls than those on the lateral faces. A large intercellular space surrounded by comparatively thin-walled cells attracts the attention. An annular tracheid outside, and a spiral tracheid between two large reticulated vessels are elements forming the wood, xylem, hadrom or vascular portion of the bundle. External to it we have the bast, phlöem, leptom or sieve portion of the bundle. The phlöem portion colors a bright violet with chlor-iodide of zinc. The first elements of importance are sieve tubes with "companion" nourishing cells. The proto-phlöem (*Cribral primanen*), or actively growing leptom, is found in this area.

The bundles at the periphery of the stem are crowded together, so that the large intercellular space disappears; the phlöem portion is also reduced. The bundle sheath, which alone remains to any extent, is continuous with a layer of thick-walled cells, called by Strasburger the hypoderm. The hypoderm and bundle sheath function as protective and strengthening tissues, and are elements in the mechanical system of the plant.[1] The separate cells of the hypoderm have been called stereids, and the whole tissue taken together has been called a stereome.

The epidermal cells in a radial longitudinal section are longer than broad. The ordinary parenchyma cells are round, or nearly so. The cells of the bundle sheath are long, with contracted lumen. The intercellular passage follows the length of the bundle without a break. The annular tracheid at the inner border of the space is one of the most characteristic elements of the stem. The large dotted ducts to the right and left are shown in the section figured. Between the two

[1] Pfitzer, Pringsheim's Jahrb., Bd. VIII.

large vessels a spiral tracheid is occasionally found. Cells with reticulated markings occupy the area between the larger dotted vessels. The phlöem appears as a bright area with sieve tubes and companion cells, while the quantity of bast increases or diminishes in different areas, but is found in largest development in the interior of the stem.

Leaf.—The leaf is divided into sheath and blade, which are separated anatomically as well as morphologically from each other by the ligule. A partial section across the base of the sheath is shown in Fig. 3, Plate XVI. Examining the upper inner surface first, we find the stereome immediately below the epidermis. The stereome breaks up into discontinuous patches near the overlapped margins of the sheath. The outer lower surface is essentially different. The superficial bundles are covered by an epidermis, the cells of which are strongly thickened on the outer wall for protection against extremes of heat or cold. Stiff, thick-walled, unicellular hairs, associated with the long, narrow guard cells of the stomata, no doubt serve the same purpose. The larger, deeper-lying bundles are normal. The smaller, superficial ones have a less number of cells, noticeably bast cells. The smaller bundles are at places near the margin surrounded by a circle of active parenchyma cells, which contain chlorophyll, and called by De Bary and Sachs the starch sheath, or starch ring.[1]

The upper inner midrib area of the blade at the base shows five or six layers of sclerotic cells (stereome or water tissue) continuous for some distance on each side of the middle line; near the margin, however, the strengthening layers are distributed in discontinuous patches with reference to large cells between the so-called bulliform cells. Near the tip of the leaf, the fibro-vascular bundles alone strengthen the leaf; the stereome disappears. The swelling of the bulliform cells (Fig. 4, Plate XVI, B) by imbibition of water causes the blade to open out in those leaves which are folded in the bud. They are found only on the upper side of the blade on each side of the

[1] De Bary, Comparative Anatomy, 416; Sachs, Botan. Zeitg., 1859, 177, Taf. VIII, IX: Pringsheim's Jahrb., III, 194.

midrib. According to Duval Jouvé,[1] these cells have thin walls and watery interior, and are found on the upper surface between the marginal nerves of the leaf. In grasses which are devoid of such fan-shaped cells, the blade always remains folded up, rush-like, as in *Stipa*, *Festuca*, *Nardus*. In steppe grasses, the blades roll up whenever these cells lose their turgescence by rapid evaporation, and they open again when the water has been restored. The lower side of the leaf has especial protective arrangements against transpiration, in strong cuticle and hypoderm.[2]

The lower surface of the blade shows a larger number of small bundles than the lower surface of the sheath. Either the fibro-vascular bundles enter the blade separately, or a number at first unite to form a strong midrib; later the single bundles separate one at a time and pass toward the edge of the leaf, giving firmness to the broad lamina. A ring of parenchyma surrounds the small bundles (Fig. 4, Plate XVI).

The stomata are placed on surface view between two long cells called accessory cells, which were formed when the stomata were differentiated. The process of stoma formation in Indian corn is essentially as follows. A vertical septum is made across one of the long epidermal cells, the small cell cut off being called the stoma mother cell. The two accessory cells are now cut off from the mother cell on either side, and the mother cell divides in two, forming the guard cells. Finally, the lamellæ of the wall separating the guard cells split and the opening is formed.[3] According to von Mohl,[4] the stomata on the uninjured leaf of *Zea mays* widen the slit to $\frac{1}{178}$ millimeter.

Mention must be made of gaps in the epidermis of the leaf. Cracks occur regularly at the apex of the leaf, from which drops of water are expressed. The cracks arise by irregular tearing of the original cowl-like apex of the leaf, when this spreads out flat as it unfolds.

[1] Duval Jouvé, Histoire des Feuilles des Graminées, Ann. d. Sc. Nat., VI sér., tom. 1, 1875, 294, tab. 4.

[2] Hackel, True Grasses.

[3] Campbell, D. H., American Naturalist, XV, 1881, 764.

[4] Mohl, H. von, Botan Zeitg., 1856, 697.

Flower.—The style is long, reaching beyond the tip of the enclosing husks. It is double morphologically. Two fibro-vascular bundles, greatly reduced, run its length. The style of *Zea* agrees with the styles of grasses in general. The entire surface of the filamentous style is covered with compound hairs, which catch and hold the smooth pollen grains.

The round, smooth pollen grains (Fig. 4, Plate XV) are pro duced in great abundance, as many as 2500 being formed in a single anther. "Each panicle of male flowers [the tassel] was found by careful estimates to contain about 7200 stamens, so that the number of pollen grains produced by each plant is 18,000,000. Allowing two ears of 1000 kernels to each plant, there are still 9000 pollen grains for every ovule to be fertilized."[1]

The epidermal layer of the grain is simple, with long diameter anticlinal. The internal cells contain starch and protein granules.[2] The starch granules closely aggregated are polygonal, with extremely delicate circular and radial markings. In size and general appearance, they are intermediate between the starches of wheat and rice. They are from .0002 to .0012 of an inch in diameter.[3]

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Synonyms.

Generic:

1735. Thalysia, Linnæus' Syst. Nat. Fund. Bot., 244; Hort. Cliff., 437.
1729. Mayz, Micheli, Nov. pl. gen., 36.
1763. Maïs, Adanson, Fam., II, 39.
Mirbel.
Mays, Tournefort.
1808. Mays zea, De Candolle, Icones Plant. Gal. rar., 3, 98.

Specific:

Mays Americana, Baumgarten.
vulgaris, Seringe.
zea, Gaertner.

Zea alba, Mill.
altissima, Gmel., Hort., Carlsr.
Americana, Mill.
canina, Sereno Watson, 1890.
Caragua, Molin.
hirta, Bonafous.
minor, Gmel.
macrosperma, Klotsch., Bot. Zeit., 1851.
præcox, Persoon.
rostrata, Bonafous, Ann. de Lyon, V, 97.

The word *Zea* is probably derived from the Greek words ζάω "I live," or ζειά (ζεά), a sort of grain (spelt) applied as the term for maize when ζεά was left unused by the creation of the genus *Triticum*. Scholars think that the Greeks first called spelt ὄλυρα, afterward ζειά, names which we find in Herodotus (Hdt. 2, 36) and Homer (Il. 5, 196; 8, 564). Dioscorides (Diosc. 2, 113) distinguishes two sorts of ζειά, which apparently answer to *Triticum spelta* and *T. monococcum*.

Maize is an Arawak word of South American origin (see Philology), from mahiz, marisi, mariky, etc. The name is derived from the Haytian word mahiz, which Columbus adopted when in Hayti.

Indian Corn.—Corn comprehends all the kinds of grain used for the food of men or of horses; in Scotland it is generally restricted to oats. In the United States it is applied to maize. Those who first landed in America found a new cereal used by the aborigines, and they naturally extended the word corn to this grain also, specifically limiting its use by the prefix "Indian." In the United States, Indian corn is called simply corn. This specific application has been confirmed by a judicial decision in Pennsylvania, in which it was ruled by the court that the word corn is a sufficient description of Indian corn.

NAMES FOR MAIZE IN VARIOUS COUNTRIES.

Abyssinia: Mashela bahry, *i. e.*, millet from the sea.

Africa: Maheende (Central), mahindi, masé (Northern). Probably imitations of the word maize.

Belgium: Mays, Turkisch koorn.

Brazil (Portuguese): Zabemo, milho de Guine, milho grande, maiz, milho da India.

Burmah: Pyoung-boo.

Ceylon: Muwa.

China: Yii-shu-shu, jade sorgho, yuh-kau-ling.

Egypt: Doura shammy, dourah de Syrie.

Fiji: Sila-ni-papalegi.

Formosa: Fanmeh (foreign corn).

France: Le maïs, blé de Turquie, blé d'Inde, blé de Rome (Vosges), blé de Barbarie (Provence), blé d'Espagne (Pyrenees), blé de Guine.

Germany: Mais, maiz, Turkischer korn, Turkischer weizen.

Great Britain: Maize, Indian corn.

Greece: Arabosite (Arabian corn).

Holland: Tursch korn, mays.

India: Mokka, bhoot, muk-jowaree-boota.

Italy: Grano Turco, grano d'India, grano Siciliano.

Japan: Nan bamthbi (foreign corn), sjo-kuso, too-kibbi.

Malays: Jagang (indigenous).

Moldavia: Kuku-rusa.

Persia: Ghendum.

Portugal: Milho d'India, maiz, milho grande.

Russia: Tureskorichljeb.

Spain: Maiz, trigo de Turkina, zara, trigo de Indias.

Sweden: Turkish hvede, korn.

Turkey: Misrbogdag (Egyptian wheat).

United States: Maize, Indian corn, corn.

CHAPTER II.

Origin.

A. Meteorological Proofs.

THE conditions most favorable to the development of the maize plant are long summers with sunny skies, hot days and nights, and sufficient rain to supply the demands of the rapidly-growing crop. The following table gives an idea of the best temperature for growth. With a temperature of.

45°–50°	the	yield was	40.8	per cent.	of	total crop.
45°–55°	"	"	75.9	"	"	"
45°–60°	"	"	87.3	"	"	"

These figures refer to the year 1880.[1] The range of temperature for the best development of the crop seems to be between 45° F. (7° C.) and 65° F. (18° C.), calculated in terms of mean annual temperature, but the largest returns resulted with a temperature in the month of July corresponding to from 75° to 80° F.; 961,123,938 bushels of the 1,754,861,535 bushels being the return in those regions having the July temperature between 75° F. (24° C.) and 80° F. (26.7° C.). The largest return was obtained in those localities where the rainfall amounted to from thirty to fifty inches.

30 to 45 inches	yielded	63.4	per cent.	of	total crop.
30 to 50 "	"	86.8	"	"	"

The largest absolute yield corresponded to a rainfall in the spring and summer months of twenty to twenty-five inches. The return was 1,143,239,093 bushels of the total crop, 1,754,861,535 bushels. Frost kills the plant in all its stages, and the crop does not flourish where the nights are cool, no

[1] Census Report U. S., Agricultural Productions, 1880.

matter how favorable the other conditions.[1] With the varieties grown in the United States, in ordinary culture, an elevation of over 2000 feet shows the yield of maize to be very small indeed.[2]

Elevation and Yield.

500 to 1000 feet,	54	per cent.	total	yield.
500 to 1500 "	82	"	"	"
Above 1500 "	4.4	"	"	"

This was not the case, however, with maize grown in Mexico and Peru. Humboldt[3] mentions that "vast maize fields are to be found on the plateau of Mexico at a height of 8680 feet, and in Peru, on the road between Lima and Pasco, maize is cultivated as high as 12,000 feet (3824 m.)." Simmonds[4] states that it is raised in tropical countries at a height of 9000 feet and more.

Professor Dugés sent, in 1888, to the Cambridge Botanical Garden, Boston, several maize plants, which he collected at Moro Leon, otherwise Congregacion, near Uriangato, four Mexican leagues north of Lake Cuitzco, and, therefore, near the boundary line between the States of Guanajuato and Michoacan. Grains from the Mexican plants sowed in 1892 in Philadelphia, in the middle of May, perished for some reason, but one developed into a specimen about five feet high, which showed great hardiness, the growing period extending to the fourteenth of November, when the stalk was cut. The plant stood well the frosty days, and a snowstorm which came before it was cut did little harm. The exceptionally dry autumn suited the plant well, which throve better in the

[1] Darwin, Variation of Animals and Plants under Domestication, I, 322.

[2] The absence of large areas of tillable land in the United States at the elevation of 2000 feet explains this distribution of crops in altitude. for Dr. William P. Wilson informs me that some of the largest and most luxuriant crops of corn he ever saw were raised on the mountains of North Carolina at an elevation of over 4000 feet. This exception to the above statement enforces the view hereafter expressed as to the elevation at which the wild corn grew. Broadly speaking, high vertical thermometric zones correspond to high latitudes, low vertical zones to low latitudes; the elevation (4000 feet) in North Carolina, therefore, represents a much higher altitude in the tropics.

[3] Meyen, Geography of Plants, Ray Soc., 1846, 304.

[4] Simmonds, Tropical Agriculture, 1877.

dry weather than the ordinary varieties, which were harvested a month before. The so-called wild corn possessed greater constitutional vigor than the ordinary cultivated forms.

The tables which follow, from the records of the United States Signal Office in Philadelphia, may prove of value in this connection. The first table shows the rainfall for the month of September, 1892:

RAINFALL, SEPTEMBER, 1892, PHILADELPHIA. (INCHES.)

Less than .01	.01 to .10	.11 to .25	.26 to .50	.51 to 1	1	Days.
5	2	1	2	1	0	11

September and October were very dry. The thermometer stood for the thirty days of September above 59° F., a temperature favorable for the plant's growth, but on only one day did the rainfall exceed one-half inch. October showed no days with the temperature below 32°. A comparison with the October rainfall of the previous twelve years showed that this was the dryest October in that whole period of years; 0.30 inch of rain fell. The thermometer did not vary so greatly; the mean of the whole month was 56.4° F.

November was also dry until the fifteenth, when two inches of rain fell. The greatest precipitation during the first fourteen days occurred on the ninth and tenth days, when .52 and .86 inch fell respectively. These figures show the power that the possible wild species had of thriving well with little rain, and are valuable as showing the conditions favorable to the growth of the plant in its Mexican home. Data collected by the Mexican Observatory from numerous stations in central Mexico are compared with the Philadelphia temperature and rainfall, as showing the localities in Mexico meteorologically suited to the wild plant's growth.

The following table, compiled from the *Boletin Mensual*,[1]

[1] Boletin Mensual Observatorio Meteorológico-Magnético Central de México, Resúmen del Año, 1889, 37.

gives the altitudes of the places, and the mean temperature and mean rainfall for the months of April, May, June, July, August, September and October, 1889:

	Altitude.	Temperature. Mean.		Rainfall, Total.	
Aguas Calientes .	5590 ft.	2.1° C.	70° F.	72.1 mm.	2.2 in.
Guadalajara . . .	4700 "	21.2° "	70° "	104.3 "	3.1 "
Guanajuato	6180 "	18.1° "	63° "	91.2 "	2.7 "
Huezutla	1128 "	25.4° "	78° "	258.6 "	7.7 "
Leon	5400 "	21.4° "	70° "	104.7 "	3.1 "
Mazatlan	20 "	28° "	83° "	96.9 "	2.9 "
Saltillo	4900 "	19.9° "	68° "	51.3 "	1.5 "
San Luis Potosi .	5670 "	19.5° "	67° "	35.3 "	1 "
Puebla	6520 "	17.6° "	64° "	110.3 "	3.3 "
Zacatecas	7488 "	21.2° "	70° "	61.1 "	1.8 "

The temperature of all the places is favorable to the growth of the wild cereal, but the rainfall in Aguas Calientes, Saltillo, San Luis Potosi and Zacatecas is so small that these places are discarded, as being outside of the limit of the possible original home of the wild form. Mazatlan, on the Pacific coast, is also omitted, because it is hardly probable that corn was a sea-side plant. The other stations answer the requirements better. On consulting a map of Mexico, it is seen that Guadalajara, Guanajuato, Huezutla, Leon and Puebla lie below the twenty-second degree of north latitude, at elevations ranging from 1128 feet, that of Huezutla, to 6520 feet, that of Puebla. From other considerations (*ante*), it is likely that maize was a highland plant; Huezutla is therefore discarded, as below the limits in altitude. The other places lie above a level of 4500 feet, and in all likelihood the original form of corn grew at this altitude and higher. The area is narrowed, therefore, to the region near Guadalajara, Guanajuato, Leon and Puebla, and a glance at a map will show that these localities are situated along the backbone of the continent, below the twenty-second degree of north latitude. A curious coincidence in places must be mentioned. Leon, 5400 feet above the level of the sea, is identical with the locality which Professor Dugés explored. From the meteorological facts we conclnde:

(1) That maize was a highland plant; (2) that the original home was south of the twenty-second degree of north latitude; (3) that the Dugés' plant in Philadelphia still preserved the habit of withstanding dry, rainless weather, which the Mexican charts show is the summer condition at Leon, its native home.

B. Botanical Proofs.

It is a principle of geographical botany that the occurrence of two or more species or genera of close relationship, in any region, indicates the probable origin of those forms within that area. This factor was of little importance to systematists before the days of Darwin and Wallace, but the studies of these two naturalists have served to throw light upon many heretofore obscure problems.

There is tendency to vary, and variation proceeds along definite lines; in the mean time, certain forms disappear from the evolutionary series, until it is broken into groups representing new species and new genera of divergent character and form.

A clear relationship, in many particulars exists between *Zea*, *Tripsacum* and *Euchlœna*; and it is probable, therefore, that Indian corn and these two latter plants originated from a common remote ancestor, which grew in Mexico. Maize has diverged most widely from the common type, in having the separate spikes fasciated into a spongy cob.

The discovery by Professor Dugés of the so-called wild form in Mexico adds weight to the argument in favor of a Mexican origin for the plant. The branching habit, the reproduction of the plant by suckers, the small size of the grain, clearly indicate a very primitive condition of the plant. With reference to the offshoots, it is necessary for perennial growth of a plant so sensitive as maize to frost, to live in a tropical climate, where the suckers can be produced with the greatest advantage to the plant.

Otis T. Mason believes that the original habitat of the maize is to be found in regions where the grains remain unharmed out of doors over the winter months; for the grain decays if left out in the fields in the United States exposed to the destructive effects of the cold and ice. He believes that a semi-arid region answers the conditions most satisfactorily. The anatomy of the leaf points to the same conclusion, for the lower epidermis is thickened to protect the leaf and prevent too rapid transpiration, when the leaf is rolled up by the loss of water in the bulliform cells.

The Maya civilization was not a growth of chance, but was dependent for its origin on the surrounding circumstances, propitious to such a development; the physical and biological features of the country influenced the settlement. The plateau of Mexico has a favorable climate and naturally yields a variety of products. On it grow the agave from the bud of which a drink is brewed, cacao which furnishes the beverage chocolate, the potato, the tobacco plant, the sweet sop (*Anona muricata*), papaw (*Carica Papaya*), nopal (*Opuntia cochinellifera*) on which the cochineal insect feeds, guava and caoutchouc (*Hevea brasiliensis*). The plants mentioned are all natives of the warmer parts of North America, and it is likely that maize also occurred in the same region in the wild state, and was one of the first plants of economic importance to be cultivated. The Mayas depended chiefly upon maize and honey for their food, and there is hardly a doubt that the natives were attracted to the warm plateau of Mexico, where the country was so inviting and rich in natural vegetal products. These facts point to the Mexican origin of maize.

C. *Archæological Proofs.*

The accounts are numerous as to the discovery of Indian corn in places of undoubted pre-Columbian antiquity, but they are general, and for the most part unsatisfactory. When archæological excavations have been made, no particular attention has been paid to the remains of maize, and the remarks as to the discovery of the cereal in ancient mounds, barrows and ruins have been, therefore, mostly incidental. The attempt will be made in this section to sift carefully the evidence which archæology affords as to the cultivation of maize in prehistoric times. For convenience, North America will be surveyed first.

The mound-builders were described ten years ago as the oldest inhabitants of the northern portions of the North American continent. The discussion relative to the antiquity of this race of men will be left to a following section; but it is well to notice, in passing, that they are now considered to have lived comparatively recently.

By far the most celebrated unearthments were made near Madisonville, Ohio. The terrain, in which the discoveries were made, lies in the valley of the Little Miami, southeast of Madisonville, where the space covered by the principal mound was from four to five acres. Virchow[1] says; "Jedenfalls hält man es für präcolumbisch." He describes the surroundings, that over the grave mound stood trees more than 300 years old, particularly an oak, six feet two inches in circumference.[2] Diggings revealed 185 human skeletons, twelve pipes, three of catlinite from Minnesota, stone rubbers, axes, lance heads, needles of perforated teeth, two small cylinders of rolled copper, two feet long, two plates of copper, and near by ash-pits filled with ashes, and sand mixed with pipes, bones, mussels, stone implements, the tooth of a mastodon, bones of the wild ruminants (buffalo, elk, deer).[3] At one place was found a kind of sacrificial altar, where ashes were mixed with numerous animal bones, deer, elk, opossum, turkey, weasel, woodchuck and bear, evidently sacrificed to the all-powerful Manito.

[1] Virchow, Zeitschrift für Ethnologie, 1879, 446.

[2] Cincinnati Daily Enquirer, 1879, April 24; Cincinnati Commercial, 1879, August 31; Short. North Americans of Antiquity.

[3] Notice the buffalo bones, as they throw light upon the antiquity of the Madisonville mounds and surrounding structures in Ohio. Cf. Shaler, Nature and Man in America 183.

Maize was found in quantities.[1] The account published in the Journal of the Cincinnati Society of Natural History is worth quoting: "On Tuesday, August 26, one of the most interesting discoveries in this cemetery was made. In excavating an ash-pit a large deposit of several bushels of carbonized maize was found." Leaf mold, gravel and clay covered the hole to the depth of thirty-nine inches, and contained animal remains, implements of flint, stone and bone, and an unfinished pipe.

	------ 3 ft. 7 in. ------		------- 3 ft. -------	
	Leaf Mold 24 in.		Leaf Mold, 24 in.	
			Gravel and Clay. 15 in.	
A.	Ashes with Animal Remains, Fragments of Pottery, Shells, etc.	-6 in.- Clay.	Ashes, Animal Remains, Shells, Sherds, 10 in.	B.
			Bark Matting, 4 in.	
			Shelled Corn.	
			Ear Corn.	
			Boulders.	

The second clearly defined stratum, in pit B, contained deer, elk, raccoon, opossum, mink, woodchuck, beaver and turkey bones, shells of Unio mixed with ashes, and potsherds, to the depth of ten inches. The third layer was made up of coarse matting, twigs, corn-stalks and bark, completely carbonized. The fourth contained shelled corn, probably three or four bushels, and immediately below ear corn, completely carbonized. The maize was turned over to Dr. Wittmack for study. He describes[2] the ears as eight-rowed (in four double rows).

[1] Verhandl. Gesellsch. Anthr. Ethn. Urg., 1881, 226; Wittmack, Zeitschrift für Ethnologie, XII, 1880, 85; Journal Scientific Society, Madisonville, Ohio: Cincinnati Society Nat. Hist., III, 66.

[2] Wittmack, Verhandl. Gesellsch. Anthr. Ethn. Urg., 1881, 226. Monatschrift f. Gartenbaues, 1879, 541.

The garden plots, so-called, of the mound-builders described in earlier publications are of uncertain value.[1] Locke[2] states that from the Cincinnati mounds was obtained "carbonized maize, with even the cob, leaves and stalk of the plant." In the Museum of Archæology, University of Pennsylvania, is some charred corn found in a mound in Portage County, Ohio, together with celts, gorget, arrow-points, clay pipe, copper beads and charcoal. Mr. Stewart Culin informs me that the specimens are authentic and undoubtedly pre-Columbian. A quantity of Indian corn and fragments of the cob with the grain still in place, and all very much charred, was sent to Lucien Carr by William P. Bales and Rev. S. B. Campbell, of Rose Hill, Va. They were found by drifting into the face of the southern wall of the central shaft of a mound about fifteen inches, and were on a level with the bottom of that shaft about eleven feet from the surface.[3] Cyrus Thomas[4] describes the Etowah mound, on the Etowah River, a few miles south of Cartersville, Bartow County, Ga.: "When the first white man visited it, a stately forest covered the works, as well as the area.[5] Although the Cherokees made use of it as a fort against the Creeks, they always denied having any knowledge of the race by whom the mound was constructed."[6] In the refuse layer, west and east of the three large mounds, four feet below the present surface, were found some partially burned corn-cobs. They were in a little heap surrounded by charcoal. Proudfit[7] states that in 1879 Mr. Stillman made an

[1] Peet, S. D., American Antiquarian, VII, 15.

[2] Locke, Trans. Amer. Assoc. Geol., I, 231; Trans. Chicago Acad. Sci., I, 242.

[3] Carr, Peabody Museum, II, 80.

[4] Thomas, Cyrus, Amer. Anthropol., IV, 109, 237.

[5] Jones, C. C., Antiquity Southern Indians, 139; First description, Amer. Journ. Arts and Sci. I, Ser. I, 322 (1814).

[6] The studies of Dr. Seler are very significant in connection with the mounds of Georgia and the Ohio valley. He analyzed with care the mode of wearing the head-dress, the clothing and weapons represented on the copper work of the Etowah mound-builders in Georgia, and compared them with the figures on the shells from the Ohio mounds. He concludes from his careful study that the Etowah builders and the Ohio artists were in all probability related, and that possibly the mound-builders and copper-working tribes were destroyed or driven to the sea-coast by the invasions of tribes [Iroquois and Algonquins] from the north and west, at a period not very remote from the discovery of the continent. Seler, Globus, Bd. LXII, No II; Science, XX, 260. See page 107.

[7] American Antiquarian, III, 278.

interesting discovery. Mr. Stillman's attention was attracted by ashes on the face of an exposure of a cut made for the passage of the Mynster Springs road, one and a half miles north of Council Bluffs, Mo. In company with Mr. Jacquemin and Mr. Burke, he opened the face of the bluff, and found what might be called a kitchen heap. The opening extended into the hill four feet, and was five feet below the surface. They found a fragment of an elk's antler, a shoulder-blade fashioned into a rude agricultural implement, fragments of bone, a pipe, a piece of deer's antler, flint scrapers, fragments of pottery, a charred corn-cob, several large mussel shells, fish bones, vertebral joints, and a stone paint-pot or mortar, of rough quartzite.

At the advent of the Europeans, the Indians were found cultivating the maize. That they practiced the first principles of agriculture before that is shown by the remains of agricultural implements of primitive form. When the whites came, they gave up their clumsy instruments and adopted the better and more lasting European tools. In a burial mound near Illinoistown, opposite St. Louis, was discovered a stone hoe seven and a half inches long, nearly six inches wide, and about half an inch thick. The fastening was facilitated by two notches. A similar but smaller hoe was found in a garden in the city of Belleville.[1] McAdams[2] says that "the majority of these ancient implements of husbandry were made after definite patterns, each kind to be used for special purposes, being similar to six of the deeply notched hoes." They tilled the ground with hoes made of clam shells.[3]

In the southwestern United States, numerous discoveries have been made of corn in the deserted cliff-dwellings, pueblos and mounds. Dr. Edward Palmer[4] found, in the summer of 1869, in a mound in the neighborhood of St. George, Utah, charred ears of maize, wood ashes and pieces of maize-cob mixed together. The cañon of the Rio Mancos, in south-

[1] Smithsonian Report, 1863. 379; 1868. 401.

[2] McAdams, Proc. Amer. Assoc. Adv. Sci., 29, 718.

[3] Mass. Hist. Soc. Coll., VII, 193. Wood, New England Prospects, 106; Bureau of Ethnology, II Report, 207.

[4] Palmer, Monatschrift f. Gartenbaues, 1874, 163

western Colorado, contains numerous ruins of the cliff-dwellers.[1] "Above the cliff village was found a crevice evidently used as a kitchen and storehouse, as is shown by the beans and corn, which were found in a good state of preservation." Members of the Peabody Museum,[2] in an exploration, found a few cobs in a cliff-house on the Mancos River, which corresponded with the "Conejos" maize in that they were five inches long, with kernels small and flinty. Dr. Hayden,[3] in exploring the ruins in southwestern Colorado, states in his account that "in some of the rooms [of the ruins, which he examined] were found human bones, bones of sheep, corn-cobs, raw hides and all colors and variety of pottery ware."[4] Birdsall[5] describes the discovery of maize in the cliff-dwellings of the Mesa Verde, in southwestern Colorado and northern New Mexico. Stalks, husks, tassels, silk, cob and kernels of corn were found. "That some of this material is as old as the building is proved by the fact that the stalks were used in the construction of the floors, being actually imbedded in the adobe; cobs being also used to chink the walls with, an impression of the cob in the now hard adobe being found on detaching one from its bed." The corn was a small dent. The cob was about three inches long. Bandelier[6] made some very interesting discoveries on the side of the Arroyo de Pecos. Human bones, walls of ancient structures, and a grave were found on the bluff much above a layer of white ashes, charcoal, corn-cobs and corrugated pottery, in a continuous seam 327 feet (100 m.) from north to south. "Consequently the walls and graves must have been built over the remains of a people which appears to have made indented and corrugated pottery [and used corn, as the remains show], and consequently the latter must be older, in time, than the former." It does not appear that the sedentary Indians of New Mexico made anything within recent times except

[1] Gannett, Henry, Pop. Sci. Month., XVI, 671.
[2] Peabody Museum, II, 552, note.
[3] Hayden, Pop. Sci. Month., XII, 21.
[4] See page 101.
[5] Birdsall, American Antiquarian, XIV, 135.
[6] Bandelier, Archeol. Inst. Amer., Rep. on Ruins of Pueblos of Pecos, 1881.

painted pottery. Caspar Castano de la Sosa,[1] when he made his trip, in 1590, into New Mexico, mentioned that they used painted pottery, red-figured and black. The indented ware is almost identical with that found in the Rio Mancos and from southwestern Utah, and it seems to be the oldest and most primitive form. The cliff-dwellings of the Mancos are, therefore, comparatively very old. The cob found at Pecos, in the ashes, or rather cut out of the bluff, is charred and small. That these remains were not left by the later Indians is proved by the fact that the Navajos and Apaches are terribly superstitious concerning the cliff-dwellings, and can never be persuaded to go near one, nor, indeed, have they ever been known to enter one.[2] The dwellings have been deserted a long time, how long it is hard to establish, probably 500 years or more, as the Navajo Indians relate. They are the farthest north, and, therefore, the oldest, for as we go southward we find indications of more and more recent habitation,[3] until we reach the "Land of the Living Cliff-Dwellers,"[4] lying between the Mexican States of Chihuahua and Sonora, in the Sierra Madre, along the course of the Bacochic. "The timid Tarahumari, a savage race, live mostly on the cliffs, or in caves, and are worshippers of the sun, and while they plant a little corn without cultivation on the steep hillsides, are not otherwise tillers of the soil, but sustain themselves by the chase."

The Nahuas had reached a comparatively high plane, as compared with the more savage tribes about them. They were a warrior race, built houses of quite skillful construction, and were agriculturists. They worshipped various deities, Quetzalcoatl occupied the chief place, but minor gods and goddesses were also objects of adoration. The goddess Centeotl, corresponding with the Ceres of the Romans presided over horticulture, the fields and harvests. Her favor was invoked both at the sowing and at the gathering of the grain, and elaborate ceremonies were devised at these seasons

[1] Memoria del Descubrimiento, 238; Holmes, Geographical Survey, III, 404, Pl. 44.
[2] Monatschrift f. Gartenbaues Kgl. Preus., 1874, 163.
[3] Barber, E. A., American Naturalist, II, 591.
[4] Schwatka, Century Magazine, XLIV, 271.

of religious observance to gain her approval. She was the first woman, the ideal, the matchless[1] Sahagun[2] pictures her with a crown upon her head, and in the right hand a vessel, her feet clothed wholly in red. In the ethnographical museum at Berlin is preserved a stone image of the goddess with two maize ears in her left hand. The Museum of Mexico[3] has a vase ornamented with the emblems of Centeotl. It is twenty-one inches high and nineteen inches in diameter above.

Of more questionable importance in the discussion are the various codices of the Nahua people, in scraps and fragments, preserved for us by the early Spanish writers, who translated them along with many of very doubtful authenticity, but the concurrent opinion of scholars seems to point to a pre-Columbian (if not very remote) origin of some of the better known writings. An important record, written in Aztec with Spanish letters, by an anonymous native author, and copied by Ixtilcochitl, which belonged to the famous Boturini Collection,[4] is the Codex Chimalpopoca, which, unfortunately, has not been published, and references to which are to be found only in the works of Brasseur de Bourbourg. The quotation given by Bancroft[5] is clearly related to the Maya narrative of the same event—the search for maize.

Until within recent years, the incriptions on the ruined Maya edifices were a sealed mystery to philological archæologists.[6] It appears that the key at last has been found.

In 1876, H. T. Cresson visited the École des Beaux-Arts, in Paris, and there saw photographs of the left-hand doorway of Casa No. 3, Palenque. "The design and technique of this masterpiece of the Maya scribe sculpture art is especially fine, particularly the ikonomatic ornament, the figure of the god Kukuitz. The head-dress of the figure represents feathers, maize leaves, the quetzal head, and other decorations, notably the heron (Baac-ha) in the act of pinching a fish in its pow-

[1] Steffen, Max, Die Landwirthschaft beiden Alt. Americanischen Kulturvölkern.
[2] Sahagun, Historia General, Casas de Neuva España, México, 1829, cap. 7.
[3] Brocklehurst, Mexico To-day, 195, Pl. XXXV.
[4] Una Historia de los Reynos de Culhuacan y Mexico, etc. Boturini Catálago 17-18.
[5] Bancroft, Native Races Pacific States, v., 193.
[6] Science, XXI, 1893, 8. Figs. 38, 39, 40, p. 9.

erful bill."[1] The inscription on the top of the left-hand slab of Casa No. 3, interpreted by the Maya alphabet, reads as follows: "the gods—earth, sky, water, maize—Kukuitz, Kukulcan, Cauac, Muluc."[2]

Many interesting finds were made in South America. That the Peruvians were agriculturists, and cultivated maize as the staple crop, is proved by the numerous works that they have left; large terraces and irrigation canals testify to the extent and development of the cultivation. The tombs, graves, or huacas, have been relied upon generally for evidence as to the Peruvian culture. These huacas nearly all contain remains of maize, either in the ear or the grain. But it has been shown conclusively that the graves, especially at Ancon, have been used since the conquest, so that we must be very judicious in the selection of our evidence and illustrations. The bodies of the Peruvians were buried in a squatting position, with the thighs flexed on the pelvis, and the legs drawn up parallel with the thighs. The face was covered with cotton flock, sometimes llama wool; the whole body being rolled in a mat, and then tightly tied up. Nuts, needles, heads of maize, and copper agricultural implements were included in the rolling.[3] With the body were placed a water-vessel, and a pot with grains of corn.[4] All along the coast of Peru, for a distance of 1200 miles, are scattered here and there thousands of ruins and huacas, while nearly every hill and mountain have some upon them. We can say with a reasonable amount of certainty that the Peruvians knew the maize and used it. Darwin[5] unearthed some ears on a seashore in South America, in a stratum which had evidently been raised from nearer the sea-level, and to which he assigns a great antiquity. Marcay[6] states that in the tombs of the Aymara Indians the grain was found the color of old mahogany, but it preserved its gloss, which he believes, from

[1] Science, XX, 1892, 100.
[2] Science, XX, 1892, 78.
[3] Journ. Anthr. Inst., III, 311, 1874.
[4] Heath, E. R., Journ. Sciences, 3 Ser., 1879, 90.
[5] Darwin, Variations of Animals and Plants under Domestication, I, 320.
[6] Marcay, Travels in South America, I, 69.

the construction of the huaca, to belong to a period long anterior to the conquest.

Wittmack[1] describes the maize taken from the graves at Ancon by Reiss and Steubel as in no way like the form found in the mounds. But a later study led to a partial modification of his views, for Steffen[2] quotes him as expressing the opinion that the small, round, spindle-shaped grains found in the graves were similar to those found in the mounds of North America. The previous statement must have been based on his third form (*genabelter*) dent maize. His second form, pointed (*spitz kornigen*), is found in many varieties in Mexico, and Wittmack believes clearly points to a union between Peru and Mexico (Steffen, 102). *The number of varieties being greater in Mexico than in Peru, shows a greater length of ttme in which variation took place.*

Heads of maize carved in stone are found in certain ruins.[3] They are mentioned in Juan and Ulloa's work, nearly a century and a half ago, and seem to have been better known at that time than they are at present.[4] Squier gives in his book on Peru (91) a bad representation of one of these stone maize heads, and says that they were specially mentioned by Padre Arriaga, in his rare book, "Extirpation of Idolatry in Peru," under the name *Zara-mama*, and were the household gods of the ancient inhabitants. "The Indians derived their idols from those events which had influenced their course through life, and which they thus commemorated."[5] They had their lares, or conopa. Corn was called *Zara-conopa*. Stones cut in the shape of maize ears were called *Zara-mama*, and were considered sacred, although not personified as deity.

The architectural and archæological evidence points to the Mayas as higher in civilization than the Peruvians, for their sculptured figures and hieroglyphical inscriptions are much beyond anything which the South American semi-civi-

[1] Wittmack, Monatschrift f. Gartenbaues, 1880, 121.

[2] Steffen, Die Landwirthschaft beiden Alt. Amerikanischen Kulturvölkern, 1883. Zeitschrift f. Anthropologie, XII, 1880.

[3] Whymper, Travels Among the Greater Andes, 1892, 275. Illustration.

[4] Relacion histórica del Viaje á la América meridional, Madrid, 1748, § 1047.

[5] Tschudi, Peruvian Antiquities, 171.

lized tribes ever produced. The Mayas excelled in many particulars: for instance, the Incas recorded their ideas by quippas, or knotted cords, a much cruder and less satisfactory method than the Maya glyphs. This indicates a much greater antiquity for the civilization in Yucatan and Guatemala than for that along the Pacific coast of the Cordilleras in South America. We conclude that from the archæological data it seems very likely that maize originated north of the Isthmus of Tehuantepec, and was carried south by barter or trade.

D. Ethnological Proofs.

The American race, as a whole, is singularly uniform in physical traits, and individuals from one part of the continent might easily be mistaken for individuals from other parts. This uniformity is due, without a doubt, to the conformation of the continents, which are within themselves geographical units, the trend of the mountains and the situation of the plains being identical in both North and South America. The direction of the mountain chains from north to south permitted a free and easy communication between the tribes along the meridians of longitude.

Attempts have been made to classify the American Indians by their ethnic traits, but the attempt so far has proved a failure. Language affords a more satisfactory method. We can, however. use ethnologic facts as a test of the correctness of results obtained in other ways.

The mound-builders were a puzzle to students, and it is only within the last few years that light has been thrown upon their ethnic relationship. Scholars previously assigned a great age to the works in the Mississippi Valley, but later research shows this opinion to be erroneous. The consensus of opinion points to the relative modernness of these tribes. Our most distinguished ethnologists and archæologists agree that the mound-builders were Indians. Cyrus Thomas, Powell, Hale, Brinton, Mooney, all state that the Indians made mounds of greater or less size, and that after the white settlers came the custom still prevailed.

Brinton[1] says, "A trip to the Ohio confirms the opinion that the Southern Indians represent the mound-builders. It would probably be hasty to point to any one of the southern tribes as being specifically the descendants of the nation who constructed the great works in the Scioto and Miami Valleys." The evidence shows that the tribes of the Gulf States and lower Mississippi constructed similar mounds, and of even greater magnitude than the Ohio mounds. The Choctas, the Natchez, the Cherokees, the Creeks, all built mounds. Do Soto states that most of the Indians visited by him built mounds. The Cherokees assert that they once lived in the upper Ohio Valley, and that they built Grave Creek and other mounds, and this tradition is supported by historic data. Cyrus Thomas[2] asserts that the Cherokees were the mound-builders. The agriculture of the mound-builders was, therefore, scarcely older than that of the adjacent southern tribes, who got maize from the west. What caused the desertion of the mounds? The Iroquois and Algonquins stayed their old-time strife, and united, as tradition goes, against a common and powerful foe. This foe was the nation, or confederacy, of the Alligewi, the "semi-civilized mound-builders" of the Ohio Valley. A desperate war ensued, which lasted about 100 years, but eventually the Alligewi fled southward, and seem to have mingled with the more southern tribes.[3] Heckewelder[4] gives the Algonquian tradition of the same event. The legend relates that the Algonquins in their southeastern migration learned the cultivation of maize after they had reached a comparatively low latitude, southern Indiana or Ohio.[5]

We have data as to the relative age of some Ohio mounds. "In the pre-European state of the country, probably some time after the year 1000, the American bison or buffalo appears to have been absent from all the region east of the

[1] Brinton, Trans. Anthrop. Soc. Wash., III, 116.

[2] Thomas, Magaz. Amer. Hist., 1884, XI, 396–407; American Anthropologist, IV, 137.

[3] Hale, Iroquois Book of Rites (Brinton's Library), II; Amer. Assoc. Adv. Science, 1882; American Antiquarian, 1883, Jan. and Apr.

[4] Heckewelder, Indian Nations.

[5] The Lenape and their Legends (The Walam Olum), 187.

Mississippi. It is doubtful if the creature existed for any distance east of the Rocky Mountains."[1] The Indians burnt the prairies to make pasturage for wild herds, and the fires communicated to the forests in the east, killed the growth and extended the distribution of the herds to the east of the Mississippi. Buffalo bones have been found in the mounds at Madisonville, Ohio, and it is probable, therefore, that the mounds at that place were raised after the year 1000 A.D. The conclusion is that some of the Ohio earthworks were erected in comparatively recent times by Indians identical in many respects with the Indians occupying the Southern States.[2]

The Huron-Iroquois[3] are evidently a comparatively old race, and date back to a period before the arrival of the Algonquins in the same region. Traditions seem to locate the original home of this people in the country between Hudson's Bay and the St. Lawrence River, a region where maize does not grow. As they moved south, they probably derived the use of the cereal from the mound-builders with whom they came in contact. The Huron-Iroquois about this time met the Algonquins, who were likewise spreading their territory to the eastward and southward. The two nations fought in a deadly feud, but eventually united their forces against a common enemy, the mound-builders. History and the traditions of both nations seem to point to this alliance for offensive purposes.[4] It is probable that the Algonquins borrowed a part of their culture at the time they came in contact with the Iroquois and the mound-builders.

The Algonquian family occupied an area extending from Labrador to the Rocky Mountains, and from Churchill River, Hudson's Bay, as far south as Pamlico Sound in North Carolina,[5] and was the most extensive stock in North America.

The Muskogean family claims our attention next They

[1] Shaler, Nature and Man in America, 183.
[2] See pages 96, 97 and 98.
[3] Annual Report, Bureau of Ethnology, 1885–86, 78; Brinton, American Race, 81.
[4] Hale, Iroquois Book of Rites, 11.
[5] Bureau of Ethnology Rep., 1885–86, 47.

occupied an extensive area from the Atlantic to the Mississippi River, and from the Tennessee River south to the Gulf. The Choctas were farthest to the west, along the Mississippi; the Muskokis were farther eastward. Their artistic development was somewhat similar to that of the mound-builders,[1] who have left such interesting remains in the Ohio Valley, and there is, to say the least, a strong probability that they are the descendants of those ancient builders driven to the south by the irruption of the wild tribes of the north.[2]

The general trend of the Siouan migration has been westward. In comparatively late prehistoric times probably most of the Siouan tribes dwelt east of the Mississippi. The later Siouan territory came in contact with the Comanche, a Shoshonean family, on the west. The Mandans attained a certain degree of culture, but the majority of the tribes pursued the herds of buffaloes and lived on the bounties of nature generally. The Sioux cultivated the soil[3] spasmodically, for when they moved west across the Mississippi, maize was not cultivated to the east, but was subsequently introduced.

The Kioways, occupying a central position in the west, were given to a wild hunting life,[4] and considered agriculture a degradation (Whipple). They were the Arabs of the American desert, depending on hunting and robbery for subsistence.

The Caddos, or Pawnees, occupied an intermediate territorial position between the tribes east of the Mississippi and the tribes to the southwest, along the Mexican border. Their nation extended from the Mississippi on the east to western Texas, and from the Kioway and Siouan dominions on the north to the Gulf of Mexico on the south. Agriculture was more in favor among them than generally on the plains. Maize, pumpkins and squashes were cultivated, each family

[1] See page 98.

[2] Brinton, American Race, 88; Essays of an Americanist, 1890, 67.

[3] Bureau of Ethnology Rep., 1885-86, 112; Dorsey, American Naturalist, 1886, 220; Brinton, American Race, 98; Bancroft, Native Races, 1, 491.

[4] American Race, 101.

having its own field of two or three acres. For about four months of the year they were sedentary, dwelling in houses built of poles and bark, covered with sods, while the remainder of the time they wandered over the hunting grounds. The Wichitas, Caddos and Pawnees were tribes of this stock.

The Pacific Coast tribes were not agriculturists. Their food consisted of fish, roots, berries and game, the spontaneous products of land and water.[1] "They reject nothing that their teeth can chew or their stomachs are capable of digesting, however tasteless, unclean or disgusting it may be."[2] We have evidence from other writers to the same effect.[3]

The Pueblo tribes have long attracted attention, and they may be divided for convenience into the following groups: Shoshonean (*Tanoan, Moqui*), Zuñian and Keresan.

It is probable that further research will result in proving the radical relationship of the Tanoan people to the Shoshonean stock. The Keresan pueblos are probably the oldest. "Die Keres sind nach Pike der hauptsächlichste Bestand der civilisirten eingebornen Völker in Neu Mexico, welche die Ueberbleibsel von so alten Stämmen sind."[4] According to Frank H. Cushing, the Nahua nations are a younger people in civilization than the Keres, and as they moved south they gradually absorbed the culture of their neighbors. The Zuñi, from their own traditions, borrowed their culture from the Keres to the east. They occupy but a single pueblo on the Zuñi River in New Mexico.

The Yuman stock occupied the valley of the Colorado and the peninsula of Lower California. They were split up into numerous tribes. Those on the peninsula were in the lowest stage, without agriculture of any kind, and it is likely that they represent the primitive condition of the Yumas, and have always lived as at present. The principal tribes

[1] Smithsonian Report, 1887, 621.
[2] Rau. Trip Across Peninsula of California, Jesuit Priest, 1773.
[3] Proc. Amer. Antiq. Soc., New Ser., 11, 327.
[4] Buschmann.

are the Yumas proper, Maricopas and Mohaves. The Yumas, Maricopas and Mohaves were long acquainted with agriculture, and grew corn, using a pointed stick in planting it.[1]

The Athapascan race, spreading over a vast territory in the north and south, were a warlike people and the main agents in destroying the civilization on the Gila and its affluents. Intellectually they were below the average. The Apaches were redoubted warriors, non-productive, subsisting wholly by plunder and the chase. They lived entirely by hunting.[2] The Navajos were the most highly cultured, yet it turns out that their culture was due to captured members of more gifted tribes. "Agriculture was not practiced, either in the north or south, the only exception being the Navajos, and with them the inspiration came from other stocks."[3] The best blanket-makers, smiths and other artisans among the Navajos were descendants of captives from Zuñi and other pueblos.[4] The Apaches and Navajos were the principal tribes.

The Shoshonean family was wide-spread and extended from the Columbia River in the north to Nicaragua in the south. Buschmann and Brinton consider the Nahuatl races related to the Shoshones of the Bureau of Ethnology,[5] and I am inclined to follow their lead in this matter. The tribes of this stock present the greatest diversity of traits. The Nahuas were highly cultured in comparison with the other nations about them, yet they belonged essentially to the same race as the poor root-digger Ute, with the lowest type of skull on the continent.[6] Living on the arid plains of the interior, the Utes had been for generations half starved. They were not agricultural; but lived on fish and wild seeds. Indeed, the Ute branch, including the Comanches, with the

[1] Emory, Rep. U. S. and Mex. Bound. Surv., I, 112; Indian Office Report, Special Com., 1867, 337; Merriwether, Ind. Off Rep., 1854, 172; American Race, 109; American Antiquarian, VIII, 276.

[2] Delgado, Ind. Off. Rep., 1860, 1864.

[3] Brinton, American Race, 71.

[4] Bourke, John G., Journ. Amer Folk Lore, 1890, 115; Bandelier, A. F., Indians S. W. United States, Boston, 1890, 175.

[5] Powell, Bureau of Ethnology Rep., 1885-86.

[6] Virchow, Crania Ethnica Americana.

exception of the Moquis, who probably borrowed their culture from the Keres, were averse to agriculture, but they were more willing to accept a civilized life than the Apaches or Kioways.

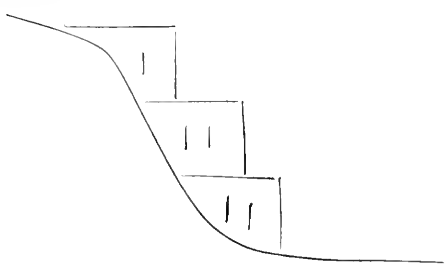
The Piman[1] or Sonoran branch (Brinton) of this family comprised the Pimas, Cahitas, Coras, Tarahumaras and Tepehuanas, as the principal tribes. Buschmann and Gatschet favor the opinion that the Pimas are Shoshones. The Pimas occupied the region of the Gila Basin and head of the Bay of Lower California. The remarkable cliff-dwellings are in this region, and it is probable that the ancestors of the Pimas were the builders and inhabitants of the rock shelters. There is nothing to warrant a contrary statement, for a culture higher than the Piman is not necessary to explain the structures. As Schwatka has pointed out,[2] the timid Tarahumaras still live in cliff-dwellings. The Pimas have a tradition that they were driven south by the Apaches.[3] These people were agricultural and irrigated their fields with canals and ditches. The Coras of this group reached farthest south into the State of Jalisco. These tribes were not in culture earlier than the Keresan, for Mindeleff has explained the probable stage of progress toward pueblo building; that the circular house of stone and mud derivable from the circular wigwam still used by the wandering tribes of the Ute branch, became square by aggregation of the buildings. The people driven to the mountain fastnesses by the warlike tribes, still built the square form of house, but for lack of sufficient building sites the families built their houses one above the other on the mountain slope (the cliff-dwelling stage), and after the danger was over, and the people returned to the plains to live, they built, as the result of their mountain experience, the pueblo with compartments one above the other, and

[1] Powell, Bureau of Ethnology Rep., 1885–86.
[2] Schwatka, Frederick, Century Magazine, 1892.
[3] Grossmann, F. E., Rep. Smithson. Inst., 407–10.

reached by ladders.[1] Lieutenant Simpson[2] records an observation, which seems, to support this view. He found, in close proximity to one of the ruins, an excavation in the cliff which had been closed with a front wall of well-laid stone and mortar, thus associating one of the simplest cave-dwellings and a perfect pueblo building, a fact of no little importance.

Before leaving the territory of the present United States, it may be well to draw a few conclusions from the facts already presented in this section. The practice of agriculture was chiefly limited to the region south of the St. Lawrence and east of the Mississippi. In this region it was far more general, and its results were far more important, than is generally supposed. To the west of the Mississippi, only comparatively small areas were occupied by agricultural tribes, and these lay chiefly in New Mexico and Arizona, and along the Arkansas, Platte and Missouri rivers. The rest of the region was tenanted by non-agricultural tribes. "The practice of agriculture, to a point where it shall prove the main and constant supply of a people, implies a degree of

[1] Mindeleff, Bureau of Ethnology Rep., 1882-83, 473. The Navajo hut, a bee-hived conical structure, made of turf, etc., in Zuñi is ham-pon-ne, from hawe, dried brush, sprigs and leaves, and po-an-ne, a covering or shelter. When the term was formulated, the Zuñis were probably acquainted with this form of building. A walled enclosure, he-sho-ta-pon-ne, from he-sho, gum, was round rather than rectangular, and was found in the southwest lava wastes. The lava resembles asphaltum, hence ahe-sho, gum rock. The rectangular hut was derived from the round by aggregation. The flat and terraced roofs, in all probability, were derived from sloping mesa sites, and this overlapping is



due to the decrease in the number of available sites on the hill. The name of an upper story, in a pueblo, is osh-ten-u thtan, from osh-ten, a shallow cave or rock shelter, and u-thla-nai-e, placed around, embracing, inclusive.

[2] Simpson, North Americans of Antiquity (Short), 292; Journal Mil. Recon., 34, 131; Domenech, Deserts, I, 199, 379-81, 385; Baldwin, Anc. Am., 86, 89; Bancroft, Native Races, I, 652-62; Barber, American Naturalist, XI, 1877, 591.

sedentariness to which our Indians, as a rule, had not attained, and an amount of steady labor without immediate return which was peculiarly irksome to them. Moreover, the imperfect methods pursued in clearing, planting and cultivating sufficiently prove that the Indians, though agriculturists, were in the early stages of development as such, a fact also attested by the imperfect and one-sided division of labor between the sexes, the men, as a rule, taking but a small share of the burdensome tasks of clearing land, planting and harvesting. It is certain that by no tribe in the United States was agriculture pursued to such an extent as to free its members from the practice of the hunter's or fisher's art." The facts collected in these few pages indicate that the tribes to the east of the Mississippi borrowed their agriculture from the west, for along the Mexican border the Indians were more sedentary and farther advanced in the arts. Again, the culture along the Mexican border had one or two probable centres of distribution, the one, the Keres, the other, the Pimas, who both derived it from farther south.

The Nahuas formed by far the most important branch of the Shoshonean family. They occupied the territory from the Rio Grande south to Nicaragua, and possessed, as it went in America, a comparatively high grade of culture. They had an elaborate government, presided over by a Montezuma; they were skillful as builders; their utensils were of copper and tin; gold and silver were worked into ornaments; their religious system was elaborate and minute, and the literature, preserved on parchment of maguey plant, in the ikonomatic characters, was large and important; they had a calendar; they tilled the soil, as was necessary for a dense population, raising maize, beans, pepper, gourds and other fruits. Finally, they had organized armies. Each king was absolute in his own country (Mexico, Tezcuco, Tlacopan) until war broke out, when they acted jointly. The country was so densely populated that floating gardens, or chinampas, were constructed. All the agricultural products of the country, particularly maize, chile and beans, were sown in abundance on the chinampas, constructed of logs, with brush and earth on the top. Prescott says: "Fairy islands of flowers overshadowed occasionally by trees of considerable size." "That archipelago of wandering islands."[1] The Nahua nation were probably no more cultured than their relatives the Utes and Comanches, until they came in contact with the Keresans in the north, or the Mayas and other cultured tribes, the Totonacos, Zapotecs and Chinantecs, in the south. The Aztecs did little more than copy the works left by their predecessors.[2] A general ethnic rule, applicable in many cases, may be laid down, that less civilized tribes coming into contact with more civilized nations imitate the customs of the more successful race, and a struggle ensues, in which the more cultured race, if a stronger one physically, has the advantage, and its culture obtains the ascendency. The fact that the Nahuas preferred the highlands of Mexico to all other districts as a dwelling-place, is accounted for by the surroundings, which were attractive and wholesome. Maize grew well, and on the plateaus, in addition to this cereal, grew the maguey (*Agave Americana*); in the neighborhood lower down the coast grew a great variety of tropical fruits, amongst others the cacao and the vanilla.[3] They were in an already long-settled country; the fields were cleared, and the country inviting, with its ancient buildings and arts. With the first germs of civilization instilled into them, it is no wonder that they developed into a great and powerful nation. The same conditions determined the location of the ancient civilizations in the rich and fertile river valleys of the Euphrates, Nile, Ganges and Yang-tse-Kiang.

The Mayas were the oldest in civilization of any race on the North American continent.[4] Copan, Palenque, Uxmal, were built by them, and these ancient architectural remains were of a high order and indicate a long process of evolution from more primitive forms. They excelled in architecture,

[1] Prescott, Conquest Mexico, II, 70, 107-8; Cortes, Cartas, 79; Sarmiento, Heredia, 95, 96; Torquemada, Monarq. Ind., II, 483; Carli, Cartas, I, 38, 39; Bancroft, Native Races, II, 344.

[2] Tylor, E. B., Anahuac, London, 1861, 188.

[3] Peschel, O., Races of Man, New York, 1876, 449.

[4] Nadaillac, Prehistoric America, 262; Contributions N. A. Ethnology, 75; Short, John T., North Americans of Antiquity, 203; Standard Natural History, VI, 219.

for their sculpturings are bold and strong, as the façades of the edifices, covered with curious designs, attest. Their boats were seaworthy, and a trade was established between Cuba and Yucatan, for Columbus was shown wax from Yucatan, and was told about the countries toward the sunset. Cacao beans and shells served as media of exchange. They had an extensive literature; they used tablets and covered the walls of their structures with hieroglyphics. "Their speech forms one of the rare examples of an American language possessing vitality enough not only to maintain its own ground, but actually to force itself on European settlers and supplant their native speech." Berendt states "that whole families of pure white blood do not know Spanish, but use Maya exclusively." The calendar attracts attention, and appears to have been the basis for that of the Nahuas. They were agriculturists. Maize, beans and pepper were cultivated, and bees were domesticated, from which both wax and honey were collected. This nation extended over the peninsula of Yucatan and into Guatemala and Tabasco.

The Chibchas extended in both directions from the Isthmus of Panama, and thus have representatives in both North and South America. Most of the tribes in New Granada were of this stock. The Chibchas proper were highly cultured. Their home was one of the most southern of the entire family. A number of tribes in the States of Panama and Costa Rica were probably branches of this nation. Agriculture was pursued, the produce being maize, potatoes, yucca and cotton. Irrigation was practiced to some extent. It is doubtful whether they had any means of writing.

The Kechuas next claim our attention. There are many reasons for believing that the tribes comprised in this stock appeared in South America at the extreme north of the region they later occupied, near the great trade highway across the Isthmus of Panama. Their seat seems to have been near the present city of Quito. Later the Incas extended their sway to the thirtieth degree of south latitude. The Peruvians were highly cultured. They were governed by an Inca, or war chief, elected by a council of the gentes. The land was owned by the gens. Agriculture was highly developed. The soil was fertilized with guano, and extensive systems of irrigation were used. Maize, potatoes, yucca, peppers, tobacco and cotton were raised. Architecture reached a high stage. It was cyclopean, erected upon tumuli, or pyramids. The Peruvians were greatly deficient in decorative skill and sculpture. They recorded their ideas by the quippas, or knotted string, a system far inferior to the hieroglyphics of the Mayas. Their religious system was elaborate and constituted a worship of the sun. A comparison of the two greatest civilizations on the American continents, the Maya and the Peruvian, leads to the opinion that the Mayas excelled in those traits which make a nation great. Their architecture was more artistic, their literature fuller and richer, as a comparison of Maya glyphs and Peruvian quippas alone shows.[1]

The Amazon and Orinoco basins were largely occupied by tribes of Tupi, Tapuya, Carib and Arawak stocks.

The Tupis were found along the seaboard from the mouth of the La Plata to the Amazon, and far up the banks of the latter. Here they are called the Guarani. "The general culture of the Tupis was superior to the that of the Brazilian tribes generally, but inferior to that of the Incas. They were, to a slight extent, agricultural, raising maize, manioc and tobacco." Some fowls, monkeys and peccaries were tamed and used as food.[2] The Tupis in Ecuador evidently profited by their nearness to the Peruvians, for they lived in permanent villages, had good roads, knew gold, silver and copper, and cultivated large fields of cotton, maize and various food plants. "The art forms which they produced, and the prevalence of sun worship, with rites similar to Peru, indicate the source of their more advanced culture."

"The Arawak stock was the most widely disseminated of any in South America. It began in the south with the Guanas, on the head-waters of the River Paraguay, and with the Baures and Moxos on the highlands of southern Bolivia,

[1] See Standard Natural History, VI, 219.

[2] Brinton, American Race, 233.

and extended in continuity to the Goajiros peninsula, the most northern land of the continent."[1]

The Antilles and Bahamas were peopled by its members. They were the first, therefore, to welcome Columbus to the Bahamas, Cuba and Hayti. The Arawak stock was above the stage of savagery. They cultivated maize, potatoes, manioc, yams and cotton. They made gold ornaments, idols of rude form, and canoes constructed of hollow logs. The Guiana Arawaks cultivated maize, but cassava afforded the chief food. The forest tribes planted in clearings intermingled with wild seedlings and sprouts from stumps. Brinton places the original home of the Arawaks somewhere in the Bolivian highlands, where, no doubt, they learned the use of maize.

The Timucuas inhabited the State of Florida, where they have been extinct for a century and over. Gatschet[2] and Brinton incline to the opinion that the Timucuas were related to the Caribs in the Bahamas and the greater Antilles. There is no objection to holding this view, for the Timucuas were isolated as regards the surrounding tribes, and the Caribs extended to the Bahamas, near the coast of Florida.

This brief ethnological survey of the North and South American tribes is useful in showing the comparative age and cultural position of the agricultural races of Indians. That the Mayas were the superiors of any other race on the North or South American continent, and were the source of a large part of the indigenous American culture is proved: (1) by the fact that the tribes and mound-builders in the present territory of the United States were just entering on the agricultural state; (2) because the Pueblos built structures of scarcely higher order than the rock shelters of the cliff-dwellers, who were driven by the invasion of wilder tribes to build in the mountain fastnesses instead of living on the plains in round or rectangular huts of stone and mud; (3) because the Nahuas evidently borrowed their agriculture from the more advanced Maya tribes in the south, with whom

[1] Brinton, American Race, 241.
[2] Bureau of Ethnology Rep., 1885-86, 123.

they came in contact in their settlements and migrations; (4) because the Incas occupying a northern location, at first near the great Panama trade route, at a later date spread their sway to the far south, carrying the germs of agriculture and the rudiments of the arts to the barbarous tribes in the Bolivian and Chilian highlands, and this argues for a comparatively recent development of their civilization and agriculture, for in Mexico all the tribes practiced agriculture, but in South America, among the wild tribes, agriculture was yet in its incipient stage.

E. Philological Proofs.

Language is important in determining the culture, migration and evolution of races of men. The study of the Aryan, or Indo-European, tongues has thrown a flood of light upon the early history of the European and Asiatic races. When the American languages shall have been studied with the same thoroughness and care, equally valuable results will be obtained.

De Candolle has shown that the study of language aids in determining the origin of our cultivated plants and their subsequent distribution. It is likely, therefore, that a comparison of Indian names for maize will aid in determining the primitive home of the cereal and its carriage through the American continental areas.

The Algonquian family, numerous in tribes, was spread over a vast territory in Canada and the United States. All the tribes have a common root for maize. This points to the knowledge of corn by the Algonquins while they still formed one nation. It is probable that the primitive seat of the undivided Algonquins was near the great lakes, and the dispersion occurred in two directions, one wing extending into the northwest, the other to the east and northeast. The use of maize was learned, in all probability, while the nation occupied their undivided home. "The root min or mún is a generic suffix applied to all sorts of small fruits,[1] and when

[1] Brinton, The Lenape and their Legends, 48.

maize became known to these Indians they extended the use of the word to the cereal, and combined other terms with it to define more positively the kind of small grain meant." Thus the Chippeway word for corn, mandamin, the Ottawa, mindamin, the Cree, mittamin, contain the radical min in full, combined with an abbreviation of the word manito, divine, meaning, of course, that the grain was divine, supernatural, mysterious. In the Delaware, the combination is different. The Delaware word jesquem (Campanius), chasquem (Zeisberger), contains the radical ask, Chippeway ashk, Delaware aski, meaning green. The reference is to the green, moving plant in the fields during the summer months. The Piegan Blackfoot word drops the radical min, but retains the root ask, thus, esko-lope. A classified list of the tribes with their names for maize will show that all the tribes, however widely separated, had a common root for that important cereal:

Abnaki skamen (Father Rasle) (Journ. Antiq. Soc., II, 305).
Algonquin, mitamin (Journ. Antiq. Soc., II, 305) (La Houtan).
Chippeway, mandahmin (Keating) (Journ. Antiq. Soc.) (Long).
mittawmin (Heriot).
Cree, mittamin (Brinton).
Delaware, khasquem (Journ. Antiq. Soc., II, 305).
husquim (Whipple, Ewbank, Turner, 1855, 9).
jesquem (Campanius).
Lenape, mesittewall corn boiled whole.
scheechgamin, coarse shelled.
schesquim, bran, husk.
schesquasquim, hulls.
winamin, corn is ripe.
winaminge, month of August: literally, time of roasting ears.
achpocm, roasted corn.
simaquon, corn-stalk.
Illinois, micipi (Duponceau).
Massachusett, eachim-meneash (R. Williams).
Menominee, waupim-meenuc (Doty) (Journ. Antiq. Soc., II, 305).
Miami, ment-sheepeh (Thornton).
Micmac (S. T. Rand, Dictionary Micmac Language, 1888).
peaskumun.
peaskumuskw, corn-cob, corn stalk.
peaskumunwees, corn-hill.

Micmac peaskumun, nao-aktook, ear of corn.
oosaboon, corn-silk; literally, head of hair.
peaskumuna, egadakim, corn-field.
Narraghansett, ewachim-neash (R. Williams).
Ottawa, mindamin (Brinton).
Passamaquoddy, piaskomin (Sturtevant).
Sac, tamin (Long's Sec. Exp. St. Peter's River, II).
Shawnee, tame (Johnson).
dame (Journ. Antiq. Soc., I, 287).
tarmi (Whipple, Ewbank, Turner).
tami (Jefferson) (A. S. Gatschet).
lena-wi-wi tami, Indian corn.
tami-skui, corn-cob.
nikutik-kah-knimi, corn-ear.
kuläskwa, corn-stalk,
kti-ka (Gatschet).

There is an apparent similarity between the Algonquian and Iroquoian words for maize. This either establishes an earlier connection between the two nations, or points to a derivation of maize from a common source. The latter view is supported by tradition, which relates that both stocks united their forces against a common foe, the Alligewi, or mound-builders. Conquest changes not only the conquered, but also the conquerors. Insensibly, it may be, but deeply, they are affected by the character of the absorbed races. A powerful inter-tribal imitation must have been constantly at work, imitation of the culture of the more highly evolved though less warlike tribes; and this imitation and absorption prove very powerful when conquest takes place. Duponceau[1] long ago compared the words for maize in the two languages:

Algonquin.	*Iroquois.*
chas-quem.	on-atschia.

There seems to be a probable connection between chas (ask, aski), Algonquian, and atschia, Iroquoian, for the Seneca drops the last portion, and calls maize onaa.

The following list gives the words for corn in Iroquois:

Cherokee, allo-selu (Journ. Antiq. Soc., II).
selutikatunung.
kungwisitung (S. A. Worcester).

[1] Duponceau, Mémoire des Langues de l'Amér. du Nord, Paris, 1838.

Mohawk, onusti (Journ. Antiq. Soc., II).
Nottoway, ohnehahk (Journ. Antiq. Soc.) (Wood).
Oneida, ohnloto (Journ. Antiq. Soc.) (Jefferson).
Onondaga, onatschia (Journ. Antiq. Soc.) (Zeisberger).
Seneca, onaa (Journ. Antiq. Soc.) (Parish).
onoohquaw.
Wyandot, nayhah (Journ. Antiq. Soc.) (Archæologia Americana).

The Muskogean family consisted of three principal tribes, the Chocta, between the Mobile and Mississippi rivers, the Chicasa, at the head-waters of the Mobile River, and the Maskoki, or Creek, between the Mobile and Savannah rivers. The words in Maskoki, or Creek, are atchi (Gallatin), atshi (Journ. Antiq. Soc.), and adshi (A. S. Gatschet).

The Creeks may have been the original mound-builders, or closely allied to them. A curious similarity appears in the Creek word atchi, adshi, the Algonquian aski (chasquem), and the Iroquoian onatschia, which, if so joined, philologically enforces the theory advanced that the Algonquins and Iroquois obtained corn from a powerful southern tribe. The Chocta word is tanchi (Whipple, Ewbank, Turner), tandshi (A. S. Gatschet), tonche (A. Wright). The Chicasa word is tuncha (Gallatin). All these words are related to the terms used by the Indians west of the Mississippi River.

The Caddoan family had three principal tribes, the Pawnee, Wichita, and Caddo. The Pawnee word for corn is task (W. E. T.), the Wichita is täsh (A. S. Gatschet), the Caddo word is kish-ee-ee (G. Gray), showing a close relation between all the words. A. S. Gatschet thinks that the Pawnee task, the Wichita täsh, and the Chocta tanchi, are related, which would show that the Choctas borrowed their use of maize from the Caddos to the west. The Siouan tribes, in all likelihood, borrowed their words from the same source, for we have Ponca, watanzi, Omaha, wattanza (Journ. Antiq. Soc.), Osage, watanshee (Journ. Antiq. Soc.), Ottoe, watooja (Say), and this carried farther in the Winnebago wachoa (Journ. Antiq. Soc.). The first half of the word is evidently wakan, meaning superior, or supernatural.[1] The Tutelos had Algonquian loan-words, mandaqei, mataqe. The Catabas (in South Car-

[1] Roehring, Language of the Dakotas, Washington, 1872, 14.

olina), clearly related to the Siouan tribes, apparently derived their word from the Caddo proper, kus, kush (A. S. Gatschet), koos (Journ. Antiq. Soc.), of the Cataba, seems to be related to kish-ee-ee, and the tash of the Caddo stock. The Dakotas have an entirely independent set of words, the affinity of which is unknown. A list of Dakota words follows:[1]

Dakota, wamnahesa, wahinske, corn.
huwapa, wahuwapa, ears of corn.
Omaha, watanzi, corn.
wahaba, corn-ear.

The words huwapa, wahaba, may be connected with the Chemehuevi hahwib (W. & T.), although this is merely conjectural.

A glance at the words for maize as used by the California Indians will show that they learned the use of maize after the advent of the white man into their country.[2]

Maize = maiz (Father Sitzar, San Antonio Mission, 1861).
Maize = maiz, Yukis, Huchnom, Pomo, Gallinomero, Yokaia, Yokuts, Mariposa, Timlinneh.

The Pueblo tribes and Yumas, which lived on the Mexican border before the Shoshonean invasion, next claim attention. A list of words will prove of advantage in a comparison.

Yuma, Yuma proper, tiyatch.
terditch (Whipple).
Cocomaricopa, terditz.
Mojave, terdicha.
Moqui, ka-ah (Bourke).
karuk (Buschmann).
Zuni, melah (Eaton).
tâ-a or a-ta-a, seed of seeds.[3]
muwai } (Buschmann),[4] (Eaton).[5]
muwe }
Tesuque, kühn.
Isleta, i-e, corn (Gatschet).
Keres, ya-oca (Whipple).
yachi (Kiwomi Clan).[6]

[1] Dorsey, J. O., Geol. Survey Rocky Mts. Ethn., VI; Bureau of Ethnology Rep., 1881-2, 304; Dakota Grammar and Language, Wash., 1852, 293.
[2] Powell, Geol. Survey Rocky Mts., III, 476.
[3] Cushing, Indianapolis Millstone, October, 1884.
[4] Buschmann, Abhand. Akad. Wissensch., Berlin, 1857, 288.
[5] Eaton, Schooler's Indian Tribes, IV, 1854, 416.
[6] Buschmann, Abhand. Akad. Wissensch., Berlin, 1857, 301.

Notwithstanding Gatschet's positive statement, that there is no connection between the words of the different Pueblo stocks for maize, I cannot forbear comparing the Zuñi tâ a or a-ta-a with the Moqui ka-ah. The statement made by Cushing, that the Moquis have words which show that they borrowed a portion of their culture from the Zuñis or Keres, is significant. The Keresan word yatchi, or yaoca, seems to be the primitive form of the Yuma tiyatch (terdich, terditz); but too much stress cannot be laid on this curious correspondence of radicals.

The Uto-Aztecan stock of three distinct branches extended from the Columbia River south to Nicaragua. A list of words for maize in the various families is given:

Shoshonean Branch.
Chemeheuvi, hahwib (W. E. T.).
Comanche, hunibist (W. E. T.). (Buschmann, 1857, 258)
Moqui (*ante*).
Sonoran Branch.
Cahita, bachis (Buschmann, 1854).
Cora, yurit (Buschmann, 1854).
Tarahumara, schunucu, sunu (Buschmann, 1854).
Tepehuana, june (Buschmann).
Pima, ou-in, oo-on (W. E. T.), (Buschmann, 1856, 356).
Nahuan Branch.[1]

	Pipils.	Aztecs.
Maize stone, ...	medat.	metlatl.
Tortilla, ...	tax.	tlaxcalli.
Ears, ...	cinti.	cintli.
Hulled maize, ...	tayugal.	tlaolli.
Full maize, ...	ulut.	olotl.
Unripe maize, ...	elot.	elotl.

[1] Stoll, Zur Ethnographie der Republic Guatemala, Zurich, 1884.

It is easy to see that the Shoshonean branch learned their use of maize from other tribes. The Moquis were the most advanced, but they were copyists. Buschmann says:[1] "Die Namen für Maiz harnewista, hahnebeteh aus welche Formen im vergleich mit pohewista [Eisen *cf.*, also pohewista, gold] und dem Namen hainena-una eines Stammes harne, hahne und haine als das eigentliche Wort für Maiz, bekleidet mit einen starken Endung; hervor springt Tarahumara schunucu, sune, Tepeguana june, Cora yurit." In other words when they learned of maize, the grain was golden or glistening, like the precious metals, and they therefore affixed the term wista to describe the grain, or seed, more particularly. The Sonoran group links together the region of the Colorado River, where the Pimas dwelt, and the State of Jalisco, in latitude twenty degrees north, where the Coras dwelt. It is safe to suppose that an inter-tribal communication was always kept up between the members of this branch; this is sufficient to account for the distribution of maize from the south into the present territory of the United States, and for its presence among the Zuñis and Keres, who afterwards taught the Moquis of later migration agricultural practice.[2] It appears that oo-um, oo-oon, the Pima for maize, are related to sunu through hainena une (une, oo-oon, oo-um, ou-in). The Pimas must be reconciled to the Uto-Aztecan stock. Buschmann[3] says: "Ich gehe daran aus dieser Wortsammlung die Resultate zu ziehen, welche die Pima Sprache, als ein wichtiges fünftes Glied des Sonorischen Sprachstammen erweisen; voll Sonorischen Stoffes, in welchen sie die Tepeguana häufig sehr und auffallend nahe steht; denoch voll eigenthümlicher Wörter, durchzogen von Aztekischen Resten."

The Mayas occupied a central position in Mexico. Stoll[4] gives a list of words in the Maya:

[1] Buschmann, Abhand. Akad. Wissench., Berlin, 1854, 396.

[2] *Cf.* pages 123 and 147.

[3] Buschmann, Die Pima Sprache, Abhand. Akad. Wissench., Berlin, 1856, 371.

[4] Stoll, Zur Ethnographie Guatemala, 53.

		Tortilla.	Ear.	Grain.	Unripe.
1	Huasteca,	bacam.	guai.	isis.	ajam.
2	Maya,	vuaj.	nal.	ixim.	nal.
3	Chontal,	"	"	"	chojno.
4	Tzental,	"	"	"	ajan.
5	Tzotzil,	"	——	"	"
6	Chanealbal,	"	jal.	"	"
7	Chol,	"	"	"	sal.
8	Quekchi,	vua.	"	"	och.
9	Pakonchi.	vuic.	"	"	raxjal.
10	Pokomam,	"	"	"	ajm.
11	Cakchiquel,	vuay.	"	"	iiz.
12	Quiche,	vua-lej.	"	"	raxjal.
13	Uspantica,	vua-lej.	"	"	cux.
14	Ixil,	——	"	"	matzinjal.
15	Aguateca,	vua.	"	"	xeba.
16	Mame,	——	"	ixin.	——

The word aima in the Xinca language of Guatemala, also found in Chontal, is probably derived from ixim, the universal word for maize in the Maya. Later, we have for corn-field, uaya'a, which is close to the Cakchiquel ouan, corn-field, or auex, when the corn is young. If this is correct, it indicates that the neighboring tribes learned the cultivation of maize from the Mayas.[1]

The Costa Rican tribes, the Boruca, Terraba and Guatuso, have words for maize,[2] as follows :

[1] Brinton, Proc. Amer. Philos. Soc., 1884, 91.

[2] Archiv. für Anthropologie, 1886, 591: Revue d'Ethnographie, tom. 16. 1887, 128.

	Boruca.	Terraba.	Guatuso.
Maize, ...	kup.	ep, ip.	ain.
Maize-field, ...	kup-kah.	te.	ani-ki-tokufa.
Ears, ...	kup.	ip-kror.	ai ki-kacheijo.

The Zapotec word is xupaac, which is comparable to kup and kupac, the Costa Rican for maize-field. The word kupac, in Costa Rican, is equivalent to the word shipyac in the language of the Timotes, a South American tribe, showing a connection between the two continents. Nor does the evidence cease here,[1] for the Mazatecs, in the northwestern part of the State of Oaxaca, were related to the Mangues and Chapanecs near Lake Managua, in Nicaragua. The Mangues had as neighbors, beyond the Cordilleras, in Costa Rica, a group of related tribes, the Talamancas, Bribris and Vezertas, which have been shown by Dr. Max Uhle, Dr. Ernst[2] and other students to be not distantly connected with the important Chibcha stock of New Granada. The Chapanecs were largely infiltrated with the blood of Costa Rican tribes, with relations in South America, enabling us to to trace influences of a South American linguistic stock as far north as the northern border of Oaxaca, a discovery full of significance for the history of aboriginal culture. The Maya word ixim agrees apparently with the Mazatec nama as shown in the comparison of nouns.

	Maya.	*Xinca.*	*Mazatec.*	*Chapanec.*
Maize.	ixim.	aima.	nama.	name.

It was stated in another section, that the Peruvians originally lived in the neighborhood of Quito, where they came in contact with the Chibchas and other tribes who carried on a trade with the Indians across the Isthmus. The Kechua (Peruvian) word for maize is sara, or zara, and cherchi signi-

[1] Proc. Amer. Philos. Soc., 1892, 67; Zeitschrift für Ethnologie, 1885, 191.
[2] Brinton, Proc. Amer. Philos. Soc., 1892, 23.

fies roasted maize.[1] The Peruvians were surrounded on all sides by wild and barbarous tribes, who learned from the Incas a little agriculture and a few arts. The Tacanas, Maropas and Araunas, situated on the Mamore River, have words—dije, shije, zia, which are related to words of the Pano stock, on the Ucayali River (see any good map). The Pano word shequi is undoubtedly the Peruvian cherchi, roasted maize, and clearly points to the source whence the Panos and the Tacanas got maize.[2] It is probable that all the inland and forest tribes borrowed the cereal from the Peruvians, as did the Indians along the Ucayali, the Mamore and the Beni rivers. The following list of words shows this :[3]

Pano, Ucayali River, schequi.
Culino, Juvary River, tschüky.
Moxoruna, Tapichi River, schuky.
Canawary, Purus River, schischy.
Araicu, Jurua River, metschy.
Carysuna, Madeira River, schröki.
Baré, Negro River, macanaschy.

The Tupis, or Guaranis, extend from the mouth of the La Plata to the Amazon, and far up the stream of the latter. The word for maize is abati in Guarani, auaty, abaty in Omagua, awati in Cocama.[4] This word, or the aba of the Chibcha, clearly appears in Guiana, and is found apparently in Florida, for the Timucua words are abo, corn-plant ; abopaha, corn-crib ; aboti, stick staff ;[5] this similarity in words, however, may prove superficial to philologists competent to speak on the subject. That the Arawaks carried these Tupi words north with them is evident from the fact that certain Arawak tribes had Tupi loan-words. Thus the Arawak tribe Mariayos, on the Rio Negro, had yua-naty ; the Manaos, on the Rio Negro, auaty ; the Maranhos, on the River Jatahy, uaty.

Columbus when he landed found maize on the West India

[1] The most archaic forms of Kechua are to be found in the Chincasaya (Northern). There the word for chicha is asua, and in Kechua proper, axa. *Cf.* American Race, 205

[2] Brinton, Proc. Amer. Philos. Soc., 1892, 47; Kansas City Review, April, 1883

[3] Martius Brasilian Sprache.

[4] Ruiz, Lengua Guarani, 1876; Martius Brasilian Sprache, 427.

[5] Proc. Amer. Philos. Soc., 1883 15.

islands, and adopted the word mahiz or mayz. The Arawak word for maize is marisi, and various forms of this word are found among the other tribes.

ARAWAK. { *Arawak*, marisi, Guiana.
Cauixana, mazy, Rio Jupura.
Goajiro, maique. Goajiros Peninsula.
Passes, mary, Lower Jupura.
Puri, maky, Rio Paraiba.
Coroado, maheky, Rio Paraiba.
Carib, marichi, marisi (female use).
Cuba, *Jamaica*, *Lucayo*, maysi.

The Caribs clearly borrowed their word for maize from the Arawaks, for the Arawak radical is used by the females of the Carib stock, the males using an entirely different noun. The Arawak word was used largely through northern South America and the West Indies, and is the one which the Spaniards adopted as the word for the new and unfamiliar grain which they saw and described.

The linguistic evidence shows: (1) That maize was introduced into the United States from two sources, from the tribes of northern Mexico and the Caribs on the West India islands; (2) that the Pueblos and northern Mexican tribes derived maize from central Mexico; (3) that tribal connections existed between the North and South American continents, and that an interchange of products was carried on by way of the Isthmus of Panama; (4) that the wild tribes living along the Andean system, in the El-Gran-Chaco and elsewhere used Peruvian loan-words for maize; (5) that South American words for maize were used throughout the Greater and Lesser Antilles and Florida, and that the Arawak word for Indian corn, adopted by Christopher Columbus, was used by tribes of that stock in the impenetrable and luxuriant Brazilian forests.

F. Historical Proofs.

The historical section has been divided for convenience of treatment into four parts, as follows: Division A, History Proper; Division B, Aboriginal Cultivation; Division C, Indian Use; Division D, Mythology. The material has been arranged in geographical sequence, starting with New England and concluding with South America, and where possible the facts have been arranged chronologically.

DIVISION I. HISTORY PROPER.—About 1002 A.D.,[1] Thorwald, brother of Lief, wintered in Vinland. The following summer, in proceeding "occidentale latus circumire," Thorwald found the sea "valde insulosum" (Mingan Islands), and on an island far westward saw a wooden crib for corn (kornjhalmer).[2] Karlsefn, in 1006, in coasting along our northern coast, brought back to the ship a bunch of grapes and a new-sown ear of wheat (corn). At Hóp they found self-sown fields of wheat where the ground was low, and vines where the ground was high. "While lying against the peninsula of Cape Cod—Furderstrand, Nausett Beach—Thorfin, that he might know the quality of the neighboring land, sent out his fleet-footed servants to run for three days over the region and return and report what they had seen, the ship lying at anchor during their absence. They brought back, one a bunch of grapes, the other an 'ear of corn.' They had two months earlier seen the 'new-sown' (Beamish) young corn at Hóp. Ear of corn is the translation of the Icelandic word hveiti-ax (J. Tomlinson Smith). Beamish and Rev. Dr. Slafter[3] translated the same expression 'ear of wheat.'" Was it Indian corn? Ax, by itself, in Icelandic, is ear of korn (Vigfusson), hveiti is wheat. Skeat, in his Etymological Dictionary, states that the word wheat is Teutonic, and signifies white, and hveiti, no doubt, refers to the color of the grain or kernel of corn of whatever kind. Hviti, is white, as applied to the White River, in Icelandic (Henderson's map), and hviti-ax would be white ear of seed.[4] It is doubtful if this seed was maize.[5]

[1] Pickering, Chronological History of Plants, 665.

[2] Trans. New York Agric. Soc., 1878, 46.

[3] Slafter, Prince's Society.

[4] Horsford, E. A., Discovery of America by Northmen, 1888.

[5] We are told in a tradition of the Tuscarora Indians, who claim they arrived on the Virginian coast about the year 1300, that they found there a race who knew nothing of maize and were eaters of raw flesh. The Northmen, in the year 1000, found the natives of Vinland, probably near Rhode Island, of the same race as those they were familiar with in Labrador. Eskimo is from the Algonquin word Eskimantic—eaters of raw flesh.—The Archæologist, 1, 13

The French arrived in Canada in the year 1534. Cartier sailed up the St. Lawrence, and in 1535 reached Montreal (*situ*) in the midst of extensive corn-fields.[1] He found everywhere maize,[2] "mil gros comme poix, pareil a celui qui croit au Bresil, dont ils magent au lieu de pain." In the brief record of the second voyage mention is made of its use by the Indians. Champlain arrived in 1603 on the St. Lawrence, and found the Five Nations at war with the Adirondacs. The Adirondacs were hunters, but the Five Nations made the planting of corn their business.[3] He says,[4] "that when coasting eastward from the River Quinibequey (Kennebec) he saw the Indians planting their 'bleds d'Inde,' and that in every hill they put four Brasilian beans which grow of many colors, and as they grow they wind about the corn, which rises to the height of five or six feet. The soil was feebly scratched with hoes of wood or bone."[5]

The Puritans landed on the bleak and inhospitable New England coast in 1620. Captain Miles Standish, with fifteen others, at once set out to explore the country. We are told that they very soon found "much plain ground," about 500 acres fit for the plough, and some signs where the Indians had formerly planted their corn.[6] Later, they discovered a cache. Indian corn carried them over the long dreary winter of 1620–21, for it is mentioned in an early narrative "that they bought greate stores of venison and eighte hogsheads of corne and beanes.[7] In the spring of 1621 the Puritans began to plant their corne, in which service Squanto (an Indian) stood them in great stead, showing them both ye manner how to set it, and after how to dress and tend it. Also he tould them excepte they got fish and set within these olde grounds, it would come to nothing, and he showed them yt in ye middle of Aprill."[8] "We set the last spring some twenty acres of

[1] Delafield, Trans. New York Agric. Soc., 1850, 382.

[2] Trumbull, J., Torrey Botan. Bull., VI, 86.

[3] Transactions Canadian Institute, I, Part I, 90; Colden, History of Five Nations, London, 1747: Bailey, J. M., Ensilage, 77, Slafter, Champlain, Prince's Soc. Publ.

[4] Champlain, Narrative (final edition), 1632.

[5] Champlain's Account, American Antiquarian, VII, 18.

[6] Mourt's Relations, 125–130.

[7] Mourt's Relations, 79.

[8] Mass. Hist. Soc. Coll., 4, III, 1856, 100; Goode, G. B., American Naturalist, XIV, 473.

Indian corne, and sowed some six acres of barley and pease." . . . . "Our corne did prove well, and, God be praised, we had a good increase of Indian corne and our barley indifferent good."[1] Before the Indians learned from the English the use of a more convenient instrument, they tilled their ground with hoes made of clam shells, for which purpose they were well adapted.[2] In Edward Johnson's "Wonder Working Providence of Sion's Saviour in New England, being a Relation of the First Planting of New England, 1628, London, 1854," he says: "Many thousands of these [herrings] they used to put under their corn, which they planted in hills five feet asunder, and assuredly when the Lord created their corn He had a special eye to supply these his people's wants with it, for ordinarily five or six grains doth produce six hundred." Winthrop, in 1630, obtained 100 pounds of corn from the sea side of Cape Cod.

The Connecticut colonies, founded at a later date than the one at Plymouth, soon came into unfriendly contact with the Indians, and in 1637 the Pequot war broke out. In the history of the Pequot war, it is recorded "that the Pequots had two plantations three miles asunder, and above 200 acres of corn, which the English destroyed."[3] Roger Williams states that in the war between the Narraghansetts and the combined forces of the Mohegans and Pequots, the latter committed extensive robberies and destroyed twenty-three fields of corn. The Puritans in King Philip's War, in 1675, took "what he had worth, spoiled the rest, and also took possession of one thousand acres of corn, which was harvested by the English and disposed according to their direction."[4] Everywhere the Puritans found maize.[5]

The Dutch East India Company sent out Hendric Hudson on a voyage of exploration. Hudson, when anchored off the

[1] Mourt's Relations, London, 1622.

[2] Mass. Hist. Soc. Coll., VII, 193: Holmes, Bureau of Ethnology, 11 Rep., 207; Wood, New England Prospects, 106.

[3] Mourt's Relations, Drake, 116: Trans. Wisc. Academy of Sciences, VI, 87.

[4] Drake, Old Indian Chronicle, 209

[5] Morton, New England Memorials, 1826, 68; Gooken, Mass. Hist. Coll., Chap. III; Bradford History Plymouth Plantation, 82, 100; Mourt's Relations, Wood, New England Prospects; Williams, Roger, Key.

Catskills in 1609 bought ears of Indian corn, pumpkins and tobacco.[1] New Amsterdam was seized by the English, but the French still claimed the northern portions along the St. Lawrence. Marquis de Nouville, in his celebrated expedition against the Seneca Indians, says: "On the fourteenth of July, 1685, we marched to one of the larger villages of the Senecas, where we encamped. We remained at the four villages of the Senecas ten days. All the time we spent in destroying the corn, which, including the old corn that was in cache, which we burned, was in such great abundance that the loss was computed at 400,000 minots, or 1,200,000 bushels. This was in Ontario County, New York.[2] The French army, under Frontenac, spent three days in 1696 destroying the corn of the Onondagas.[3]

The Swedish settlements in New Jersey and Pennsylvania were obliged to buy maize of the Indians for sowing and eating, as Kalm writes.[4] Quaint old Gabriel Thomas, writing about 1696, tells us that "they live chiefly on maze or Indian corn, roasted in the ashes, sometimes beaten, boyled with water, called homine."[5] Heriot refers to the cultivation of maize in Virginia, in 1586, called by them pagatour.

Jamestown was founded in 1607. During this year, Captain Newport, who commanded the colony, went up the Powhatan River to visit the chief Powhatan, who he relates had extensive fields that came down to the river's edge, in which fields Powhatan cultivated corn, beans, pumpkins, tobacco. The English at Jamestown were sustained by the liberality of the natives. Pocahontas in person accompanied "conductas" of grain.[6]

The Indians taught the settlers the use of maize.[7] Captain John Smith, in his "Indians of Virginia," says: "The greatest labor they take is in planting their corne, for the country is naturally overgrown with wood. To prepare the ground, they

[1] Trumbull, J. E., Torrey Botanical Bulletin, VI, 86; Wisc. Academy of Sciences, 30.
[2] Aboriginal Monuments of New York, 63-66.
[3] Documentary History, New York, I, 212
[4] Trans. New York Agric. Soc., 1850.
[5] Public Ledger, Dec. 27, 1892, 3.
[6] Jones Antiquity of Southern Indians, 296.
[7] Jefferson's Notes on Virginia; U. S. Patent Office Report, 1854, 98.

bruise the barke of the trees neare the root, then doe they scortch the roots with fire, that they grow no more. The next year, with a crooked piece of wood, they beat up the weeds by the roots, and in that mould they plant their corne. Their manner is this: They make a hole in the earth with a sticke [*cf.* "John Pope, his Tour," 1792], and into it they put foure foote one from another the graine. Their women and children do continually keepe it with weeding, and when it is growne middle high they hill it about like a hopyard. In Aprill, they begin to plant, and so they continue till the midst of June. What they plant in Aprill they reap in August; for May in September; for June in October. Every stalke of their corne commonly beareth two ears, some three, seldom any foure, many but one, and some none. Every eare ordinarily hath betwixt 200 and 500 grains. The stalke being green hath a sweet juice in it somewhat like sugar cane, which is the cause that when they gather their corne they sucke the stalks."

Cabeça de Vaca landed in Florida in 1528, near Tampa Bay. He found there maize, beans and pumpkins in great plenty and abundance.[1] De Soto set sail for the New World in 1538. He landed in Florida in 1539. De Soto frequently speaks of the Indian villages, that contained from 150 to 200 dwellings, guarded sometimes with tall palisades, and surrounded by extensive fields of maize, pumpkins and beans. In one instance, he narrates that his army passed through continuous fields of maize for two leagues. His band soon ran short of provisions, and the Indians were robbed to furnish a supply. At one place, they took enough corn to feed the Spanish company for five days. He writes: "On October 18, we came to Mobile, a walled city, which we captured, and where we rested forty days. On March 3, we departed north with maize enough for sixty leagues."[2] From Tampa Bay, De Soto addressed a letter to the justice and board of managers in Santiago de Cuba, informing them that Baltazzar

[1] Torrey Botanical Bulletin, VI, 86: Cabeça de Vaca Relations, 1528, translation by Buckingham Smith, New York, 1871

[2] Wisc. Academy of Sciences, VI, 87.

de Galligos, who with eighty lancers and one hundred foot soldiers he had sent to reconnoitre the country, had seen fields of maize, beans and pumpkins, with other fruits and provisions in such quantity as would suffice to subsist a very large army without knowing a want. De Soto's officers found in one place 500 measures of ground maize, besides a large quantity of grain.[1]

Captain Ribaut and the French Huguenots sailed up the St. John's River, Florida, in 1562, and founded Port Royal. Captain Ribaut[2] says: "About their houses they labor and till the ground, sowing the fields with a grain called mahis, whereof they make them meal, and in their gardens they plant beans, gourds, cucumber, citrons, peas and many other fruits and roots unknown to us."[3] In the narrative of René Laudonnière (1564), he says of his expedition from Fort Caroline, at the mouth of the River May (St. John's): "I departed with fifty of my best soldiers in two barks, and arrived in the dominion of Utma, distant from the river, where we took him prisoner. They [his tribe], therefore, brought me fish in their little boats and their meal of maize." Le Moine, in his "Narrative," illustrated with drawings and written in 1564, mentions maize. "I sent a second expedition with two shallops, having soldiers and sailors aboard, with a present to be given in my name to the widow of a deceased chief named Hionacara, who lived twelve miles north of us. She received my men kindly, and loaded both of our shallops for me with maize and nuts, and sent in addition some baskets of cassine leaves, of which they make a drink."

In Plate XXI, Brevis Narratio,[4] six Indians are seen preparing the ground and sowing corn. The explanatory note reads:

"Diligenter colunt terram Indi; eam ob causam ligones e piscium ossibus parare norunt viri quibus manubria lignea aptantes, terram fodiunt satis facile, nam mollior est: ea de-

[1] Lawson, History of the Carolinas, 296.

[2] Jones, Antiquity of Southern Indians, 299.

[3] The Whole True Discovereye of Terra Florida, London, 1563.

[4] A Brief and True Report of the new found land of Virginia (Florida is meant here). Thomas Hariot, 1590.

inde probe confracta et aequata feminæ fabas et milium sive. Mayzum serunt, præeuntibus nonnullis, quæ defixo in terram baculo foramina faciunt, in quæ fabæ et milii grana injiciaantur."

A Jesuit missionary named Marquette, with a trader named Joliet, and five other Frenchmen, started out to reach a great river in the far west, of which much had been heard. The explorers reached the Mississippi, and sailed to the mouth of the Arkansas. Marquette says: "The first was a dish of sagamite, that is, some Indian meal boiled in water."[1] La Salle, another Frenchman, built a canoe on Lake Erie and paddled through the Lakes, in 1679, as far as Green Bay. From there, by Lake Michigan, they went to the mouth of the St Joseph, crossed the Illinois and made their way back by Lake Ontario. Father Hennepin and another priest, during La Salle's absence, went down the Illinois to the Mississippi, and up this river to the Falls of St. Anthony. La Salle and Hennepin met on the Illinois, for Hennepin, in his narrative, states: "We continued our course (up) this river very near the whole of December, toward the end of which we arrived at the village of the Illinois, about one hundred and thirty leagues from Fort Miami. We found nobody in the village, yet we durst not meddle with the corn they had laid under ground for their subsistence, and to sow their land with, it being the most sensible wrong one can do them, in their opinion, to take some of their corn in their absence. However, our necessity being very great, and it being impossible to continue our voyage, M. La Salle took about forty bushels of it hoping to appease them with some presents. We embarked again with this fresh provision, and fell down the river the first of January, 1680. We took the elevation of the pole, which was 33° 45′."[2] Hennepin evidently accompanied La Salle in 1682 to the lower Mississippi. In his narrative he says: "I was surprised to see their Indian corn, which was left very green, grown already to maturity, but I have learned since that their corn is ripe sixty days after it is sown." M. Le Page

[1] Contributions to North American Ethnology, v, 53

[2] Hennepin's Account, Reprint Trans. Antiq. Soc., 1, 73.

Du Pratz[1] states (page 226) that maize is the natural product of this country. "Louisiana produces several kinds of maiz, namely, flour maiz, which is white, with a flat and shriveled surface, and is the softest of all kinds; homony corn, which is round, hard and shining—of this there are four sorts, the white, the yellow, the red and the blue; the maiz of these two last colors is more common in the highlands than in lower Louisiana. For the grinding of their corn they use large wooden mortars, formed by hollowing the trunks of trees with fire."

General Wayne, writing in 1783 about the Miamis, states that along the river were endless maize fields, the like of which he never saw from Canada to Florida.[2]

Cabeça de Vaca traveled westward through Texas,[3] and the Indians supplied him with prickly pears and occasionally maize, but after crossing a great river coming from the north (Rio Grande), he came into a country "whose inhabitants lived on maize, beans and pumpkins." On August 4, 1528, "incursions were made with the people and horses that were available, and on them were brought back as many as 400 fanegas of maize"[4] [3200 bushels].[5] Friar Marco de Nica, in 1539, traveled through northeastern Mexico, and New Mexico. "And they presented unto me many wilde beastes, as Conies, Quailes, Maiz, Nuttes of Pine trees and all in great abundance."[6] Coronado (1540) immediately set to work to explore the adjacent country near Cibolo (Pueblos). Hearing there was a province in which there were seven towns similar to those of Cibolo, he dispatched thither Dom Pedro de Tobar with seventeen horsemen, three or four soldiers and Friar Juan Padilla, a Franciscan, who had been a soldier in his youth, to explore it. "The rumor had spread among the inhabitants of a very ferocious race of people who bestrode horses that devoured men, and, as they knew nothing about horses, this information filled them with the greatest aston-

[1] Du Pratz, History of Louisiana, 1758, translation, London, 1763.
[2] Arch. für Anthropologie, 1886, 535; Carr, Lucien, Kentucky Geol. Survey, 11.
[3] Trumbull, J. E., Torrey Botanical Bulletin, VI, 86.
[4] Relation Cabeça de Vaca, Smith, N. Y., 1871, 47.
[5] Fanega represents eight bushels.
[6] Hakluyt's Early Discovery and Voyages, 1600, 441.

ishment."[1] They, however, made some show of resistance to the invaders, in their approach to their towns, but the Spaniards charged upon them with vigor; many were killed, when the remainder fled to the houses, sued for peace, offering as an inducement, presents of cotton stuff, tanned hides, flour, pine nuts, maize, native fowls and some turquoises."[2]

Ferdinand Alarçon discovered and entered the Colorado River in the year 1542. He states "that he went up the river eighty-five leagues, when his pirogue was arrested by lofty mountains, through which the river ran, where it was impossible to draw their boats; and as far as they went they found the Indians cultivating maize."

Columbus,[3] in his letter to Ferdinand and Isabella, dated May 30, 1498, writes, "the most remarkable inference is that they used maize, which is a plant that bears a spine (or awn) [silk] like an ear of wheat, some of which [wheat] I took with me from Spain, where it grows abundantly; this they regard as most excellent, and set a great value upon it." Columbus saw the bread of the plant called mahiz.[4] In one of his letters, he speaks of his brother: "During a journey in the interior he found a dense population entirely agricultural, and at one place passed through eighteen miles of corn fields."[5]

When the eastern coast of Yucatan was discovered maize was found cultivated. Cordova, in 1517, sailed from Cuba,[6] and explored the north coast of Yucatan, where "the Indians sowed maize, and were in possession of gold."[7] The Spanish Governor of Cuba later sent out an expedition (1518), in the same direction under the command of Grijalva, He explored Yucatan and the southern shore of Mexico, and verified the belief that there was a rich empire in the interior. The Indians presented Grijalva with the bread of maize.[8] Cortez landed in Mexico, and at Cempaolla ate bread of maize. He

[1] Castaneda's Relations. Ternaux Compans. 59

[2] Smithsonian Report, 1869. 316.

[3] Ford, Paul L., Writing of Christopher Columbus, 1892. 125.

[4] Bailey, J. M., Ensilage, 77.

[5] Aborigines of the Isthmus of Panama: Popular Science Monthly, XXII 427.

[6] Bailey, J. M., Ensilage. 77.

[7] Agricultural Production, U. S. Census, 1880. Maize.

[8] Agricultural Production, Tenth Census, 1880. Maize.

found Geronimo, a Spaniard, digging as a slave in the maize fields. On the road to the City of Mexico they passed through large fields of waving corn, where the Aztecs ambushed themselves, and shot arrows at the cruel and hated invaders.[1]

The following extracts taken from a variety of sources will prove sufficiently the general cultivation of *Zea mays.*

"The Indians of Yucatan put the maize into water with lime to steep over night. It is then given to carriers, who make it into large balls or pellets, which they take with them for food."[2] Villagutierre[3] says: "Grandes milperias, en que se dans dos cosechas de frutos, consecutivos al año y las mazorcas y granos de maiz en extremo gruessos." Clavigero[4] contains the substance of the earlier writers. He says:[5] "In the labor of the fields the men assisted the women. It was the business of the men to dig and hoe the ground, to sow, to keep the earth about the plants, and to reap [contrast the Iroquois, among whom the squaws tilled the soil]; to the women it belonged to strip off the leaves from the ear; and to clean the grains; to weed and shell it was the employment of both."

"In the market places in Nicaraugua the women sell slaves, maize, fish, deer, etc." "Maize and cacao are the principal objects of barter, and form media of exchange."[6] "The men were above all things farmers, and cultivated maize and other crops."[7] There was a mountain tribe who, in burying a corpse, crooked the legs, and put the head on the knees, and tied it tightly, so that it would remain in this posture; then they digged a round hole and put the body in it; round the body they put food, a chocolate cup, a calabash with atole, salvados of maize, and large maize tortillas; the whole was then covered with earth. The salvados were destined for the animals that the dead ate; the tortillas for the dogs that were killed and eaten.

[1] Cortes, Cartas, 64; Torquemada, Monarq. Ind., I, 515
[2] Landa, § 21.
[3] Villagutierre, Hist. Itza y Lacandon, Lib. 8, cap. 12, Madrid. 1761.
[4] Clavigero, Storia Antica de Messico, 1780.
[5] Bk. VII, ch. 28.
[6] Oviedo, Bk. XLII, ch. 3 (1535).
[7] Landa, § 23.

"The food of the poor Indian was maize."[1] "Among the Indians of Huancavilcas, the best-flavored maize bread is made in all the Indies."[2] "As no maize can be raised at the elevation of Callao the people obtained their supply by the Titimaes, who brought up loads of maize, cacao and fruits of all kinds, besides plenty of honey" (Cieza, ch. 99). The Incas extended the maize land over the newly conquered provinces by the construction of irrigating canals and terraces.[3]

Garcilasso de la Vega, the last of the Incas, whose accounts are highly overdrawn and must be received with caution, says[4] that the palace gardens of the Incas were ornamented with gold and silver figures of maize, and in one case he tells us that there was an entire corn-field of considerable size, representing maize in its erect and natural shape.

DIVISION 2. ABORIGINAL CULTIVATION.—The Indians of North America followed very closely one method in the sowing and cultivation of their maize; in the hot, arid districts the practice necessarily differed from that pursued in more favored localities, but broadly speaking the methods were one.

The Navajos and Mojaves, of New Mexico, planted their corn with a pointed stick.[5] The Moquis, of Arizona, in raising corn, are beset with annoyances, like drought and flood. The soil is thin and sandy, with very little moisture at the top, because of the evaporation induced by the heat and dryness of the atmosphere. The under strata of clay and sandstone, however, retain the moisture a long time. The Moqui farmer consequently buries the seed deep in the ground. He takes his planting stick (see illustration) in his right hand, and presses on the horizontal bar with his foot, making a

[1] Pizarro, P., Relacion de la Descubrimento y Conqueste Peru, 1529, 379.

[2] Cieza, Travels, 1532, ch. 114.

[3] Garcilasso de la Vega, 1609, Bk. v, ch. 5.

[4] Garcilasso, Com. Real, Lib. 8, cap. 26; Sarmiento Relacion, MSS., cap. 24; Sturtevant, New York Agric. Soc., 1878, 45.

[5] Emory, Rep. U. S. and Mexican Bound. Surv., 1, 112; Ind. Off. Rep. Spec. Com., 1867, 337; Merriwether, Ind. Off. Rep., 1854, 172.

hole in the ground from twelve to eighteen inches deep, in which he drops the kernel of corn. As a guard against

floods and winds the corn is planted in bunches. In the Moqui fields five, six, and even ten stalks will be seen growing close together with another cluster ten feet off, and so on; each cluster is almost surrounded at the foot by small branches, wisps of hay, and little piles of mud brought down by rain currents.[1]

The Mexicans, having neither plows nor oxen, used a hoe called coatl, made of copper, fitted with a wooden handle. The fields, in many cases, were surrounded by stones and a hedge of aloes. The maize sower drilled the ground with a stick and dropped the grain, covering the kernel with his foot.[2]

The production of maize was manifold. Gomara[3] cites the yield as 100 to 150 fold: "Suelo dar una hanega de maiz en sembradura seys, diez, veynte, treynta, cinqüenta, ciento é aun ciento é cinqüenta é mas é menos hanegas segund la fertilidad é bondad de la tierra donde se siembra."[4] Humboldt says: "In the fine plain between San Juan del Rio near Queretaro, one bushel produces eight hundred bushels. It can be laid down, as a general rule, that the production of this cereal in New Spain was about 150 fold."

Division 3. Indian Use.—Dr. Franklin mentions one of the methods that the Indians adopted in the preparation of their maize as an article of food. A vessel of sand was heated. The corn was then mixed with this sand and slowly heated

[1] Bourke, J. G., Moquis of Arizona, 96; Loew, Oscar, Popular Science Monthly, V, 354.

[2] Clavigero, Bk. VII, ch. 28.

[3] Steffen, Die Landwirthschaft beiden Alt Amerikanischen Kulturvölkern, Leipzig, 1883.

[4] Oviedo, Hist. Gen., Lib. 7, cap. 1.

until the grain burst. It was then taken out and ground to a fine powder, which kept fresh for a number of years. Heckewelder[1] called this preparation psindamocan. Captain John Smith, in his narrative states that "they rost their corne in the eare greene, and bruising it in a mortar of wood with a polt, lap it in rowles in the leaves of their corne, and so boyle it for a dainty." "They also preserve their corne late planted that will not ripe, by roasting it in hot ashes, the heat thereof drying it. In winter they esteem it, being boiled in leaves, for a rare dish they call pausarowmena." Heckewelder[2] says: "That the bread is of two kinds, one made of milk corn, the other of the dry and fully ripe. The last is finely pounded and sifted and kneaded into dough. This dough is made into round cakes about six inches in diameter and about an inch thick. These cakes are baked in the cleanest of wood ashes. Frequently they mixed with the dough pieces of pumpkin, beans, chestnuts, whortleberries and other palatable ingredients. They make an excellent pottage of their corn by boiling it with fresh or dried meat (the latter pounded), dried pumpkins, beans or chestnuts. The pottage is sometimes sweetened with the sugar or molasses from the maple tree. A very good dish is made by boiling well-pounded hickory nut kernels with the maize. The nut liquor gives a rich and agreeable flavor to the food." Loskiel[3] mentions that the Indians frequently mixed smoked eels and shell fish, chopped fine, with their corn-meal in the making of bread. Their common food, says Captain Bernard Romans,[4] is *Zea*, or Indian corn. "They make meal; they boil it; they parch and then pound it, taking this pounded material on long journeys." "They also have a way of drying and pounding their corn before it comes to maturity; this they call bootacopassa, *i. e.*, cold flour. This, in small quantities, thrown into cold water, boils and swells up, as much as common meal boiled over a fire. It is a hearty food, and, being sweet,

[1] Heckewelder, Indian Nations, 195.

[2] Heckewelder, Indian Nations, Mem. Hist. Soc. Penna., XII, 195.

[3] Loskiel, Mission North American Indians, Lond., 1794; Abbott, C. C., Primitive Industry, 1881, 149.

[4] Romans, Concise Natural History of East and West Florida, New York, 1775, 68.

they are fond of it." Du Pratz describes the making of what he calls farina froide. The corn is first parboiled in water; the water is drained off and the grain is dried. The dried kernels are roasted on a plate, ashes being mixed with them to prevent burning. The grains soon take on a red color with constant stirring, and are then removed and well rubbed. They are then mixed with the ashes of the dried stalk of kidney bean and a little water added, and the mixture is thoroughly pounded into meal. The dough is thoroughly dried in the sun, and when wanted for use is mixed with about two-thirds water. It affords a nourishing and satisfying food.

Dr. Edward Palmer[1] describes the use of maize among the Indians of the southwestern States. The Apaches cook their maize by dropping hot stones into the vessel containing the ears or grain. They ferment a drink from the grain which is strong enough to affect the Indians powerfully. He describes the uses of the cereal among the Pueblos. The blue grains are rubbed in a stone mortar and give a meal of a bluish-gray color. A thin dough is then kneaded with this meal. A hot fire is kindled, over which a flat stone or iron plate is laid. The women, with the fingers of the right hand, together dip them into the dough and draw them out again thickly covered, and spread the paste in a thin layer on a hot stone or plate. The mass quickly puffs up, a sign that one side is done, and it is then turned over, while the second cake is placed on to bake. Finally the flap-jack is rolled over and finished. When eaten it appears at first dry, but is sweet and easily chewed. A second method of preparation is to cook in lime water until the hard covering is removed. It is then pounded to a white flour and made into bread. The "enthülste korn" is often cooked with pieces of meat, and red or green pepper is added. When this is baked in the husks it forms what is called by the Mexicans tomale, The maize meal, when cooked with the sugar from the mesquite (*Prosopis juliflora D. C.*), constitutes the dish called pinole. The crude meal is often made into a kind of bread, which the Spaniards call tortillas.

[1] Palmer, Monatschrift f. Gartenbaues, 1874, 163, cited.

The Mexicans made their bread in the following way: They put a large pot filled with water on the fire, which they allowed to remain until the water boiled; then they put out the fire and poured the grain into a pot. A little lime was added to destroy the skin of the corn, and next morning they carefully cleansed the grain, ground it by stones, and, moistening the meal, formed it into a paste, which they kneaded and baked into tortillas.[1] Tortillas of maize, accompanied by the inevitable frijoles, or beans seasoned with chile or pepper, and washed down with drinks prepared from the maguey and cacao, were the all-sustaining diet of the Nahuas.[2]

The Mexican drink, "chicha," is made from maize. A quantity of grain is soaked in water, and is taken out and sprouted. The sprouted grain is bruised and placed in a large vessel filled with water, where it stays until it begins to ferment. A number of old women then collect and chew some of the grain until they have a sufficient quantity, which is added to water and allowed to ferment. The fluid is drawn off after fermentation, and a strongly intoxicating liquor is produced.

DIVISION 4. MYTHOLOGY.—It has been frequently asserted that the Indian had no religion excepting what has been called "the meaningless mummery of the medicine man." This is the very reverse of the truth. The Indian was essentially religious and contemplative, and it might be said that every act of his life was regulated by his religious belief, as the following accounts of ceremonies, myths and legends show. George Catlin[3] has described the green corn dance, as practiced by the Minnetaree: "The green corn is considered a great luxury by all those tribes who cultivate it. This joyful occasion is one valued alike and conducted in a similar manner by most of the tribes who raise corn, however remote they may be from each other. It lasts but for a week or ten days, being limited to the longest terms that the corn remains in this

[1] Brocklehurst, Mexico of To-day, 1883, 200.
[2] Bancroft, Native Races Pacific States, 347.
[3] Smithsonian Report, 1885, Part II, Catlin Indian Gallery, 314.

tender and palatable state, during which time all hunting, and all war excursions, and all other avocations, are positively dispensed with, and all join in the most excessive indulgence of gluttony and conviviality that can possibly be conceived. The fields of corn are pretty generally stripped during this excess, and the poor, improvident Indian thanks the Great Spirit for the indulgence he has had, and is satisfied to ripen merely the few ears that are necessary for his next year's planting, without reproaching himself for his wanton lavishness, which has laid waste his fine field and robbed him of the golden harvest which might have gladdened his heart, with those of his children, through the cold and dreariness of winter."

The time of the harvest was also a season of festival and rejoicing, when elaborate ceremonies were performed. The festival was known among the Creeks as the Boos-ke tau (time of maturity), or, for short, in English, the "Festival of the Busk." Colonel Benjamin Hawkins has left us an account of this feast:[1] "On the morning of the first day the warriors clean the yard of the square and sprinkle it with white sand. The acee, or decoction of the cassine yupan (*Ilex cassine*), is made. The fire-maker kindles the fire as early as he can by friction. Four logs, each as long as a man can cover by extending his two arms, are cut and brought by the warriors and placed in the centre of the square, end to end, thus forming a cross. The outer ends indicate the cardinal points of the compass. In the centre of the cross the new fire is made. These four logs are burnt out during the first four days. The Pin-e-bun-gau (turkey dance) is danced by the women of the turkey tribe, and while they are dancing the possau is brewed. This is a powerful emetic. From twelve o'clock to the middle of the afternoon the possau is drunk. After this four men and four women dance the Toc-co-yuh-gau (tadpole) from evening until daylight. E-ne-hau-bun-gau (the dance of the people second in command) is danced by the men. About ten

[1] Hawkins, Sketch of Creek Country, Coll. of Georgia Hist. Soc., III, 75: Jones, C. C., Antiquity of Southern Indians, 303.

o'clock the second day the women dance Its-ho-bun-gau (the gun dance), and after twelve o'clock the men go to the new fire, take some of the ashes, rub them on the chin, neck and body, jump head foremost into the river, and then return again into the square. The women having prepared the new corn for the feast, the men take some of it and rub it between their hands, and on their faces and breasts, and then feast."

"During the third day the men sit in the square. Early in the morning of the fourth day the women get the new fire, clean out the hearths, sprinkle them with sand, and kindle their fires. The men finish burning out the first four logs, and then, rubbing themselves with the ashes on their chins, necks, and bodies, go into the water. This day salt is eaten, and they dance O-bung-gau-chap-co (the long dance). The fifth day four new logs are brought and placed in the same position as on the first. They drink also acee, the strong decoction of the cassine yupan. During the sixth day they remain in the square, and on the eighth, they get two large pots and their physic plants, and beat up with water. The chemist (E-lic-chul-gu) blows into the decoction through a small reed, and then the men drink it and rub it over their joints until afternoon. They then collect old corn-cobs and pine-cones, and placing them in a pot burn them to ashes. Four virgins bring ashes from their houses, and having put them into the pot, stir all together. The men take white clay and mix it with water in two pans. A pan of this clay and one of ashes are carried to the cabin of the Mico. Two pans similarly filled are taken to the cabin of the warriors; with the clay and ashes they rub themselves. Two men, appointed to that office, bring flowers of tobacco of a small kind (itch-au-chu-le-puc-pug-gee), or, as the name imports, the old man's tobacco, which was prepared on the first day, and putting it in a pan in the Mico's cabin, give a little of it to all who are present. The Mico and the counsellors then go four times around the fire, and every time they face the east throw some of the flowers into the fire. They then go and stand to the west; the same ceremony is repeated by the warriors. A cane is stuck up in the cabin of the Mico, with two white feathers in its end. A member of the fish tribe (Thlot-lo-ul-go) takes it just as the sun goes down, and moves off toward the river, all following him. When half way to the river he gives the death whoop. This he repeats four times between the square and the water's edge. Here they all locate themselves as close together as they can stand. The cane is stuck up at the water's edge, and they all put a grain of old man's tobacco on their heads and in each ear. At a given signal, four times repeated, they throw some of this tobacco into the river, and every man upon a like signal plunges into the stream and picks up four stones from the bottom. With these they cross themselves four times on the breast, each time throwing a stone into the river and giving the death whoop. They then wash themselves, take up the cane with the feather, return and stick it up in the square, and visit through the town; at night they dance the mad dance, and this ends the ceremony."

The Zuñians were divided into fifteen clans, organized chiefly for social intercourse and amusement, which are of very ancient origin. These clans corresponded in no way with the division of the people into gentes. The corn clan was especially sacred among the Zuñians. The Moquis and Pueblo Indians of San Felipe, Santa Anna, Zia, Zemez, Cochiti and Isleta had corn clans.[1] During the frequent ceremonies carried on by this clan, the songs sung were in a language long since lost.[2]

Cushing[3] has vividly described the dances of the Zuñi, and the important use that corn has played in all their mystic ceremonies. He has described the mythological creation and origin of corn as narrated by the Zuñians. "Yet, not less precious was the gift of the seed people or Ta-a-kwe. This was Tchu'-e-ton, or the medicine seed of corn, for from this came the parents of flesh and beauty, the Solace of Hunger, the Emblem of Birth, Mortal Life, Death and Immortality. Born before our ancients had been other men, and

[1] Journ. Amer. Folk Lore. III, 1890.

[2] Smithson. Miscel. Col. Philos. Soc., Wash., IV, V; Trans. Anthrop. Soc., XXV, 88.

[3] Cushing, Zuñi Bread Stuffs, The Millstone, Indianapolis, Vol. IX, Jan, 1884.

these our fathers sometimes overtook and looked not peacefully on them. It thus happened, when our ancients came to their fourth resting place on their eastward journey, that they named Shi-po-lo-lon-kaia, or The Place of Misty Waters, there already dwelt a clan of people called A'-ta a, or Seed People, and the seed clan of our ancients, challenged them to know by what right they assumed the name and attributes of their own clan. It is well, replied the strangers, yet life ye did not bring. Behold! . . . . Behold, indeed, where the plumes had been planted and the tchu'-e-ton placed, grew seven corn-plants, their tassels waving in the wind, their stalks ladened with ripened grain. These, said the strangers, are the severed flesh of seven maidens, our own sisters and children. The eldest sister was yellow corn; the second, blue; the third, red; the fourth, white; the fifth, speckled; the sixth, black; the seventh, sweet corn. . . . . Aye, we may, replied the strangers, and of the flesh of our maidens ye may eat, no more seeking the seeds of grasses." Cushing thinks that the strangers A'-ta-a, or Seed People, were the Keres to the east of Zuñi, who taught the Zuñi the use of corn.

Bourke[1] describes the snake dance as practiced by the Moquis: "The women extend their line fully, all the while scattering corn-meal. A portion occupy the terrace directly above the arcade, a few on ladders near the archway; the main body, however, stand in the space between the sacred rock and the sacred lodge. Two or three, reinforced by a lot of old cronies, do effective work at the eastern end of the rectangle. Nearly all carried the beautiful woven baskets, ornamented in yellow and black with the butterfly and thunder-bird painted on the side. The baskets were filled with finely ground corn-flour, which was scattered with reckless profusion into the air and upon the reptiles as fast as thrown down."

"This corn-meal has a sacred meaning, which might be well to remember. Every time the corn was scattered the lips of the squaws moved, as if in prayer. A sacred meal is prepared of corn-meal and chalchihuitl, called cunque. All

[1] Bourke, Moquis of Arizona, 163

the Pueblo Indians along the Rio Grande use it, and upon rising in the morning throw a pinch of it to the east. The Zuñis and Moquis are never without it, but carry it in little bags tied to their waists." The use of this meal resembles the crithomancy of the Greeks, but is not identical with it. Space will not permit any further account of the use of maize in the ceremonial religious observances of the Pueblo Indians, but the reader is referred for more detailed accounts to

A Journal of American Archæology and Ethnology, Vol. II; (A Few Summer Ceremonials at the Tusayan Pueblos; Hemenway Expedition.)

The Millstone, Indianapolis, Ind., 1884—Article, Zuñi Bread Stuffs; Cushing.

The Aztecs worshipped several deities. Tlaloc, for instance. was the god of waters, of rain, and of the fertilized earth, Ixtlixochitl represents him in the picture of the month Etzalli with a cane of maize in one hand and in the other an agricultural implement.[1] Centeotl (Ceres) was the goddess of maize, and, consequently, from the importance of the grain, the goddess of agriculture and of production generally. Many of her names seem dependent on the varying aspects of maize. The fruits of the field were consecrated to her.[2] The feast to this goddess, begun April 27, was elaborate, and maize was used in a variety of forms at various stages of the performance. Bancroft has given a detailed account, and those who wish a fuller description can find it in his colossal work, "The Native Races of the Pacific States."

The Mayas similarly used maize in their festivities. The Cakchiquels, in Guatemala, were a Maya tribe. "A little more, and they would make a god of maize," says an old writer. All the labors of the field were conducted with religious rites. The men, for instance, who did a large part of the field work, refrained from approaching their wives for some days before they planted the corn. Incense was burned at the corners of the field to the four gods of rain and wind

[1] Bancroft, H. H., Native Races Pacific States, III, 325.

[2] Jos. de Acosta, Nat. Hist. West Ind., Lib. 4, cap. 16, 236; New York Agric. Soc., 1848, 682; Trans. Illinois Agric Soc., 1856-7, 473; Trans. New York Agric Soc., 1878, 47.

before weeding the plot. The first fruits were consecrated to their deities.[1]

The Peruvians, during the feast Capacraqui, in the first month Raymi, permitted no stranger to lodge in Cuzco. In the early portion of the month Hatuncuzqui, corresponding to our May, the Peruvians gathered their maize, and kept the feast Aymorai. "They returned home singing from the fields, with them a large heap of maize, which they called Perua, wrapping it up in rich garments. They continued these ceremonies for three nights, imploring the Perua to preserve their harvest of maize from any danger."[2]

This historical review shows conclusively that maize was of all plants the one used universally by the Indians.

G. *Summary and Recapitulation.*

A glance at the American continents a century before the Columbian voyages shows the greater portion of the continental areas occupied by hunter tribes just emerging from a wild nomadic life and entering upon a partial sedentary agricultural condition. In the eastern United States, the trees were girdled by the stone axes of the aborigines, seed was sown between the trees, and corn planted in these forest clearings and on the rich river bottoms grew luxuriantly. The prairie was inhabited by nomadic tribes, who made buffalo hunting their principal business, while here and there over the broad surface of the central plain, tribes more sedentarily inclined, as the Mound-builders of the Ohio and the Pawnees of Louisiana, cultivated maize. A little further to the west, in the arid tracts of the West, lived tribes in storied structures of adobe, who raised their crops by irrigation of the simplest description. Closely allied to these Pueblo Indians, in the common derivation of their house styles, were the timid cliff-dwellers, who hid themselves in the caves and pockets of the cañon sides. Far to the south, on the plains of Anahuac,

[1] Ximenez. Francisco, Las Historias del Origin de los Indios. London. 1857. 191; Brinton, Annals of the Cakchiquels, 13.

[2] Trans. New York Agric. Soc., 1878, 47; Browne. D. J., Trans New York Agric. Soc., 1848. 690.

dwelt a people with established armies, central government and populous cities, with temples, palaces and market places, the latter supplied with the fresh produce of the surrounding country. The Nahua civilization, which reached so high a plane, was, nevertheless, preceded by one which in many respects excelled that of the Aztecs, and excavations clearly attest to the vigor and numerical strength of this peaceful agricultural race.

The different tribes of the American race all showed peculiar individual idiosyncrasies, but linguistic study shows that, with all this diversity, American agriculture was borrowed from a common source—the Mayas of central Mexico.

Philological comparisons show that the Indians east of the Mississippi, the Iroquois, the Mound-builders, the Algonquins and the Muskogees obtained maize from across the "Father of Waters," probably from the Caddos, who in turn derived it from the northern Mexican tribes. The Pueblos, as archæology and ethnology seem to prove, are only a few centuries removed from the wild state exhibited by the roving Apaches and Navajos, and, therefore, as compared with that of the Mayas, their agriculture is comparatively recent.

Philology places the Nahuas in the Shoshonean stock with the poor root-digging Ute of the plains. Their warlike propensities and love of conquest carried them south, until they reached the plateau of Anahuac, when, attracted by the peaceful and promising surroundings, they laid aside their savage life and copied the superior civilization and agriculture of the tribes (Maya) about them.

Archæology and ethnology both place the Mayas in the vanguard as husbandmen, and to reach this development required considerable time; the cultivation of Yucatan and southern central Mexico, as the permanent seat of this race, antedates the tilling of the soil by the Peruvians[1] on the one hand, or the pueblo-builders on the other.

Hieroglyphics[2] on the monuments at Palenque, indicate that maize was the chief food of the people of Yucatan;

[1] The Standard Natural History, Vol. VI, 219, corroborates this statement.

[2] Science, XXI, 1893, 8.

here it was first used and distributed to the surrounding tribes, who by barter carried it to the farthest limits of the continents.

The evidence of archæology, history, ethnology and philology, which points to central and southern Mexico as the original home of maize is supported by botany and meteorology. All of the plants closely related to maize are Mexican. It is an accepted evolutionary principle, that several species of the same genus, or genera of the same tribe, though dispersed to the most distant quarters of the globe must originally have proceeded from the same source, as they are descended from the same progenitor. It is also obvious, that the individuals of the same species, though now in distant regions, must have proceeded from one spot, where their parents were first produced; for it is incredible that individuals, identically the same, should have been produced from parents specifically distinct. Applying these principles to maize, we reach the conclusion that maize was originally Mexican. Monotypes and genera, which contain but a few species have, as a rule, a very restricted area. *Zea* is monotypic, and is singularly unprovided with means of dispersal, so that the area of its original home must have been especially circumscribed. The discovery of a very primitive form in Mexico aids in determining the wild limits of the species. Meteorology helps in fixing the area more definitely. The question naturally arises, in what part of southern central Mexico did the Indians first find the maize plant? Its original home must not be looked for in low-lying districts nor in forests, for maize does not thrive in warm, damp climates, where manioc is grown.[1] The region above 4500 feet altitude and south of twenty-two degrees north latitude, and north of the River Coatzalcoalcos (ninety-four degrees west, seventeen degrees north) and the Isthmus of Tehuantepec, fulfills more nearly the conditions which the wild form required for its development.

The evidence to the present date places the original home of our American cereal, maize, in central Mexico.

[1] Sogot, Cult. des Cereales de la Guyane, Franc. Journ. de la Soc. Centr. d'Hortic. de France, 1872, 94.

Notwithstanding the indisputable fact that maize is of American origin, and the statements of such men as Dodoens, Camerarius, Matthioli, Gerard, Ray, Parmentier, Discourlitz, Bonpland, De Candolle, Humboldt, Darwin, F. Unger, von Heer, James, Targioni-Tazzetti, Hooker, Figuer, Nuttall, Mrs. Summerville and Flint, the contrary that the cereal is of eastern origin has been asserted. Bock, 1532, Ruellius, 1536, Fuchsius, 1542, Sismondi, Michaud, Gregory, Lonicer, Regnier, Viterbo, Tabernamontanus, Bonafous, St. John, De-Herbelat and Klippart have argued for an Asiatic origin. A discussion of this question is interesting historically.

The ancient authors on agriculture, Theophrastus, Varro, Columella, Pliny, Palladius, Galen and Dioscorides, do not mention maize. The principal argument for an eastern origin is based upon a charter of the thirteenth century, the Chart of Incisa, according to which the Crusaders, in 1204, gave to the town of Incisa a piece of the true cross, and a purse containing a seed of a golden color. Comte de Riant[1] has shown this charter to be a fictitious fabrication of a modern impostor.

Such names as Turkish wheat, Sicilian corn, Spanish corn, Guinea corn, Roman corn, have been used in the argument for the eastern origin of maize, but they prove no more than the word turkey (coq d'Inde) argues for the Turkish origin of the American fowl.

The total silence of the travellers who visited Asia and Africa before the discovery of America, also militates against an eastern origin. Notwithstanding this, China has been frequently called the original home of maize; this impression became current because of an illustration in an ancient Chinese work on natural history. Dr. Bretschneider,[2] an authority on Chinese cultivated plants, does not hesitate to say that Indian corn is not indigenous to China, and Shigeno Aneki has undertaken to prove how in Japan certain historical episodes were "cooked" under the Tokugawa dynasty of Shoguns. "A little reflection will show that such manipulations of history are likely to be the rule rather than the

[1] Riant, La Charte d'Incisa, 1877.

[2] Bretschneider, Study and Value Chinese Botan. Works, 7, 18.

exception in Asiatic countries. The love of truth for truth's sake is not a general human characteristic, but one of the exceptional traits of the modern European mind, developed slowly by many causes, chiefly by those of habits of accuracy, which physical science does so much to foster. Outside Europe and her colonies, it is easy to manipulate records, because such manipulation shocks no one deeply, because the people are told nothing about the matter, and because, even if they were told, they have neither the means nor the inclination to be critical."[1] Siebold places the home in Japan,[2] but Rein[3] speaks unhesitatingly against a Japanese origin. Maize is not used largely as a food in Japan, and but two varieties are known there. The Japanese name (to-morakoshi or nau-bau-kibi, grain of the southern barbarians, Portuguese or Spaniard) clearly indicates a foreign origin.

All these arguments come to naught when thoroughly sifted, and do not in the least militate against the American origin of maize.

[1] Chamberlain, Things Japanese, 164.
[2] Siebold, Verhandl. Batav. Genotsch, XII.
[3] Rein. Petermann's Geogr. Mittheil, 1878, 215-17.

CHAPTER III.

Geographical Distribution.

MAIZE originated in all probability in a circumscribed locality, above 4500 feet elevation, north of the Isthmus of Tehuantepec and south of the twenty-second degree of north latitude, near the ancient seat of the Maya tribes. There is hardly a doubt but that the Mayas first cultivated maize and distributed it in every direction. The time that this people emerged from obscure savagery is not known, but it was not earlier than the advent of the Christian era. This places a time limit on the cultivation of maize. From the Mayas, the use of the cereal spread north and south. The Nicaraguan and Isthmian tribes obtained it from tribes farther north. The Isthmian Indians traded with the Chibchas, who were in close commercial intercourse with the Peruvian State, in the region of Quito. The indomitable Inca race enlarged its territory by conquest until its influence, dominion and agriculture extended to the farthest limits of Chili. Comparative philology affords definite proof that the wild tribes in the El-Gran-Chaco and on the Cordilleras learned their use from the Incas, for the tribes along the Ucayali, Mamore and Beni rivers have Peruvian loan-words for maize. The Arawaks, who later peopled the West Indian Islands, knew maize when still in their primitive home in the Bolivian highlands, and it is probable that their knowledge of agriculture was derived from their more cultured neighbors on the Pacific coast plain. The Arawak words for maize used by the tribes on the islands and in central South America are identical in form in many cases, and it is surely safe to say, therefore, that Indian corn was carried by the Caribs and Arawaks from the South American continent by way of Guiana and the Greater and Lesser Antilles to Florida.

The Nahuas borrowed their arts, sciences and agriculture largely from the Mayas. Agriculture, the chief occupation of the Aztec race, spread to the Pueblo Indians on the Rio Grande River, and from there it extended eastward to the Mississippi. A comparative linguistic study shows that the Chahta-Maskokis had loan-words, indicating that the cereal came from the West across the "Father of Waters." Some of these Southern tribes are identical with the mound-builders, who were driven south by the Iroquois-Algonquian eruption. During times of movement and conquest the impulse is powerful toward imitation, and inter-tribal imitation is even more strong than that between one individual and another. It is easy to show how, under the bracing influence of race competition, the forces of change would operate to initiate new habits and progress toward a higher state of existence. This tribal interchange of culture happened when the Algonquins and Iroquois moved southward, where they simultaneously learned the germs of agriculture.

The northern extension was limited by the isothermal line of 50° F. (13° C.), or the latitude of the great lakes. Corn can be raised in Maine with certainty a few miles south of Umbagog. It is raised with less certainty on the lake shores, and on the upper stretches of the Penobscot the corn crop is precarious.

In South America, east of the Andes, the cultivation was limited to districts comparatively free of forest, and where the ground was sufficiently elevated for the best growth of the plant.

The map of the western hemisphere (Plate XVII) accompanying this chapter displays the original home of maize and its distribution in space and time.[1] It is probable that maize reached the Rio Grande about 700 A.D., for Humboldt states that the Aztecs learned of maize in 666 A.D. By the year 1000 A.D. it had reached the coast of Maine. The Incas used

[1] The squared areas on the map (Plate XVII) show the position of the agricultural tribes in North and South America. It is evident that the position of the agricultural tribes and the area of maize distribution are identical. See explanation accompanying map. See also chapter on Ethnology for position of said tribes and the grade of their culture.

it before 700 A.D. Agriculture was practiced on both continents and on the islands in the Gulf of Mexico by the year 1492, for when the Europeans arrived it was found everywhere. The Europeans carried it to Europe, from whence it spread.

Maize was introduced first into Spain. Gerard, in his Herbal, states that "these kinds of grain were first brought to Spain, and thence into the other provinces of Europe, not (as some suppose) out of Asia Minor, which is the Turk's dominion, but out of America and the islands adjoining, as out of Florida and Virginia, or Norumbega." M. E. Discourlitz says positively that maize was brought to Europe by the Spaniards from Peru,[1] and Matthioli, in 1645, affirms that Turkish wheat is not a proper name for maize, but that it should be called Indian wheat, because it came from the West Indies.

The names in Spain, Belgium, France, Germany, Greece, Italy, Russia, Sicily and Sweden indicate that it was received from Turkey, but this confusion was due to associating the newly-discovered islands and continents with the East Indies, the trade with which was carried on by way of Turkey and the eastern Mediterranean. These mistaken geographical notions were not rectified until 1522, when the globe was first circumnavigated, and the lands to the west were proved to be wholly distinct from the Asiatic continent. But the name given to corn naturally lingered and became part of common language, and as time passed it was impossible to correct the mistaken impression. France appears to have derived the plant from Spanish and West Indian sources. Grains of it were sown in the sixteenth century in Spanish, Italian, French, German and English gardens, and soon the plant was cultivated on a larger scale in the fields. Under the name kukuruz, it was naturalized in Turkey, the Danubian countries and Hungary.

It came to Germany from Italy, as Turkish wheat, or wälschkorn. "Our Germany," says Hieronymus Bock (Tragus), in his Neu Kreüterbuch, Strasburg, 1539, "will soon be called

[1] Peruvian word zara was used in Spain (see pages 89 and 126), which shows that the word mahiz, maize, was not yet generally adopted.

felix Arabia, because we accustom so many foreign plants to our soil, from day to day, among which the large wälsch-korn is not the least important." Italy probably obtained seed from Sicily and Spain, and Sicily from Spain and the Americas. The confusion of names is great. Maize is called in Lorraine and in the Vosges, Roman corn; in Tuscany, Sicilian corn; in Sicily, Indian corn; in the Pyrenees, Spanish corn; in Provence, Barbary or Guinea corn. The Turks call it Egyptian corn, and the Egyptians, Syrian dhourrah. But the widest spread name was Turkish wheat, which came from a misconceived notion as to its origin. Ruellius uses it first in 1536[1] All that can be said with certainty, however, is that Indian corn reached northern and central Europe from the countries bordering on the Mediterranean. It was introduced into Africa by the Portuguese in the sixteenth century, and is cultivated more or less from the Middle Sea and the Libyan Desert to the Cape of Good Hope.[2] It is particularly deserving of attention that the greater number of the plants cultivated on the Congo, and among them nearly all of the most important species, have been introduced from other parts of the world—maize, manioc, or cassava, and pine-apple.[3]

Maize early reached India and Burmah. Baden Powell observes in his "Punjaub Products," that maize grows everywhere throughout the hills, and appears to flourish as well in a temperate as in a tropical climate at 7000 feet or more. It is the favorite crop of the people, and for six months of the year forms their common food. It is supplanted in the valleys by rice, but even here there is always a little plot of maize about the cottages of the peasant classes.

The Chinese used it early after the discovery of America, for the Portuguese reached Java in 1496, and China in 1516.[4] Mayers[5] believes that it was introduced into China from Lower Mongolia in the sixteenth century. The introduction through Mongolia is highly improbable, but the date of a

[1] Ruellius, De Natura Stirpium, 428.

[2] Simmonds, Tropical Agriculture, 1877, 295.

[3] Brown, Robert, Miscellaneous Botanical Works of, Ray Soc. 1, 155.

[4] Malte Brun, Geographie, 1, 493.

[5] Mayers, Journ. Bot., Seeman's, 1871, 62.

treatise on Natural History, published in 1597 (Pen-tsao-kung-mu), furnishes us abundant proof that the Chinese did not know it before the discovery.

1557, introduced into the Cape Verde Islands.

1593, Hawkins finds it in the Canaries.

1595, maize introduced into the Marquesas Islands.

1775, Thunberg enumerates maize among the edible plants of Japan.

The present cultivation of maize extends throughout both American continents. In Europe, M. de Gasparin[1] assigns as the region of maize the plains which border on the Pyrenees, the valleys which descend from the Jura, all Italy, Corinthia, Austria and Hungary. It is cultivated in Asia Minor, India, China, the Phillippines, the Malay Archipelago and Australia, and furnishes in all these places a most important food for man and beast. The surprising and rapid extension, in such a short period of time, has depended on the merits of the plant as an important article of food.

[1] Gasparin, Lecouteux, "Le Mais" Paris, 1853, 260

CHAPTER IV.

CHEMICAL.

IT is important to study the chemistry of a plant for the following reasons: (1) It is necessary to know the value of the plant as a human food. This has been determined by practice, but scientific analyses are essential if we desire to compare a new food with older and more established ones. The Germans have made painstaking analyses to discover the cheapest and most economical foods for use in the army, and the commissary department, after much experimentation, has turned its attention to maize. (2) Different plants take from the soil a varying proportion of plant food. It is necessary to estimate this loss in order to supply deficiencies. (3) Products once wasted are now saved. This is essentially a utilization of bye-products. Chemical investigation is useful in ascertaining the value of refuse.

The chemical analyses which follow have been selected and arranged with great care from the most reliable sources.

TABLE I.

Relations in Weight between Different Portions of Maize in the Green State.[1]

Leaves	29.20	
Tassel	.66	47.87
Ear, stem	18.01	
Upper stalk	7.56	
Middle "	14.86	52.13
Lower "	30.01	
	100.00	100.00

1 Goffart, Culture and Ensilage of Maize. 41.

The analyses which follow display in a summarized form the constitution of the plant at different seasons of growth. Boussingault[1] gives an analysis of seedlings of maize, after a period of twenty days' germination. The table has been adapted for the chapter.

As the embryo grows the reserve materials in the seed diminish in quantity. They are conveyed to the seedling, and are used by it to form new protoplasm and new cell walls. "The effect of the absorption of these substances by the embryo is that the cell-sap of the cells of its ground-tissue become charged with them, for the absorption is much more rapid than the consumption in the formation of proteid; consequently the seedling soon comes to contain a larger percentage of them than does the organ in which they are being formed. If the seedling is growing under favorable conditions these substances gradually disappear, and this is accompanied by an increase in the amount of proteid contained in the seedling." The following table shows this exactly:

TABLE II.

Analysis of Seeds and Seedlings After Twenty Days' Germination. Absolute Weight in Grammes.

	Total Dry Weight.	Carbohydrates, Starch, Sugar.	Oil.	Fibre, Cellulose.	N. Substance.	Ash.	Extractives.
	Gr.	Gr.	Gr.	Gr.	Gr.	Gr.	Gr
Seeds . . .	8.636	6.386	0.463	0.516	0.880	0.156	0.235
Seedlings .	4.529	1.730	0.150	1.316	0.880	0.156	0.297

[1] Vines' Physiology of Plants, 176.

TABLE III.

Proximate Composition of the Whole Plant at Successive Periods of Growth.[1]

Weight of One Plant on	Grammes Dry Matter.	Per Cent. Dry Matter.	Crude Ash Per Cent.	Ether Extract. Per Cent.	Crude Fibre, Per Cent	Crude Protein, Per Cent.	Carbo-hydrates, Per Cent	Nitrogen Per Cent.	Period of Growth.
June 11	3.25	13.91	8.46	3.39	19.82	25.00	43.33	4.00	Vegetative Period.
" 16	2.94	11.34	. . .	2.80	20.24	. . .	. . .	. .	
" 21	18.35	11.22	11.82	3.09	24.82	28.06	32.21	4.49	
" 26	29.35	11.77	8.35	3.70	24.78	21.56	41.61	3.45	
July 2	50.08	9.11	9.81	2.13	26.20	14.62	47.24	2.34	
" 9	83.27	11.05	6.97	2.78	28.46	13.18	48.61	2.11	
July 16	280.32	15.71	4.43	2.70	32.12	9.12	51.63	1.46	Flowering Period.
" 23	236.04	15.30	5.09	3.01	29.92	10.25	51.73	1.64	
" 30	256.05	19.06	5.50	2.01	30.58	8.00	53.91	1.28	
Aug. 6	331.96	17.82	5.22	2.29	28.81	9.37	54.31	1.50	
" 13	411.40	20.31	4.59	1.64	23.88	10.56	59.63	1.69	
" 27	612.91	23.41	4.31	1.03	24.48	7.12	63.05	1.14	
Sep. 10	542.15	. . .	3.66	1.03	19.24	8.89	67.18	1.42	
" 24	563.35	. . .	3.88	1.03	17.56	10.26	67.27	1.64	

[1] Schweitzer, P., Missouri Agric. Exp. Stat. Bul., December, 1889, 23.

The foregoing table gives analyses at different periods of growth.

This table shows the general tendency of the plant to increase rapidly in all its parts up to August 6. After this the stores are emptied into ear and grain, and additional increase comes from the activity of the husks rather than from the leaves. These, in so far as they are situated below the eighth or ninth node, the usual seat of the ear, become productively inactive and dry up, whilst those above them yield their substance to the ear, and after drying represent a less valuable material than the lower ones. Both become very brittle when dry and are usually lost in the process of harvesting.

The following table, prepared for the United States Department of Agriculture, collected from the reports of forty-nine experiment stations and many other sources, including the publications of schools, colleges and agricultural societies in the United States and Canada, is a compilation of all analyses published before September 1, 1890. A variety of methods were used in the determinations by the earlier chemists, so that a slight discrepancy exists between the results of the older and later published analyses.

TABLE IV. (*a*)

Analysis of Maize Fodder of Different Varieties,[1] *Cut Green. Percentage.*

		In Fresh or Air-dried Material.					
	No. of Analyses.	Water.	Ash.	Protein (N. x 6.25).	Crude Fibre.	N. Free Extract.	Fat.
Flint . . .	40	79.8	1.1	2.0	4.3	12.1	0.7
Dent . . .	53	79.0	1.2	1.7	5.6	12.0	0.5
Sweet . .	21	79.1	1.3	1.9	4.4	12.8	0.5
All variet.	129	79.3	1.2	1.8	5.0	12.2	0.5

[1] Experiment Station Record, II, 702.

TABLE IV. (*b*)

Analysis of Maize Fodder of Different Varieties, Cut Green. Percentage.

CALCULATED TO WATER-FREE SUBSTANCE.

	NUMBER OF ANALYSES.	ASH.	PROTEIN.	FIBRE.	N. FREE EXTRACT.	FAT.
Flint	40	5.2	9.7	21.3	60.6	3.2
Dent	63	5.7	8.3	26.3	57.1	2.6
Sweet	21	6.0	8.9	21.2	61.7	2.2
All varieties . . .	129	5.6	8.8	24.1	58.9	2.6

An analysis of the roots is given. The roots, especially in their later stages of growth, are covered by a brown and exceedingly tough incrustation of sand and clay, which can be removed only by much washing and rubbing, and thus retain much earthy matter, as the analytical data show.

TABLE V.

Proximate Composition of Roots at the Close of the Growing Period.[1]

Crude ash	2.93
Ether extract	0.48
Crude fibre	41.94
Crude protein	6.43
Carbo-hydrates	48.22
Nitrogen	1.03

[1] Schweitzer, P., Missouri Agric. Exper. Stat. Bul. 9 1889 5.

Table VI.

Percentage Composition of the Ash of the Root of One Plant.[1]

	June 21.	Sept. 10.
Silica	16.73	32.10
Ferric oxide	8.21	0.22
Phosphoric-pentoxide	4.38	14.41
Lime	10.12	5.57
Magnesia	5.37	4.02
Potassa	37.95	37.69
Soda	2.58	4.38
Total	85.32	98.39
Missing	14.68	1.61

Table VII.

Composition of the Different Parts of the Maize Plant.[2]

	Tassel.	Ears.	Leaves.	Stalk. Upper	Stalk. Mid.	Stalk. Lower.	Entire Plant.
Nitrogen	6.27	11.09	6.28	4.34	3.86	3.37	6.47
Fats, Sol. in Ether	1.90	2.50	1.30	1.00	.40	.30	1.28
Saccharine	4.70	8.30	6.50	17.00	20.60	21.00	11.77
Starchy	25.23	73.51	64.33	39.49	38.65	35.79	56.35
Cellulose	56.70	2.90	10.60	33.10	33.80	38.00	18.37
Mineral	5.20	1.70	10.99	4.57	2.69	1.74	5.74

[1] Schweitzer.
[2] Goffart, Composition and Ensilage of Maize.

TABLE VIII.

Centesimal Composition of the Ash of the Different Parts.

	Entire Plant.	Ears.	Leaves.	Tassels.	Stalk. Upper	Stalk. Mid.	Stalk. Lower
Phosporic Acid	71.70	33.50	3.97	10.01	9.07	14.02	7.17
Sulphuric "	3.81	3.58	3.21	6.13	5.61	8.65	3.81
Chlorine	1.35	3.52	1.04	2.73	2.15	traces.	1.35
Potash	4.41	27.11	1.23	7.88	14.61	2.41	4.41
Soda	8.26	21.36	6.78	10.37	12.57	8.39	8.26
Lime	12.96	3.46	13.78	11.87	10.29	14.31	12.96
Magnesia	6.60	7.04	5.64	15.03	10.52	8.73	6.60
Iron	0.51	traces.	0.46	0.11	2.08	0.63	0.51
Silex	54.75	0.34	63.76	35.83	29.83	41.37	54.75
CO and Waste	0.18	0.09	0.13	0.03	3.27	1.49	0.18
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In a subsequent chapter the manufacture of maize paper will be discussed. It is, therefore, necessary that the chemical composition of the maize husks, out of which the paper pulp is principally made, should be ascertained. (Schweitzer.)

TABLE IX.

Proximate Analysis of Maize Husks. September 10.

Crude Ash	6.23
Ether Extract	0.83
Crude Fibre	33.77
" Protein	4.37
Carbohydrates	54.80
Nitrogen	0.70

TABLE X.

Percentage Composition of Husks. September 10.

Silica	36.22
Ferric oxide	0.37
Phosphoric pentoxide	2.03
Lime	5.58
Magnesia	6.62
Potassa	37.66
Soda	2.68
Total	91.16
Missing	8.84

The table below gives the average of 500 analyses of corn kernel of dent, flint, sweet and pop varieties, raised in Connecticut, Kansas, Michigan, Missouri, Texas, Wisconsin, Massachusets, New Hampshire and Pennsylvania.

TABLE XI.

Analysis of Corn Kernel.[1]

	In Fresh or Air-dried Material.	Water-free Substance.
Water	11.0	..
Ash	1.5	1.8
Protein x 6.25	10.8	12.1
Crude fibre	2.1	2.4
N. free extract	69.5	77.4
Fat	5.5	6.2

[1] Experiment Station Record, 11, 706.

The nutrient ratio for the first half of the table is 1 : 7.5; for the second, 1 : 7.5.

Chittenden and Osborn have made an extended investigation of the proteids of the kernel of maize. The variety used was a white dent corn.[1] The grain contains several distinct proteids.

(1) Three globulins separable from the kernel by extraction with 10 per cent. salt solution; (*a*) myosin coagulable in 10 per cent. salt solution at 70° C., and directly dissolvable in water from the meal; (*b*) vitellin, non-coagulable in dilute salt solution, insoluble in water, 10 per cent. salt solution dissolving it after water extraction; (*c*) globulin separates from the above residient only after prolonged dialysis. It is coagulable in 10 per cent. salt solution at 62 C.

TABLE XII.

Composition of Maize Globulins.

	MYOSIN.	VITELLIN.	GLOBULIN.
Carbon	52.66	51.71	52.38
Hydrogen	7.02	6.85	6.82
Nitrogen	16.76	18.12	15.25
Sulphur	1.30	0.86	1.26
Oxygen	22.26	22.46	24.29

(2) Two albumins unlike in chemical composition and of uncertain structure.

(3) The chief proteid in the maize kernel is the peculiar body maize fibrin (zein), soluble in warm dilute alcohol, insoluble in absolute alcohol or water. Zein acts characteristically, is yellow resembling beeswax, is soft, tenacious, elastic and heavier than water. When heated it swells, turns brown, and leaves a bulky charcoal. It burns, but not rapidly.[2] The insoluble state is formed when zein is heated with water or a weak alkali.

[1] Amer. Chem. Journ., XIII, 453, 529. XIV, 14; Exp. Stat. Rec., III, 768.

[2] Gorham, Jno., Philos. Magaz., LVII, 311.

Table XIII.
Composition of Zein.

	Soluble Zein.	Insoluble Zein.
Carbon	55.28	55.15
Hydrogen	7.27	7.24
Nitrogen	16.09	16.22
Sulphur	0.59	0.62
Oxygen	20.77	20.77

The ferments in maize are: (1) diastase; (2) invertase; (3) a glyceride enzyme; (4) proteo-hydrolyst.[2]

Table XIV.
Composition of Ash of Kernels.[1]

	Chinese Tree.	Tuscarora, 11.	Rhode Island Sweet, 15.
Carbon dioxide	trace.	trace.	trace.
Silicic acid	1.700	0 775	1 125
Sulphuric acid	1.075	1.275	0 550
Phosphoric acid / Peroxide iron	49.185	44 135	44 050
Lime	0.620	0 395	0.335
Magnesia	16 200	12.875	12.810
Potassa	12.930	14.240	12.867
Soda	15.365	20 545	22 968
Chlorine	0.440	0.450	0.270
Organic acids	2.125	3 520	3.025

[1] Salisbury, J. H., Journ. New York Agric. Soc., 1849.
[2] Green, Annals of Botany, March, 1893, 91-116.

The cob yields a rich and abundant supply of potash. One hundred parts of dried cobs yield after drying at 212° F. the following:

TABLE XV.

Potash in Corn Cobs.[1]

	Ashes	K Cl.	K_2CO_3.	Silica, Iron, Lime.	Loss.
1	1.120	.820	.750	.140	.230
2	1.040	.805	.745	.180	.115
3	1.015	.840	.755	.245	.605
4	1.115	.830	.795	.300	.020

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[1] Hazard, H., Amer. Journ. Pharm., 4 ser., II, 152.

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CHAPTER V.

Agriculture—Physiological.

THE cultivation of Indian corn has been greatly improved within recent years. New machines have been devised for drilling the kernel into the ground, and new cultivators of improved pattern have been introduced. It is not essential, in describing the maize plant, to decide such questions as the merits of deep or shallow cultivation, the value of removing the tassels as a means of increasing the yield, the value of root-pruning, etc. These are questions of agricultural practice and extra limital.

This chapter will deal with practical physiological considerations, such as the effect of fertilizers and the measures necessary to restore soil fertility. The chemical changes which the soil undergoes during plant growth, and the proper rotation to be used in intensive agriculture will be discussed. The object will be to investigate rather the principles underlying fundamental practices, and it is hoped that the results will be of general and wide application.

From experiments at Rothamsted, on a large number of cereal and non-cereal plants, Messrs. Lawes and Gilbert have deduced many important principles. The German stations and the experiment stations of the United States also furnish material at hand for a general agricultural survey. A few general rules are given.

It is certain that the increased growth of our staple starch-yielding grains is greatly dependent on a supply of nitrogen in the soil.[1] The better the cereals are matured, the lower is their percentage of nitrogen, the explanation being that maturation means the greater formation of non-nitrogenous

[1] Gilbert, J. H., Agricultural Investigation, Rutgers College, N. J., 1884.

substance—starch.[1] It is equally certain that the increased production of sugar, as in sugar cane, is also greatly dependent on the supply of nitrogen.[2] With root crops, the amount of sugar is increased by the use of nitrogenous manures. Nitrogen applied to leguminous crops has comparatively little effect in increasing the product of such crops.[3]

Potash is essential for the formation of the chief non-nitrogenous matters, starch and sugar.

The results with leguminous crops show that mineral manures (particularly potash) considerably increased the early crops. Ammonia salts were of little or no benefit, and were sometimes injurious. It may be added that the beneficial effects of long previous applications of potash were apparent whenever there was any growth at all. When the land is "clover sick," none of the ordinary manures, whether artificial or natural, can be relied upon to secure a crop.

In experiments on the effect of various manures, applied on fields at Rothamsted for forty years, it was found that the plats which received ammonia salts alone, gave the smallest yield in bushels, twenty and one-quarter of wheat, and twenty-nine of barley. The sulphates with 600 pounds of ammonia, gave a yield of thirty-six and three-quarter bushels. It is seen that a mixture of mineral and nitrogenous manures worked to the best advantage.

Will principles laid down for England and English cereals hold for American cereal productions, especially maize? The results attained in the United States are summarized as follows:

Nitrogenous fertilizers materially increase the crop,[4] and the yield was poor when nitrogen was not applied.[5] Numerous experiments indicate that corn thrives well and yields fair returns when the fertilizer contains one-third or one-half the nitrogen removed by the crop.[6] The crops on the plats

[1] Gilbert, J. H., On Growth of Potatoes. Rothamsted, 20.
[2] Gilbert, J. H., Lecture at Rutgers College, N. J., 11.
[3] Lawes, Sources of N. of Leguminous Crops, 1892, 4.
[4] Georgia, Bul. 10, 1890 20; Exp. Stat. Rec., II, 550.
[5] Massachusetts Stat., 7th Annual Rep., 1889, 148; Exp. Stat. Rec., II, 579.
[6] Connecticut, Storr's Stat., 2 Rep., 1889.

receiving no nitrogenous manures were of a light green color, and during the first half of the season the same condition of the plant was noticeable on the plats receiving ammonium sulphate.[1] The light green color of a crop will indicate, generally, that the soil is deficient in available nitrogen. It is evident that chlorophyll formation has a close connection with the proper assimilation of nitrogen, but that the increased carbon assimilation does not take place unless with this additional chlorophyll sufficient mineral matter is present. The corn plant does not respond to heavy applications of nitrogenous manures. It is therefore easy to apply too much.[2]

The use of large quantities of nitrogen above the quantity utilized by the plant is a direct waste of money.[3] The use of superphosphates alone on corn is unsatisfactory.[4] The use of potash alone is unadvisable,[5] and of doubtful value. "The yield of ear corn on the two unmanured plats were respectively thirty-four and forty bushels per acre; on the three plats receiving fertilizers containing no potash, from thirty-three to thirty-six bushels, and on those receiving potash fertilizers, from sixty-five to seventy-six bushels; the largest yield was with the combination of potash and nitrogen."[6] When potash was used, there was a marked increase of crop (twenty-eight to thirty-nine bushels per acre), and the greatest increase was with a manure composed of potash and nitrogen (thirty-nine bushels). There was a profit in every instance where potash was used, and a loss (financially) where that element was left out.[7] Mixed superphosphate, potash and nitrate of soda yielded the best results.[8] The yield in all cases was larger when potash and superphosphate were applied with nitrogenous fertilizers.[9] Nitrogenous manures,

[1] Massachusetts Stat., 7 Rep., 1889, 148: Exp. Stat. Rec., II, 579.
[2] South Carolina Stat., 2 Rep., 1889, 210-268: Exp. Stat. Rec., II, 550.
[3] Connecticut, Storr's Stat., 2 Rep., 1889.
[4] Georgia, Stat. Bul., 10, 1890, 20.
[5] South Carolina Stat., 2 Rep., 1889, 210-268.
[6] Kentucky Stat. Bul., 33, 1891.
[7] Exp. Stat Rec., II, 725.
[8] Georgia Stat. Bul., 10, 1890, 20.
[9] Georgia Stat. Bul., 15, 1891: Exp. Stat. Rec., III, 604.

with potash alone, or phosphoric acid alone, or all three combined, increased the yield materially.[1]

The results prove that nitrogen combined with some mineral salt (potash preferably) materially benefits maize, and this essentially agrees with the physiological habit of the other cereals, wheat, oats, barley and rye. Notwithstanding this, William Frear and H. P. Armsby raised the question[2] as to the truth of the statement that maize, as a cereal, responded in increased starch to the increase of the nitrogenous manures applied. "Upon comparison of the results it was found that the nitrogen free extract in the grain produced upon plats receiving complete fertilizers, was the same in percentage no matter what form of nitrogen had been applied, and that in all cases where this ingredient was applied there was less nitrogen free extract than was found in the crops from the unfertilized plats." This argument is weakened by the fact that maize is a gross feeder, and must have its food in a shape to be readily absorbed by its deeply penetrating roots, and it seems that some time must elapse for the action of recently applied manures especially nitrogenous, which become slowly available, to take place. The Kentucky station records the fact "that the fertilizers applied in 1888 were of benefit to the crop of 1890," which clearly shows that it takes time for the nitrifying process to take place.

The nitrogen in the soil is prepared for the plant by the process of nitrification. The older theories explained this oxydizing process as a merely passive chemical reaction, taking place when suitable compounds were in contact. The newer theory, however, which is gaining ground, ascribes this process of nitrite and nitrate formation to living organisms—minute bacteria. The historical development is interesting. Pasteur stated long ago that probably the nitric acid was produced in soil by a living organism similar to those which cause fermentation and putrefaction. Schlösing and

[1] New York Stat., 8 Rep., 1892, 56-260.

[2] Nitrogen Supply of Maize, Soc. Promotion Agric. Sci. Proc., VII, 33: Rep. Penna. State College, 1889, Part II, 199.

Müntz established by experiment the true nature of nitrification.[1] Since these earlier trials additional proof has accumulated, showing that nitrification in water and soils is due to bacterial agents. Winogradsky[2] isolated by culture the nitrifying organism. Frank, Wilfarth, Hellriegel and other investigators have made many experiments which serve to show that the nitrification of ammonia in the soil, and probably the nitrification of other nitrogenous matters, takes place in two stages, and is performed by two distinct organisms. One converts ammonia into nitrite, the other changes the nitrite into nitrate. In the soil both organisms are present in large numbers. The action of the two proceeds together. The conditions favorable to their growth are alkalinity of soil, oxygen, and a proper base with which the acid can combine. Calcium carbonate usually plays this *rôle* in the ground. A soil deficient in such a base is generally infertile and needs dressings of chalk or lime.

These discoveries, combined with the equally important one that the utilization of free nitrogen by leguminous plants is due to bacteria which form nodules on the roots, will eventually revolutionize modern agricultural methods. Mr. Mason, of Eynsham, Oxfordshire, England, commenced some experiments in 1889, with a view of applying to practical agriculture the knowledge accumulated concerning the minute organisms. "His method is to grow nitrogen accumulating crops for home consumption, and afterwards nitrogen consuming crops for sale." He grows mixed crops of *Leguminosæ*, liberally fertilized with basic slag and kainit. He converts the first year's crop into silage, which he feeds to his cattle, returning the manure to the soil, and converts the second year's produce into hay. The land thus produces highly nitrogenous crops without manure, and is left in a high condition for potatoes or grain, which need nitrogenous manuring. The fact that it is necessary, in order to prevent "clover sickness," to grow in sucession a variety of *Leguminosæ*, will lead to radical and important changes in our present system of rotation.

[1] Compt. Rend., LXXXIV, 301.
[2] Winogradsky. Ann. de l'Inst. Pasteur, IV (1890-91), 213, etc.

The question is how best to conserve the nitrogen, the supply of which in sufficient quantity is so invaluable. The nitrogen is lost to the soil in three principal ways: (1) By drainage; (2) by removal of crops; (3) through the air. This waste goes on in all soils, in some more than in others. Sir John Lawes, in a paper on fertility, concludes that 3000 pounds of nitrogen have been lost in the Broadbalk wheat field at Rothamsted in the last 250 years. It is generally conceded that this waste can be prevented directly, to some degree, by growing crops through the season of the greatest production of the nitrates. Rotations properly arranged conserve the soil nitrogen. Thus, if red clover is sown in a growing crop of barley the land is covered immediately after the barley is cut, and the effect is as nearly perfect as possible, the growth of the second crop following the first without a break in the continuity. At Rothamsted it was found that on sampling the drainage waters and calculating the amount of nitrogen as nitrates contained therein, that the maximum discharge takes place from October to February, and the maximum nitrification takes place during the autumnal months.

The cereals, after a wet winter, begin to grow in the spring in a soil drained of nitrates, and the growth is over before the greatest production of nitrates takes place. These crops are, therefore, greatly benefited by nitrogenous manures. As the growth of maize takes place in the late summer months, it is more independent of nitrogenous fertilizers[1] than wheat, barley, etc.

The nitrogen, therefore, is best conserved with a crop whose period of growth extends into the period of maximum nitrification and maximum drainage of nitrates from the soil. Maize is just such a crop. Cereal crops whose growing periods are confined to the spring and early summer are very poor conservers of nitrogen. This accounts for the fact that maize does not exhaust the soil nearly so rapidly as wheat, which has its period of growth much earlier in the year.

[1] See Page 174.

CHAPTER VI.

Utility.

THE maize plant subserves many important uses. The study of our plants from a utilitarian point of view is recent.

Professor Goodale, in his presidential address at Washington, in 1891, before the American Association for the Advancement of Science, said[1]: "Improvement of the good plants we now utilize, and the discovery of new ones, must remain the care of a large number of diligent students and assiduous workers." "One phase of it is being attentively and systematically regarded in the great experiment stations; another phase is being studied in the laboratories of chemistry and pharmacy, while still another presents itself in the museums of economic botany."

As population increases, and the centres of mart and trade become more closely aggregated together, economic use of our food supplies must be inaugurated, and foods of small cost and great nutritive power must be substituted for those of great cost and very little food value.

Human Food.—Does maize possess the quality of a perfect food? This question can be answered only by a reference to analytical tables, and a comparison of the nutritive ratios of maize with other foods which enter into our dietaries. Evidently a proper food must minister to all the requirements of the human frame. A good food must supply the waste which takes place and maintain the system in a condition of vigorous health.

[1] Goodale, Pop. Sci. Month., November and December, 1891.

TABLE XVI.

Nutrient Ratios and Nutritive Values of a Series of Foods, for Comparison with Maize.

	RATIO.	VALUE.		RATIO.	VALUE.
Wheat	1 : 6.5	82.0	Yams	: 7.1	—
Indian wheat	: 5.2	84.6	Cabbages	: 4	7.5
Macaroni	: 5.6	89.6	Vegetable marrow	: 5	3.5
Oats	: 5.7	102	Tomatoes	: 5	8.5
Barley	: 12.25	85	Iceland moss	: 8	79
Rye	: 7	85	Irish moss	: 5.5	64
Rice	: 10	84	Celery	1 : 4.5	5
Maize	**: 7.5**	**87**	Apples	: 27	11.5
Millet	: 5.57	84.7	Gooseberries	: 20	9
Buckwheat	: 4.75	86	Grapes	: 20	16
Peas	1 : 2.50	79	Figs	: 10	68
Haricots	: 2.5	80	Bananas	: 4	24
Lentils	: 2.4	86	Carob beans	: 8.5	68
Peanuts	: 5.2	151	Walnuts	: 6.5	94
Soy	: 2	101	Coconuts	: 16	90
Potatoes	: 17	22	Milk	1 : 4	—
Turnips	: 6	4	Cheese	: 2.4	99
Carrots	: 14	7.5	Eggs	: 1.9	40
Parsnips	: 12	16	Calves' liver	: .3	—
Beet root	: 29	12	Beef	: .8	—
Jerusalem artichokes	: 8	16	Veal	: .1	—
Onions	: 3.5	7	Pork	: .7	—
Sweet potatoes	: 13	22	Mutton	: 1.1	—

The nutrient ratio is a comparison of the albuminoids, or flesh-formers, and the carbo-hydrates, or fat-formers. It is obtained by adding the quantity of starch, sugar, and the starch equivalent of fat together, and comparing the sum with the protein substances present. For a man at moderate work this ratio should stand as 1 : 5. The foregoing table gives the nutrient ratio and nutritive value of a large series of foods for comparison with maize.

The sum of the albuminoids, starch, dextrin and sugar, and the starch equivalent of fats, is called the nutritive value; this value is that of 100 parts (grains, ounces or pounds). It is seen from this table that the various food materials depart more or less from the standard ratio that we have adopted, 1 : 5, as most nearly expressing the proportion which the nitrogenous should bear to the starchy food. Maize departs considerably from the standard, and is poor in protein substances at the best. This fact rather unfits it for a standard article of food, unless combined with some other products which are richer in albuminoids. Thus peas, with the nutrient ratio of 1 : 2.5, can be combined with maize, and the deficiencies of both be equalized.

Animal Food.—The food requirements of an animal are very similar to those of man. A proper proportion of flesh producers must be combined with fat producers, in order to nourish the animal satisfactorily. The digestive systems of the different domesticated animals, however, differ from that of man, so the material fed must be of a different kind; for although broad principles can be deduced from experimental work on man, these principles must be modified and corrected by experiments carried on with farm-yard animals. Again, the kind of feeding must be conditioned by the purposes for which the animal is grown. Mutton for table use must be lean, and the shepherd must have a knowledge of the principles of nutrition, in order to prevent fat accumulation. On the other hand, if the sheep are to be grown for tallow, then fattening foods must be used. When these principles become more thoroughly recognized and observed, it will be possible to obtain more condensed protein matter for human food without the necessary loss in fat.

Milch Cows.—To determine the value of maize for all-round feeding reference must be made to a few experiments. The following is significant:[1] "The nutritive value of our dry corn stover and of a good corn ensilage, taking into consideration pound for pound of the dry vegetable matter they contain, has proved in our case fully equal, if not superior, to that of the average English hay." "The total cost of the feed for the production of milk is lowest whenever corn fodder or corn ensilage have replaced in the whole or in part English hay." The Wisconsin station made some experiments on the yield of butter and milk by animals fed on fodder corn. For a period of forty-two days, 1227 pounds of corn supplemented with 672 pounds of bran and corn meal produced 1487.72 pounds of milk and 58.68 pounds of butter.

A discussion of ensiled corn *versus* fodder corn has been engaged in. If it can be shown that the nutritive value of the ensiled material is higher than the field-cured, then the loss which occurs in the silo is immaterial.

TABLE XVII.

Results of Feeding Ensiled and Fodder Corn.[2]

	Food Consumed.				Products.	
	C.	Bran.	Corn Meal.	Water.	Milk.	Butter.
Ensilage . .	4960	504	168	2376	1688.14	62.3
Fodder corn .	1227	504	168	5235	1487.12	58.11

This table indicates that the largest product both of milk and butter occurred when the ensiled material was used. The Maine station (Rep. 1889) compares the value of corn silage and hay: "In these experiments the addition of ensiled corn

[1] Massachusetts Agr. Exp. Stat. Rep., 1888.
[2] Wisconsin Agric. Stat. Rep., 1888; Exp. Stat. Bul., U. S. D. A., II, 193.

resulted in an increased production of milk solids over that produced by hay." Again, with steers, the results showed that a pound of digestible matter from the corn silage produced somewhat more growth (flesh) than a pound of timothy hay. In comparing ensiled maize with hay, we find that the gain in live weight is the greatest when the ensiled material was used, as the following table shows:[1]

TABLE XVIII.

Showing Gain per Animal (Steers).

	WITH SILAGE.	WITH HAY.
First three weeks	66.3 pounds	43.3 pounds
Second three weeks . . .	57.7 "	46.3 "
Third three weeks	38.0 "	21.0 "

Pigs.—It has been largely the practice in the Western States to fatten pigs with Indian corn. The farmers have selected that breed of pigs which will take the greatest live weight (chiefly fat) to market. Experiments have been tried with the idea of determining the best and quickest way of fattening hogs for sale. The conclusions reached at the Kentucky station[2] were that fat is more rapidly produced by feeding shelled corn, and that corn affords the cheapest material for this purpose. The breeders in the great corn belt have considered it profitable to feed their corn instead of shipping the corn itself. Experiments at the Illinois station indicate "that during the first five or eight weeks of each trial, when one lot received only the half feed of corn with pasturage, the gain per bushel of corn was best in the case of the pigs on the full ration of corn, either with or without pasturage."[3] A mixed diet is not only cheaper, but more beneficial. At the Wisconsin station,

[1] Exp. Stat. Rec., III, 180; Virginia Stat. Bul., 10, June, 1891.
[2] Kentucky Stat. Bul., 19, May, 1889.
[3] Illinois Stat. Bul., 16, May, 1891; Exp. Stat. Rec., III, 149.
[4] Wisconsin Stat., 7 Rep., 1890; Exp. Stat. Rec., II, 438

experiments were made with hogs feeding for fat and for lean. The experiments showed the following points in favor of the hogs that had been fed on corn, shorts and bran, over those getting corn alone: (1) a more rapid growth; (2) a much more economical gain for food consumed; (3) much more blood in the body; (4) larger livers; (5) stronger bones in proportion to the weight of the body. Notwithstanding, a large part of the pork produced in the United States is grown on corn, and in consequence is excessively fat. With nitrogenous food swine have better developed organs and leaner flesh. Lean pork is more valuable as a human food, and commands better prices.

Sheep.—Facts indicate that corn as an exclusive grain ration does not give the best results when fed to growing or fattening sheep. The production of wool is very greatly dependent upon the nitrogen in the ration.

Chickens.—A consideration of the feed of chickens, which consists largely of maize, a highly carbonaceous food, shows that this diet works to the detriment of the fowls. "The fowls having the more nitrogenous food were always in better health, and their plumage, except during a short moulting period, was always full and glossy, while those having the more carbonaceous ration were oftener sick, and their plumage was always ragged and dull."[1] The gain in weight was the largest for the nitrogen-fed chickens.[2]

	Live Weight.		Gain.	
	July 26.	Nov. 27.	Pounds.	Per Cent.
I, Nitrogenous food	8.94	17.89	8.95	100.11
II, Carbonaceous food	9.06	12.63	3.57	39.40

"But the eggs laid (E. S. R., II, 506) by nitrogenous-fed hens were of small size, having a disagreeable flavor and smell, watery albumen, an especially small, dark-colored yolk,

[1] Exp. Stat. Rec., III, 37.
[2] Exp. Stat. Rec., II, 506.

with a tender, vitelline membrane, which turned black after being kept several weeks, while the eggs of the carbonaceous-fed hens were large, of fine flavor, natural smell, large, normal albumen, an especially large, rich yellow yolk, with strong vitelline membrane, which was perfectly preserved after being kept for weeks in the same brine with the other eggs." The following table is interesting in this connection. In the case both of the larger and smaller breeds the number and weight of the eggs were larger with the corn-meal ration than with the more nitrogenous mixture, the difference being greater with the smaller fowls. The fowls having the corn-meal ration continued to lay foı a longer period.

TABLE XIX.

Average Number of Eggs and Weight with Nitrogenous and Carbonaceous Foods.[1]

		No. Eggs.	Weight.	Food Per Day.
Smaller Fowls,	More nitrogenous food	43.7	91.48	2.43
Larger "	More nitrogenous food	48.9	108.24	3.30
Smaller Fowls,	Corn-meal ration	68.7	136.29	2.57
Larger "	Corn-meal ration	50.1	112.16	3.27

For chickens, feed nitrogenous materials; for eggs, carbonaceous.

Maize, with a nutrient ratio of 1:7.5, does not fill entirely the requirements of a well-rounded dietary. Unless combined with other more highly-charged nitrogenous foods, it works detrimentally. American agricultural production is one-sided. We are a generation of fat and sugar-eaters. Corn, our great staple, is poor in protein, at the best, and is poorly adopted for a staple food, unless combined with other materials. American dietaries range from 1:6 to 1:8, while the European standard is 1:4.5 to 1:5.5. The high consumption of carbo-hydrate vegetal food is largely augmented

[1] New York Stat. Bul., 29 N. S., April, 1891; Exp. Stat. Rec., III, 36.

by the use of fat meats. The ranchmen and swine-growers convert a large part of the product of the soil into the fat of beef and pork. The European farmer cannot afford to practice these wasteful methods, as the soil soon would become exhausted.

"Not only must Americans develop American resources, but Americans must adjust themselves to American conditions. American people in the end must live upon those articles of food for which American soil is most productive, and must cease to consume in large quantities, as they do, those articles for which our soil is poorly adapted. New articles of diet will find their way into use, and habits and customs will develop which will make the American of the future a man utilizing all the resources of our country."[1]

Principal Maize Products.

1	Whiskey.	10	Fuel.
2	Beer.	11	Fire Lighters.
3	Medicine.	12	Packing Material.
4	Glucose.	13	Mattresses.
5	Alcohol.	14	Pipes.
6	Oil.	15	Baskets.
7	Soap.	16	Thatch.
8	Paper.	17	Corks.
9	Fabrics.	18	Potash.
	(*a*) Fibres.	19	Substitute for Coffee.
	(*b*) Yarn.	20	Green Manures.
	(*c*) Cloth.		

MEDICINAL.—The stigmas of maize (corn silk) are used in medicine as maydis stigmata. They are diuretic and lithontriptic. The corn smut of fungal origin is used as an emmenagogue and parturient. An excessive use of ergot is

[1] Patten, S. N., Economic Basis Protection, 103.

attended by a shedding of the hair, or even of the teeth of man. Mules fed on it lose their hoofs, and fowls lay eggs without shells. Its action is as powerful, and even more so, than the ergot of rye. An infusion of maize leaves has been used as an anti-febrile, but its action is unreliable.[1]

SUGAR.—Experiments were conducted in 1879 to determine the yield of sugar from the maize plant. The stems contain, if taken at the proper time, a great quantity of saccharine juice. The sugar is crystallizable cane-sugar, and is not the worthless corn-sugar expressed from the plant. Professor Collier, in a special report, states that the sugar obtained was in a satisfactory condition in every respect, as shown by its high polarization, 90° (*cf.* sorghum 94°).

TABLE XX.

Comparison of Maize and Sorghum Sugar.

STALK.	PER CENT. JUICE.	SP. GR. JUICE.	PER CENT SYRUP TO JUICE.
Corn Butt Ends	29.04	1053	14.62
Corn Tops	19.94	1050	13.46
Sorghum Butts	44.49	1060.5	16.44
Sorghum Tops	38.62	1058	14.48

PAPER.—The moment must come sooner or later, when it will be absolutely impossible for the paper-makers to keep pace with the paper consumption, if they should not discover a satisfactory substitute for rags. Experiments have been made with the various vegetal fibres as a substitute for rags. Only plants produced in large quantities can satisfy the demand. Of the plants tried, maize seems to be the best adapted to the purpose. In the last century two maize-straw paper manufactories were in existence in Italy, according to Dr. Johann Christ Schaeffer's "Sammtliche Papierversuche" (Regens-

[1] Amer. Journ. Pharm., 3 ser. v, 315.

burg, 1772). Moritz Diamant, a Jewish writing master, in 1856, called the attention of the Bohemian Minister of Finance, Baron Bruck, to the value of maize fibre in the making of paper-pulp. The imperial paper factory at Schlögelmühle, near Glognitz, was authorized under Diamant's direction to make a certain amount of maize paper. The paper produced was not of a satisfactory quality, the cost was too great, and the manufacture forthwith stopped. Moritz then tried to interest private parties in his enterprise, but without success. In 1859 he again applied to the government, and Baron Bruck, at the advice of judicious men, again permitted Diamant to try his hand. It was found that the chief expense lay in the transportation of the crude material to the seat of operations. A half-stuff factory was erected in 1860, at Roman-Szt-Mihaly, near Temesvar, where the cultivation of Indian corn was extensive. The half-stuff was so poor that operations were again suspended. The first period in the manufacture of maize paper closed. These failures led to important results, for it was found upon further experimentation that the husks yielded a fibre which could be spun and woven. All the fibre and gluten wastes can be used in the manufacture of paper. Dr. Alois Ritter von Welsbach, Director of the Royal State Printing Establishment, discovered the process. The catalogues of the Austrian exhibition at London (1862), in German, French and English, consists of such paper. The manufacture of paper in Vienna from maize is, at the present time, in extensive operation. The "Allgemeine Zeitung," a scientific paper of importance, is made of maize paper. The yellowish tint is restful to the eyes.[1] The advantages of using Indian corn in the manufacture of paper are many: (1) Very little sizing is required; (2) it bleaches well; (3) it has greater strength than rag paper; (4) no machinery is necessary for tearing up the leaves.[2] In the manufacture of paper, the leaves are digested in hot water for two days. They are then separable into three parts: (1) The large veins and ribs, which serve for coarse gunny

[1] Intellectual Observer, III, 468.
[2] Amer. Journ. Pharm., 3 ser., IX, 232.

bags, cordage and the finer fibres for cloth; (2) the material between the ribs is made into bread of an agreeable taste; (3) the coarse paste, which finally separates, is used in the making of paper. The perfection of the process is largely due to the efforts of Pfob, Jung, Marsanich and others, men who deserve the highest commendation for their industrious perseverance.

Oil.—The oil is not obtained by direct expression, but the grain is malted, and the germ is separated by careful crushing and winnowing. The germs are then submitted to hydraulic pressure, and yield 15 per cent. oil, and a press cake rich in albumen, containing 4 to 5 per cent. oil. Maize oil is of a pale golden-yellow color, and has a peculiarly agreeable taste and odor. It is a thick liquid, and has a specific gravity of 0.9215 at 59° F. In consists of olein, stearin, palmitin, and contains some volatile oil. It solidifies to a quite solid mass at 10° C. (14° F.)[1]

Maize oil is well adapted for illuminating purposes, giving a bright white flame, and in burning it develops a high degree of heat. It is used advantageously in the dressing of wool, as a lubricant for machines. The yield is sixteen pounds to every 100 bushels of grain.

Fuel.—In the Western States, where the supply of fuel is precarious, the whole ear of corn has been used as fuel, but preferably the cob deprived of its kernels. Three tons of corn-cobs equal one ton of hard coal as fuel.[2] In France, the cobs, saturated with resinous matters (sixty parts melted resin, forty parts tar) are used as fire lighters, and are bought at prices ranging from twelve to twenty francs ($2.40 to $4.00) per thousand, according to the size used.[3]

The husks are used in packing oranges and cigars, in the stuffing of pillows, mattresses and lounges. The cob is used as a stopper for bottles. The toasted meal is substituted for coffee.

[1] Amer. Journ. Pharm., 4 ser., XV, 403; Bronnt, Animal and Vegetal Fats and Oils, 263.

[2] Journ. Soc. Arts, XXI, 235; Council Bluffs Nonpareil.

[3] Journ. Soc. Arts, XXIII, 887.

The cobs yield an abundant supply of potash. Large mills can furnish a big product of corn-cob potash. A mill shelling 500 bushels an hour turns out 7000 pounds of cobs an hour, or equal to 70,000 pounds per working day.[1] The cobs are used for fuel in the mills, and the refuse ashes are collected for the extraction of the potash, 1000 pounds of cobs yielding 7.62 pounds of potassium carbonate, or in a factory of the above capacity 535 pounds per day.

It seems strange that during the century which has elapsed since our birth as a nation no adequate conception has been reached as to the true value of the commonest product of our soil—our native Indian corn.

[1] Hazard, Amer. Journ. Pharm., 4 ser., 11, 152.

CHAPTER VII.

Economic Considerations.

THE importance of agriculture in laying the groundwork of a true national prosperity is recognized by all. A historical retrospect proves that with the decay of agriculture in the States of Greece and Rome and the growth of cities, the political habits of the people underwent a decided change for the worse. Many writers have pointed, therefore, with justifiable alarm to the last decennial census, which shows that one fourth of the entire population of the United States dwells in large towns and cities, and in many places the most progressive part of the rural classes have moved to the large industrial centres. Many forces conspire to produce this change. A few of them are the diminishing returns of agriculture, exorbitant transportation rates, natural monopolies, unsatisfactory financial conditions and state interference by partisan legislation.

The law of diminishing returns is that the product proportionally decreases with increased application of labor; that a time will be reached when, with intensive cultivation, the land will be finally and irremediably impoverished. Some decades ago very bad agricultural practice prevailed in the United States; one crop was grown exclusively on the same piece of land. The cereals, wheat, rye and barley, which were largely raised, sown successively for years in the same field, rapidly exhausted the soil of the most valuable ingredients. It is characteristic of starch and sugar-forming plants to take large quantities of nitrogen from the soil. The plants are so constituted physiologically as to need large supplies of nitrogen, potash and phosphorus for the proper storage of the carbo-hydrates. These three essential elements are the most difficult to restore to the land in sufficient quantities when once the soil is exhausted of them. There has been an over-production of the cereals in America, with the natural deteriorating effects upon the soil. The enormous exportation of 55,131,948 bushels of wheat in 1891 illustrates vaguely the annual drain upon our soils. The American system of agriculture is imperfect, slovenly and wasteful in the extreme. A change for the better has been manifested of late years.

Modern experiments prove that the production of the nitrogen-consuming plants (cereals, root-crops and fruits) should be alternated with the production of the nitrogen-storing plants, such as clover, beans, peas, vetches and lupins, which accumulate atmospheric nitrogen by the agency of the nodules on the roots, inasmuch as the soil is best conserved with a properly adjusted rotation. Mr. Mason's trials at Eynsham, Oxfordshire, are referred to a second time, as illustrating this important principle. His idea is to grow mixed crops of leguminous plants, liberally manured with basic slag and kainit, and to convert the produce of the first year into silage and of the second into hay. The land is thus occupied for two years and the assumption is that in this way highly nitrogenous crops will be obtained with mineral, but without any nitrogenous manure, and that the land will be left, so far as nitrogen is concerned, in a high condition for the growth of saleable crops, such as potatoes or grain, which need nitrogenous manuring. In other words, the plan, as he puts it, is "to grow nitrogen-accumulating crops for home consumption and afterwards nitrogen-consuming crops for sale or export to foreign countries."

This system should be extended so as to comprehend the whole country in a complete and perfect system of rotation. The adaptability of particular districts of the United States for certain kinds of agriculture, should be observed in combination with the most scientific succession of crops, one crop following another in such a manner as to yield the largest returns, and at the same time maintain the fertility of the soil. The plant best suited to any rural section, that is, the one from which best financial returns are expected, should be grown as the major crop, and the other plants subordinated as minor crops. In the growth of maize as a major crop, for instance, in any locality, the minor crops should be associated with each other and with maize, so as to permit of the largest production of maize, and, at the same time, prevent rapid soil exhaustion. The major crop, again, in the New England States, for example, should be associated with the major crop in the Central States, and that with the major crop of the Southern States, to constitute a national system of rotation. The national rotation will permit the best use of the whole country, and will make it an agricultural unit.

A partial division of labor in agriculture will be feasible, for the farmer becomes a specialist in the growth of that plant for which his region is especially adapted. He will study, more scientifically, the physiological requirements of his major crop, and be able better to solve the numerous questions of practice which constantly arise. It will be necessary, however, for the central government to study the especial adaptability of the physiographical sections of the United States before an agricultural subdivision of the country can be scientifically made. These regions, at the present time, can be designated only roughly.

Thus the physical conditions of Florida make it plain that this peninsula is to develop its life on the lines of agriculture and marine industries. The agriculture is destined to be of a peculiar sort, gardening and fruit-growing rather than ordinary field tillage. Such tropical and sub-tropical fruits as the orange, the lemon, the mango, the sapodilla and tender vegetables, are easily raised, and assure the agricultural position of the district. The low-lying portion of the Gulf States, an old sea bottom, which has been elevated recently above the ocean, contains soil of only moderate fertility, but well suited to the great staple, cotton ; rice can be grown to advantage along the river bottoms. The Blue Grass region of Kentucky and Tennessee lies in the range of the Silurian limestones, and the soil possesses great fertility. This region, which grows very nutritive grasses, will be given up to stock raising. The northern Central States, Ohio, Indiana, Illinois, Missouri, Iowa, Kansas and Nebraska have soils and climates especially adapted for the growth of maize. They form collectively the great corn belt, and are also known as the surplus States. Regions protected from late frosts will be eminently suited for most large and small fruits. Such places are situated in western New York, Vermont, Pennsylvania, peninsular Michigan, Delaware, peninsular Maryland and California, including the irrigable lands. The irrigable lands have very great fertility, and are singularly enduring to tillage. Their vast extent permits a great diversity in the product of the watered fields. Thus in Montana and Idaho the natural products, grasses, are grown, while in New Mexico and Arizona the finer fruits may be advantageously cultivated. Future research will reveal the particular regions where definite crops, such as cotton in the South, will be raised exclusively by reason of the climatic, geological and meteorological conditions.

The national system of rotation will cause the supply required for use in any section to be drawn from the region where the crop, as a major one, is raised most advantageously. The production of maize illustrates this. The seven States of Ohio, Indiana, Illinois, Iowa, Missouri, Kansas and Nebraska are the "corn surplus States," practically furnishing all that enters commercial channels. Outside of these seven States the yield is practically of only local interest. The crop is consumed where grown, and it exerts an influence on commercial corn only *as it supplies home requirements or makes necessary a demand on the surplus States.* The great bulk of the corn crop is used at home, in fact, is consumed upon the farms where grown, and but a very small proportion is ever shipped abroad.

Distribution and Consumption of Maize, 1891.

Section.	Retained for County Consumption.		Distribution beyond County Lines.	
	Bushels.	Per Cent.	Bushels.	Per Cent.
Eastern	8,336,000	99.4	53,120	.6
Middle	64,331,190	91.3	6,125,810	8.7
Southern	352,019,990	94.3	21,155,010	5.7
Western	859,505,700	84.4	159,211,300	15.6
Pacific	3,992,330	87.4	576,670	12.6

Suppose the supply of maize required for consumption in New England to fall below the quantity raised, which may happen, since in New England maize is a minor crop. The deficiency is met by drawing upon the regions where there is a surplus of maize, which will be where it is grown most advantageously as a major crop. The price is regulated by the cost at the locality where it is raised at the greatest disadvantage. The farmer in District A disposes of his major crop at the same rate which prevails in District D, where the product is grown as a minor crop at a greater relative disadvantage. Likewise, the farmer B derives from his major crop what the farmer C obtains for it. An equalizing and compensatory action, therefore, is established in agricultural production.

		Crops.
Districts	A.	a + 2b + 3c 4d + **5e** = 15x.
	B.	**5a** + b + 2c + 3d + 4e = 15x.
	C.	3a + **5b** + 4c + 2d e = 15x.
	D.	2a + 3b + c + **5d** + 4e = 15x.
	E.	4a + 2b + **5c** + 3d + e = 15x.

Legend.—a = b = c = d = e = x: x = unit of usefulness (utility). Figures and letters in heavy-faced type indicate major crops.

The above diagram represents the national system of agriculture. The algebraic letters indicate the separate crops grown; the coefficients indicate the relative importance of the crops a, b, c in terms of the utility x. It is seen that the sum of the utilities in each region, A, B, C, D and E, is the same. The lands of the United States by this system become of equal usefulness, for the relative disadvantage of District A, for instance, in one crop is equalized by its relative great advantage with respect to some other crop. This equalization of usefulness will have a material influence on rent. If the productiveness of the various agricultural regions of the United States can be equalized, rent will be equalized. If the Ricardian theory, that rent depends on the difference in the productiveness of different soils, is true, then this equalization will result in the lowering or total abolition of rent.

Districts and farms, besides varying in fertility, vary also with respect to their nearness or remoteness from centres of population. Even if we succeeded by a proper national rotation in making all agricultural lands of equal productivity, yet rent would arise owing to the differences in the distance from market. A farm in proximity to the market would be better situated and would command a higher rent. A national protective system, which builds up local centres of trade and industry, materially diminishes market distance and correspondingly lowers rent. The products of the soil are consumed in the vicinity of the farms, and the farmer has at hand the means of making such a return to the soil as will maintain and even increase its fertility.

What shall be the motive force that shall inaugurate a wiser system of agriculture and distribution? Increase of intelligence must be the main factor in accomplishing a progressive and substantial advance. Man rises superior to his environment. Progress is possible because the intellectual superiority of man enables him to modify infinitely the forces of nature. Progress should begin subjectively in the men themselves. They should become familiar with the idea of self-government, of moral restraint, of the beautiful and of the good. This change will first become apparent in the consumption of individuals. Old articles, which before satisfied the cravings of their appetites, will be replaced by new articles, which are better adapted to intellectual and enlightened men. Nowhere will this change be more apparent than in the consumption of food.

Instead of consuming such large quantities of food (particularly of fats and starches), a less quantity better adapted to the needs of the human system will be substituted. Muscular labor requires large supplies of proteids; intellectual labor, light food with condensed nutriment. Americans should observe these physiological laws, for, as a rule, their diet is poorly adapted to the labor they perform. The large consumption of carbo-hydrate vegetal food is largely augmented by the use of fat meats. It is evident from principles already advanced, that the excessive production of fats (in animals), starches and sugars impoverishes the soil. The American people must live upon those articles of food of which the American soil is most productive, and must cease to consume in large quantities those articles for which the soil is poorly suited. It is possible with this change to get relatively the same nourishment at a fraction of the previous cost, because food is produced cheaper. A more extended dietary will follow such an alteration in the tastes of individuals, for there are many articles which are nourishing and cheap which are easily substituted for the dearer forms of food.

A high standard of life means a variety in consumption. The first condition of such a standard is the reduction of primitive appetites and passions. "So long as a few primitive wants are intense the standard will be limited to the few articles which gratify them."[1] The relative urgency of the other wants can only increase when the primitive wants sink to a level with the new desires of civilized life. These changes in the consumption of men will work eventually enormous changes in production.

Agricultural production will be greatly improved. "The best use of all our land will come when this change in the habits of the American people is [accomplished]. There are large tracts of land which cannot be utilized because the

[1] Patten, S. N., Dynamic Economics, 129.

American people do not want the plants which can be grown in these areas. So long as the home market does not demand any other articles of food than those staple ones to which our ancestors in Europe were adjusted, there can be but little use made of districts of our country for which [certain plants] are most fitted. A much greater improvement in the condition of the American people could be made by adjusting our consumption to American conditions than by all the machines that it is possible to devise."[1] These changes in the consumption of food make it possible to construct a national system of agriculture.

The national rotation makes it possible to have many articles upon a plane as regards price and nutritive value. Meat, beans, peas, cheese, for instance, will be placed essentially on the same level, as regards marginal utility or value. When a scarcity of any one of these articles occurs, another can be substituted immediately without effecting any hardship.

In the standard of life old articles will be replaced by new ones which have the same ratio of cost to utility as the old ones. This renders it easy to construct a scale of total consumption. The total consumption of an individual consists of groups composed of isolated articles, which stand higher or lower in the scale according to their marginal utilities. Articles of the same marginal utility (value) and same nutritive ratio can replace old articles of the same value in the group without in the least affecting the general usefulness of the group. The association of the articles together in a food group can be represented by a curve. The highest point of the curve represents the position of the articles which give the most satisfaction and pleasure, and the lowest point represents the position of those articles which give the least pleasure:

[1] Patten, S. N., Economic Basis of Protection, 121 I am indebted for many of the views here presented, concerning a dynamic society, to the lectures of Professor Patten, delivered at the University during 1892-93, and to his books and numerous of his articles on the subject, but the responsibility for their connection in this chapter rests with me.

(a) Bananas: (b) Oranges: (c) Apples: (d) Peaches: (e) Pears: (f) Plums: (g) Figs.

5

(a^1) Beef: (b^1) Mutton: (c^1) Cheese: (d^1) Pork: (e^1) Eggs.

4

(a^2) Wheat: (b^2) Maize: (c^2) Oats: (d^2) Rice.

3

(a^3) Potatoes: (b^3) Tomatoes: (c^3) Beets.

2

(a^4) Water: (b^4) Milk: (c^4) Beer.

1

The articles on the numbered horizontal lines in the diagram separately indicate the complimentary goods which can be substituted the one for the other, because article $a = b = c = d = x$ marginal utility. The articles on line 5, which give, suppositionally, the most pleasure, have the same marginal utility, and have been produced in the national system of agriculture at relatively the same cost. The articles a^1, b^1, c^1 etc., on line 4, also have the same marginal utility, as also those on the lines 1, 2 and 3, respectively. Articles can be equal in value only when the same degree of utility is imputed to them. When every individual shall recognize, for instance, that cheese in definite proportions has the same nutritive value as meat, *i. e.*, supplies the same bodily wants, when meat no longer satisfies the taste, cheese, beans, eggs or lentils will be substituted for meat, and the usefulness of the group remain the same.

Agricultural production directly responds to this change in consumption, and the national system is possible. The general rotation is feasible, because the demand is for a large variety of goods arranged in scientific proportions. The farmer is directly benefited, because he derives a larger surplus, which can be devoted to social and agricultural improvement.

Cheaper food is also possible to the industrial population with the better agricultural system, for a division of labor into particular specialties of agricultural production is possible. This means a larger surplus for the laboring classes and increase of efficiency, because the bodily system and mind are improved by the use of better food. With increased efficiency the hours of labor will be shortened, and, as a concomitant of the greater efficiency of the laborer, the cost of manufactured goods will be lowered. The farmer is benefited as well as the city man by this reduction in costs.

The larger surplus applied to education increases the intelligence of the community.[1] The increase of intelligence checks the rapid multiplication of the population. "Only when the increase of mankind shall be under the deliberate guidance of judicious foresight can the conquest made from the powers of nature by the energy of scientific discoveries become the common property of the [race]." With the improved industrial conditions and decrease of selfishness, by philanthropic sympathy, a larger return goes to the laborer as wages. Higher wages mean more comfort, and with cheaper food the laboring man will make enormous strides toward a high standard of life.

The full development of the agriculture of a country follows a strong protective policy, for by it new markets are created and fostered. New centres of industry mean a short haul for the farmer. The soil is not exhausted as rapidly of its ingredients, because the waste of large centers of population is returned to the fields in the immediate vicinity of the market.

The stability of the social fabric, *the agricultural prosperity* and the future industrial achievements of the nation, depends upon a strong national spirit, which renders a society dynamic.

[1] The very suggestive report of Dr. Harris, United States Commissioner of Education, should be read in connection with the above. It shows clearly what a diversification of industry and agriculture means for the social and moral education of the masses. Rep. Com. Educ., 1889-90, Vol. 1, pages 22-26.

CHAPTER VIII.

FUTURE.

THE use of maize promises to increase in the near future. The plant subserves so many important purposes that it cannot fail to occupy a prominent position in the future agricultural production of our country.

Not only will Indian corn be raised for home consumption, but also for foreign export. The people of Europe must be taught to enjoy maize as a food. President Harrison's administration, in the person of Secretary Rusk, made a wise movement when it appointed a special agent to look after corn interests in Europe. His efforts have met thus far with a due measure of success, but Colonel William J. Murphy finds it difficult to overcome the prejudices and conservatism of the peasants who need most sorely a cheaper food. Except an insignificant amount, exported corn is used chiefly in Europe as a food for animals, as a grain for distillery purposes and starch manufacture. "The only form of corn at all known abroad is corn starch, which is sold principally in the British Isles under the name of corn flour." "A better knowledge of maize as a human food, in addition to bringing into use its other forms, will increase the demand for all its products, which will call forth a supply that will cause the price in Europe to fall from its present high artificial point." "There are multitudes of half-starved toilers in Europe who would welcome the golden grain if only they were taught its merits."

To supply the wants of these people would be to render a philanthropic service worthy of our best endeavors, and the increased export of our cereal maize would be a sure, practical and speedy benefit to the farming interests of our country. Great crops and a demand for the products of the soil strengthen credit, expand the volume of manufacture, speed the wheels and fill the sails of commerce, and make a nation prosperous.

Maize, the greatest arable crop which we grow, occupying the largest portion of our cultivated area, has never been known to fail. It is destined to occupy, in America, the place that rice fills in India, China and Japan, that cassava fills in South America, and that sago occupies in Borneo, Java and the Indian Archipelago—the staple food of man.

Maize lends itself thoroughly to use in architecture and mural decoration; for industrial designing it has unrivaled pre-eminence. "Let the rose, queen of flowers, bloom for England; let Ireland honor the shamrock; Scotland her thistle bold; let the lily unfold her pure white petals for the joy of France; but let the shield of our great republic bear the stalk of bounteous golden corn."

The author is indebted to the following gentlemen, who materially aided him: Major J. W. Powell, A. S. Gatschet, F. Webb Hodge and Frank H. Cushing, of the United States Bureau of Ethnology, for suggestions as to the North American Indians; Professor Otis T. Mason, National Museum; Mr. Stewart Culin; Professors Simon N. Patten, whose economic works have been drawn upon, J. T. Rothrock, W. P. Wilson, John A. Ryder and J. M. Macfarlane, of the University of Pennsylvania; Dr. William Carruthers, British Museum, Dr. J. H. Gilbert, Rothamsted, England, Mr. John Redfield and others.

PHILADELPHIA, June, 1893.

EXPLANATION OF PLATES.

Illustrating Dr. John W. Harshberger's paper on *Maize*.

PLATE XIV.

Wild Mexican Plant grown in Philadelphia. Shows terminal pendulous male panicle and contracted lateral branch, with ears set alternately upon it. In the axils of other leaves, as shown in the plate, ears are developed. Size of full-grown plant, five feet.

See Cornell Agricultural Experiment Station Bulletin (Bul. 49, Dec., 1892, p. 332) for photograph of a plant with fully developed lateral branches with ears set upon them, each branch terminated by a small male tassel.

PLATE XV.

Details of Gross Anatomy.

Fig. 1. Branch of male panicle showing spikelets.
Fig. 2. Paired spikelets removed.
Fig. 3. Male spikelet dissected showing two flowers.
Fig. 4. Cross plan of male spikelet with pollen below.
Fig. 5. Dissection of pointed grain of Mexican corn.
Fig. 6. Sprouted grain.
Fig. 7. Lateral branch with husked ears. Front view.
Fig. 8. Lateral branch with husked ears. Back view.
Fig. 9 Branch with alternate arrangement of ears. Husks removed.

Fig. 10. Ideal longitudinal section of a portion of an ear with female spikelets in a hardened depression of cob with ovary, glumes and palets.

Fig. 11. Cross plan of female spikelet, showing empty flower.

Fig. 12. Cross plan of lateral branch with four ears. Husks, or leaves, lettered in order from base of branch to top.

PLATE XVI.

Histology.

Fig. 1. Cross section of secondary root.
P. Phlöem patches.
Fig. 2. Longitudinal section of emerging secondary root (*i. e.* aerial).
C. Calyptrogen layer.
Fig. 3. Cross section of leaf.
S. Stereome.
Fig. 4. Cross section of leaf-blade near margin.
B. Bulliform cells.

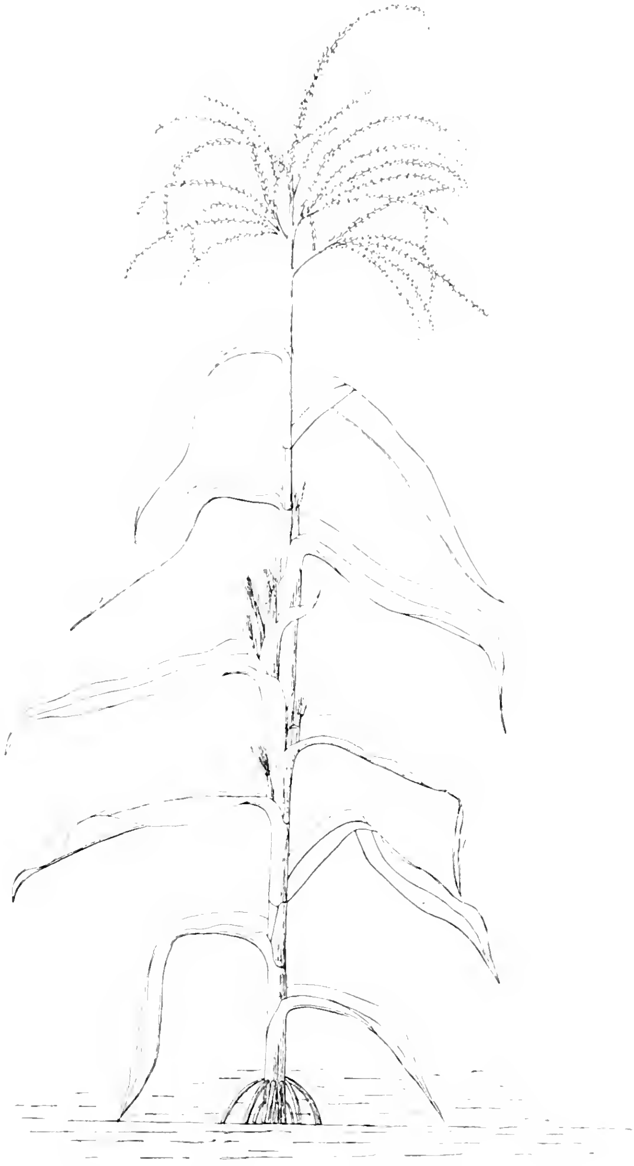
PLATE XVII.

Map showing the original home of maize with its geographical distribution in space and time. The heavy contour lines represent elevation; one set shows an elevation of 1000 feet, the other 4500 feet and over, as indicated by the letters. The arrows show the direction of maize distribution. Note that corn entered the United States from Mexico and the West Indies.

The squared area on the map shows the position of the agricultural tribes in North and South America. It is evident that the position of the agricultural tribes and the area of maize distribution are identical. See for discussion the Chapter on Ethnology.

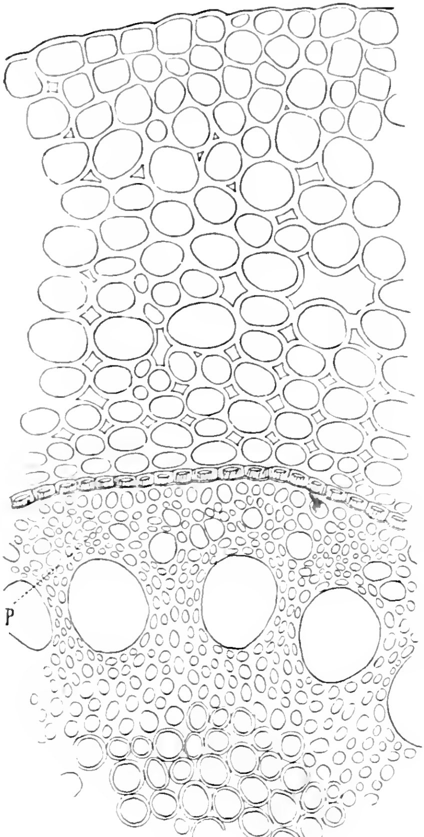
Legend in squares at the side:

1. Original home of maize.
2. Limits of primitive cultivation by the Mayas and allied tribes.
3. Limits of distribution in North and South America prior to the year 700 A.D.
4. Limits reached in North and South America by the year 1000 A.D.



HARSHBERGER ON MAIZE.

HARSHBERGER ON MAIZE.



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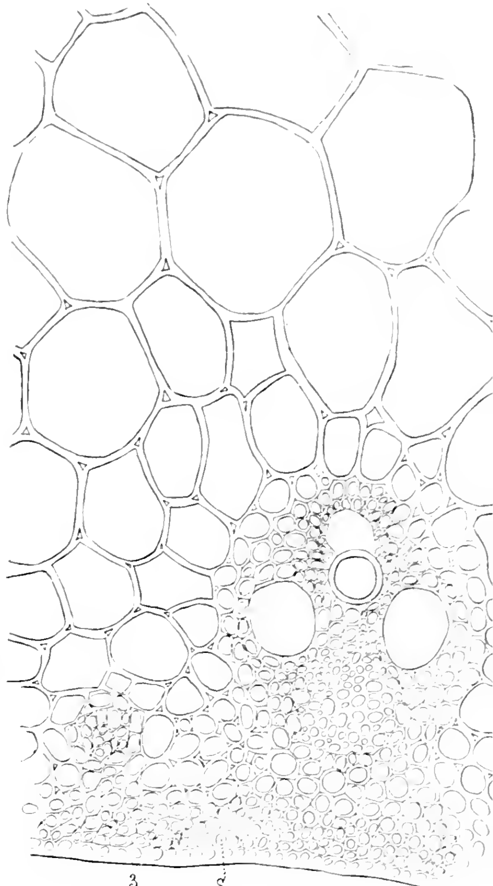

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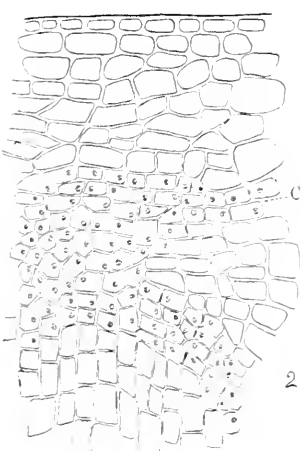

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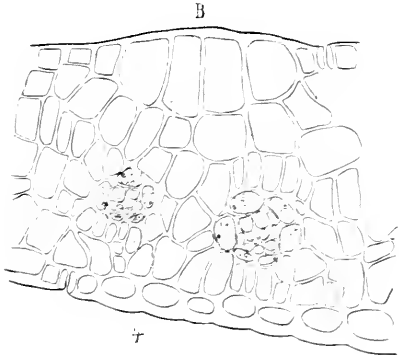

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HARSHBERGER ON MAIZE.

HARSHBERGER ON MAIZE.

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PUBLISHED FOR THE UNIVERSITY OF PENNSYLVANIA
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PHILADELPHIA.
1897.

A Chemico-Physiological Study of Spirogyra nitida.

By Mary Engle Pennington, Ph.D.

Research Fellow in Botany.

As the physiologist investigates more and more minutely the problems of plant life, he is confronted on every hand by chemical questions, to many of which he can still give no answer. The pharmacist has introduced us to a great variety of substances obtained from vegetable sources, but he has told us nothing of their origin or use in the plant economy.

Together the chemists and physiologists, working in this field, are little by little surmounting the difficulties which beset the path leading to our more perfect understanding of the complex results as we find them in plant life. It was with the hope of adding a few additional observations to our knowledge of chemico physiology that the following investigation was undertaken.

Spirogyra nitida was selected for this work because of its quick response to stimuli and because of its simple structure. A considerable quantity of easily accessible and unusually pure material which appeared in a pond in the Botanic Garden of the University of Pennsylvania made the selection possible.

By far the greater share of the knowledge which we possess of the laws of growth has been derived from a study of the higher plants, where we have a division of labor. In this simple alga each cell functions, so far as we have observed, as an independent organism, building up the necessary compounds for its maintenance and giving off its waste products. The study of such simple forms should be rich in suggestions for the explanation of the life-history of higher types.

The results of the investigation here offered are, in many respects, incomplete. But it is believed that the work so begun may suggest further study along the lines which are here touched upon.

The research was carried out under the direction of Prof. John M. Macfarlane, of this university, and it gives me pleasure to express my appreciation of his never-failing kindness throughout the entire progress of the work. I am also indebted to Prof. Edgar F. Smith, who has placed at my disposal all the facilities of the John Harrison Laboratory of Chemistry for the prosecution of the purely chemical part of the research.

Analysis of Spirogyra Nitida.

For the analyses made during this investigation *Spirogyra nitida*, in pure culture, was used. The material was obtained from a pond in the Botanic Garden of the University which was singularly free from other species of the genus. Some *Elodea* and a large water lily were the only plants growing in the pond. The depth of water in the deepest part was about four feet. The material was always collected during the morning of clear days and was prepared for use immediately. It was washed in running water until any mud which might have adhered to the filaments was removed. Distilled water served to free it from all inorganic salts which the river water held in solution. The clean threads were then laid on glass plates which were inclined at a sharp angle, so that all water clinging to the threads might run off. The threads were accepted as dry when they assumed a light green color and their individuality could be distinguished.

In order to determine the water, dry substances, and ash of *Spirogyra*, about sixty-eight grams of pure material were dried at 110° C. until constant weight was obtained. It was then found to have lost 89.94 per cent. of water. The dry substance remaining was carefully burnt, when another loss in weight occurred corresponding to 7.54 per cent. The ash, after this treatment, was 2.52 per cent. of the original material. *Spirogyra nitida* then contains:—

Water	89.94%
Dry matter	7.54%
Ash	2.52%
Total	100.00

G. Mann,* gives for a mixture of *S. nitida* and *S. jugalis*

Water	96.8 %
Dry matter	2.72%
Ash	.48%
Total	100.00

which differs widely from the results obtained in this laboratory with pure *Spirogyra nitida.* Several determinations were made with material gathered on different days, but the results were practically in accord.

Combustions.

While Mann, in the paper cited, gives the water, dry matter and ash, he makes no mention of an analysis for carbon, hydrogen, nitrogen and oxygen. In fact such an analysis has not been found in the literature on algæ. Therefore, in order to determine the primary composition, a series of combustions was made under the following conditions:—

The plant was removed from the pond on a clear, cool day in early October. It was prepared for use as previously described, then dried at 110° C. to constant weight. The same material was used for the entire series of combustions, and after each portion had been removed from the weighing bottle the remainder was again heated to 110° C. This precaution is necessary in order to secure uniform samples, since the finely divided material is exceedingly hygroscopic.

* Proc. Bot. Soc., Edinburgh, Vol. 18, (1890).

The weighing bottle, for additional protection, was kept in a sulphuric acid desiccator.

The combustions were made in an open tube in a current, first of air, then of oxygen, because the substance proved exceedingly hard to burn. A period of eight hours was required and the highest temperature available in the combustion furnace. Very hard glass tubing was used. This difficulty in burning is noteworthy, since it is rather opposed to preconceived ideas.

A white sublimate was invariably found in the front part of the tube at the close of the operation. This proved to be volatilized alkaline chlorides. The ash remaining in the boat was light gray, but could not be weighed because the loss of alkali introduced an error.

The heating should be very gradual at first, so as to drive over the water slowly but steadily. When this has been collected in the calcium chloride tube the heat is increased and maintained until all the carbon has been burnt to oxide.

The oxygen in the potash bulb and calcium chloride tube was displaced by a carefully purified air current and the weighings made in this gas. Seven analyses of the material yielded the following results:

	Maximum	Minimum	Mean
Substance taken . . .	0.2398	0.0931	0.1810
Carbon found	46.66%	46.15%	46.35%
Hydrogen found . .	5.69%	5.005%	5.43%

Accepting for nitrogen 2.61 per cent., as was found by a Kjeldahl determination, and for the percentage of ash in the dry substance 15.43, the oxygen by difference is shown to be 30.21 per cent. The primary composition of *Spirogyra nitida* may then be formulated as

Carbon	46.35
Hydrogen	5.43
Nitrogen	2.61
Oxygen	30.21
Ash.	15.40
	100.00

ANALYSIS OF THE ASH.

During the preparation of considerable quantities of ash, the apparatus best suited to obtain a perfect combustion was found to be a broad platinum dish, over which was suspended a wide glass tube a little longer than an ordinary lamp-chimney, (Schultze method.) The air current so produced causes an even and rapid oxidation of the carbon, with the expenditure of a minimum amount of heat. The ash so burnt was of a pale gray color and perfectly homogeneous. It was preserved for analysis in closely stoppered weighing bottles.

The method of analysis was essentially that of Bunsen as described in his "Aschen Analyse." According to this analyst the weighed ash should be brought into a cylinder with water, and the latter saturated with carbon dioxide until the liquid becomes colorless. The solution should then be transferred to a platinum dish and evaporated to dryness on the water bath, heating finally at 160° C. By this means all the lime should exist as neutral carbonate, and a water extraction should give only the salts of the alkalies.

The aqueous extract was made up to a known volume and divided into five portions. In the first the chlorine was determined, in the second the sulphuric acid, in the third the alkalies, in the fourth phosphoric acid, and in the fifth carbon dioxide. The insoluble residue was analyzed for silicic acid, phosphoric acid, calcium, magnesium, iron and aluminium, sulphuric acid and carbon dioxide.

An analysis of *Spirogyra* ash, conducted as above outlined, gave the following percentage composition:

	I.	II.	III.
SiO_2	5.29	5.38	5.30
SO_3	9.13	9.11	
Cl	24.24	24.08	24.51
P_2O_5	0.898	0.91	
CaO	9.01	9.20	
MgO	2.21	2.18	

Fe_2O_3 / Al_2O_3	2.06	2.00
Na_2O	32.15	32.00
K_2O	3.78	3.93
CO_2	11.10	10.90
Total	99.86	99.69

A glance at the recorded analyses of plant ash shows immediately the great variation in their quantitative, though not in their qualitative, composition. Not only do plants of different genera vary largely, but those of different species are quite as changeable.

	Fucus vesiculosus.	Fucus nodosus.	Fucus serratus.	Laminaria digitata.
K_2O	15.23	10.07	4.51	22.40
Na_2O	24.54	26.59	31.37	24.09
CaO	9.78	12.80	16.36	11.86
MgO	7.16	10.93	11.66	7.44
Fe_2O_3	0.33	0.29	0.34	0.62
P_2O_5	1.36	1.55	4.40	2.56
SO_3	28.16	26.69	21.06	13.26
SiO_2	1.35	1.20	0.43	1.56
Cl	15.24	12.24	11.39	17.23
I	0.31	0.46	1.13	3.08
Total ash	13.89	14.51	13 89	18.64
Total	103.46	103.32	102.65	104.10

But few analyses of the ash of aquatic plants are to be found in chemico-botanical literature, and these consist largely of salt water forms. Fucoid plants were analyzed by Gödechens,* and his results are given in the preceding table.†

A comparison of the ash of these aquatic plants, *Fucus* and *Spirogyra*, one a salt-water form, the other growing in fresh water, is in several respects, interesting. The sodium content of the ash is in both cases higher than the potassium, and this is even more exaggerated in *Spirogyra* than in sea forms. Chlorine attains a percentage of 17.23 in *Laminaria*, but in *Spirogyra* we have 24.24 per cent. It is exceedingly difficult to account for the unusually large quantity of silica, considering the soft and almost gelatinous consistence of the plant. The amount is even greater than we find in many hard, wiry land plants. Sulphuric acid is considerably less in *Spirogyra* than in *Fucus*, and phosphoric acid is in very small quantity. The magnesia here falls below the magnesia content of *Fucus*, likewise the lime; but, on the other hand, iron and alumina are much higher.

We have in *Spirogyra* a plant which, though inhabiting fresh water that contains essentially the same constituents as the soil through which it flows, yet differs essentially in its ash composition from the land plants, and approaches closely to the sea plants in its high sodium and chlorine content, and its small amount of potash.

This great similarity to the salt water types led to a careful search for bromine and iodine, but these elements could not be detected.

* Von Gorup-Besanez has analyzed *Trapa natans* and finds for it an ash content as given in this table. (Chem. Pharm. Centralblatt, 1861.)

Total ash	K_2O	Na_2O	CaO	MgO	Fe_2O_3	SO_3	SiO_2	Cl
13.69	6.06	2.71	17.65	5.15	23.40	2.53	27.34	0.46

Both iron and silica, in this analysis, are extraordinarily high.

† Ann. d. Chem. und Pharm., (1854) Vol. 54. p. 351.

Analysis of the Dry Material.

The material used in this analysis was prepared as already described in this paper, and was dried at 110° C. It was then ground to a fine powder.

O. Loew. and Th. Bokorny,* state that an analysis of the dry substance of *Spirogyra* (species not mentioned) yielded them 6 per cent. to 9 per cent. of fat, 28 per cent. to 32 per cent. albumenoids, and 60 per cent. to 66 per cent. cellulose and starch. These authors also consider lecithin to be one of the plant's constituents, as well as cholesterine and succinic acid.

Because of the large chlorophyll content of the plant it was deemed advisable to extract the fat with petroleum ether in such quantity that for each gram of substance there was 10 cc. of solvent. It was allowed to stand, with frequent shaking, for eight days. The supernatant liquid was then decanted into a weighed flask, the residue well washed with petroleum ether, and both extract and washings were evaporated to dryness in a vacuum desiccator. The substance remaining was semi-solid and deep brown; it had a resinous odor. In quantity it amounted to 3.45 per cent. of the substance taken. Saponification yielded a body resembling a resin. It was reddish brown, soluble in potassium hydrate, from which it was reprecipitated by hydrochloric acid. It was also soluble in sulphuric acid, forming with this agent a deep red solution. Water precipitated the substance unchanged. Its melting point lay between 85° and 90° C.

Probably a fatty acid was mixed with this resinous substance, since the filtrate, after extracting with alcohol and ether, gave 0.43 per cent. of glycerol. The resinous body itself amounted to 3.02 per cent.

Micro-chemical tests failed to show the presence of a resin in the cells. Fats, likewise, were not detected in the vegetating cells. It is therefore likely that these sub-

*Journ. f. Prakt. Chem., Vol. 36, p. 273.

stances were incorporated with the chlorophyll. Indeed, the presence of a resinous substance in a plant of this character is hardly to be expected. Yet if we consider the close relationship between the tannins and the resins some light is thrown upon the matter. The tannin content of the cell is comparatively great—8.71 per cent—and according to Bastian * and others, resin is, in some plants at least, produced from tannin.

The residue from the petroleum ether extraction was treated with ethyl ether until everything soluble in this menstruum had been removed. The extract was evaporated to dryness in a tared flask and weighed. The dry material so prepared was treated with cold water, but nothing dissolved. It was then taken up with absolute alcohol and proved to be totally soluble in this solvent. The solution was clear, dark green, and seemed to consist of very pure chlorophyll. The quantity amounted to 2.62 per cent.

An extraction of the dry residue with absolute alcohol gave a tannin content of 8.71 per cent. The method used was that of Löwenthal, as modified by Procter,† in which the tannin solution to be determined is titrated with a permanganate solution of known strength, after the addition of an indigo carmine solution.

The aqueous extraction yielded 14.70 per cent. of a gum soluble in water, but insoluble in dilute alcohol. The addition of strong alcohol to the filtrate produced a precipitate of dextrine-like carbohydrate, which amounted to 7.24 per cent. This high content of mucilaginous substance is perfectly accounted for by the appearance of the plant and by its soft mucilaginous character.

The acid content was found by precipitating a portion of the aqueous extract with lead acetate, weighing the precipitate on a tared filter, then igniting. The loss in weight represented the organic acids and amounted to 3.01 per cent.

* Am. Jour. Pharm., Vol. 68, p. 137.

† Journ. Soc. Chem. Industry, Vol. 3, p. 82.

An effort to determine the individual acids of the mixture failed because of the small quantity of material available, but succinic acid could not be found, and tartaric acid yielded its characteristic reactions.

The sugars were determined by the reduction of Fehling's solution and the electrolytic estimation of the copper. Starch was hydrolyzed and determined in like manner. The sugar yielded 4.8 per cent., the starch 10.7 per cent. of the material taken.

The substance insoluble in hydrochloric acid was, when dry, a perfectly white, homogeneous powder. It was accepted as cellulose and the insoluble portions of the plant ash, and upon weighing was found to equal 9.76 per cent.

A Kjeldahl nitrogen determination, conducted according to Gunning's modification of the method, gave a nitrogen content of 2.61 per cent. Calculating the albumenoids on this basis we have 16.31 per cent. of such compounds.

The ash content of the water-free plant is 15.43 per cent. If this be included in the analysis of the dry material we have:

Resin	3.02
Glycerol	0.43
Coloring matter	2.62
Tannin	8.71
Mucilage	14.70
Gums	7.24
Acids	3.01
Starch	10.7
Sugar	4.8
Cellulose	9.76
Albumenoids	16.31
Ash	15.43
Total	96.73

It is greatly to be regretted that the material could not be obtained in pure culture in sufficient quantity to permit of an investigation into the exact nature of the individual substances of which it was composed.

Micro-Chemical Investigation.

Fresh, healthy material was examined under the microscope for the substances usually present in plant cells.

As was expected, starch was present in abundance, and was easily seen even without the aid of iodine solution.

Tannin was shown by ferric chloride solution, which gave a color varying from deep green to black, according to the quantity of the substance in the cell. Copper acetate, in a saturated solution of which the threads were allowed to remain for several days, gave a brown precipitate.

If a vegetating cell be tested for a reducing sugar by Fehling's solution there will be seen in the interior of the cell one, or more generally two, areas over which the copper oxide is deposited. These areas have the appearance of contracted pellicles carrying the cuprous oxide in their walls. They are situated inside the chlorophyll bands, and if the test is properly carried out, the position of the bands in the cell is not materially altered.

The appearance and position of these structures indicate that one of the innermost protoplasmic layers bounding the vacuole of the cell carries in its substance the glucose. By the prompt reaction of the Fehling's solution and the glucose, the cuprous oxide was deposited where originally the glucose existed.

The most characteristic form for the pellicle to assume is that of a flattened cone having the base directed toward the end of the cell. One such cone is placed on either side of the nucleus. In no other part of the cell can any deposit of cuprous oxide be detected, though careless handling may cause these pellicles to break into a number of pieces, when these will be found scattered over the cell. Since only a small quantity of glucose is present in the vegetating cell the pellicle bearing the copper deposit was colored a light red-brown when viewed by transmitted light.

The microscope revealed the presence of two varieties of crystal, one form having, normally, four pointed arms of equal length radiating from a centre. Sometimes these arms were broken off or splintered, or the crystals otherwise maltreated, so that fragments could be seen lying about. The size of these crystals was very variable. They proved to be calcium oxalate, and as such were first described by Mann.* He gives seventeen as the number found in a single cell. In the material studied here more than twenty were sometimes counted.

Another form had four short arms, two or three times as broad as the oxalate crystals. The arms were smooth and did not show any tendency to splinter. Though they varied considerably, some attained a much larger size than the oxalate crystals ever reached. Occasionally one was found having a diameter more than half that of the cell. They were dissolved by a 10 per cent. solution of caustic potash; likewise by hydrochloric and dilute sulphuric acid. Sulphuric acid in alcohol gave a precipitate of calcium sulphate. A 2 per cent. solution of acetic acid took these crystals into solution, while a concentrated solution did not affect them. This behavior corresponds to calcium tartrate, and furnished an evidence of the presence of tartaric acid, which was later confirmed in the gross analysis.

I have not been able to find any mention in the literature on this subject of the presence of calcium tartrate crystals in *Spirogyra*. While not nearly so numerous as the oxalate crystals, their presence was so constant that they may be safely taken as a normal constituent of the plant.

Trimethylamine Content of Spirogyra.

While preparing Spirogyra for use, that is, freeing it from foreign matter, washing, drying, etc., it was noticed that the hands of the operator acquired a fishy odor, as did also the vessels in which the air-dried substance was preserved, and that, while drying, the same odor could be distinctly detected. Drying at 100° C. to constant weight,

*Proc. Bot. Soc. of Edinburgh, Vol. 18, (1890).

caused a total disappearance of the trimethylamine, which proved to be the source of the odor. It did not reappear even on boiling with potassium hydrate.

Fresh material boiled with caustic alkalies yields trimethylamine in considerable quantity. Air-dried *Spirogyra* also gives it, but in small amount, showing that loss has occurred by drying.

Loew, in the paper before cited, asserts that the plant contains lecithin because of the trimethylamine evolution when acted upon by caustic alkalies, and states, as a further proof, that he obtained phosphorus from the ether-alcohol extract. He does not refer to the evolution of trimethylamine at the ordinary temperatures, and indeed this begins almost immediately upon removing the plant from water.

While we have considerable evidence to show that chlorophyll is either a substitution product of, or closely allied to, a lecithin-like body, we believe that the compound so formed possesses greater stability than is indicated by such a ready evolution of trimethylamine as we find in *Spirogyra*. Such behavior is more generally attributed to a proteid.

We have, among plants, a number of instances in which this amine is given off, notably in the Stinking Goosefoot (*Chenopodium Vulvaria*), where it is produced by the leaves, and in the Hawthorn (*Cratægus Oxyacantha*) in which the small white flowers are the active parts. In these cases the amine is regarded in the light of an alkaloidal waste product, which, being gaseous at ordinary temperatures, is not stored up in the plant tissues.

Trimethylamine is one of the simplest nitrogenous compounds with which we are acquainted. Hence its presence in plant tissues is exceedingly interesting, and the question arises, Is it always present as a katabolic product, or is it, in some cases if not all, produced as one of the primary products in the synthesis of nitrogenous bodies?

Borodin * has found from his investigations with grow-

* Bot. Zeit., (1878).

ing shoots of certain plants that etiolation tends to produce a large amount of asparagine, and accounts for the accumulation of the amide by the carbohydrate having been used up, while nitrogen assimilation can proceed independently of light. From such experiments we may suppose that either the proteid decomposes in yielding the amide, or that it is produced synthetically and not further used because of a lack of suitable combining material. As there can be little doubt but that amides are, under normal conditions, synthetically formed as intermediate products toward the building up of proteid, the latter supposition is more likely to be the correct one.

In order to determine if possible the rôle of trimethylamine in *Spirogyra*, the plant was de-starched and kept in darkness for about thirty-six hours. A portion was then placed in a large test tube containing sufficient water, and the tube tightly corked. After standing in the dark for about half an hour, the cork was removed and the odor of trimethylamine was plainly detected. Heating with potassium hydrate gave a larger amount than was obtained from starch-containing cells, showing that the amine had accumulated in the cells which were kept in the dark.

While the less complex nitrogenous substances can be found in the leaves and stems of healthy plants, neither sugar, starch nor amide is to be detected in the actively growing tip, the energy here being so great that there is immediately a union of carbohydrate and nitrogen compound, the amount of each constituent being present in exactly the correct proportion to form proteid. In other parts of the plant, where the activity is not so great, the separate constituents can be detected in the cell. If trimethylamine is a synthetic product, does it ever, when growth conditions are favorable, accumulate in the cell, or is it given off in the water by the plant?

Bokorny* has found that *Spirogyra* remained healthy in a 0.05 per cent. solution of trimethylamine neutralized with

* Chemiker Ztg., 1894, No. 2.

sulphuric acid, but that a deposition of starch did not occur until the eighth day. It is not, then, injurious when in small quantity.

Since the amine is readily absorbed by mineral acids, yielding with them stable salts, we have a ready means by which to detect and estimate it, and to answer some of these questions for *Spirogyra*.

Newly formed threads of *Spirogyra* were placed in a flask of distilled water which had been rendered ammonia-free. A culture mixture, containing the nitrogen as nitrate, provided the necessary inorganic food. As the plant grew the gases were pulled out of the flask by means of an air current and caught in sulphuric acid, from which the trimethylamine was isolated. The apparatus in which this work was carried out was arranged in the following manner:

Air was admitted to the flask by means of a tube extending almost to the bottom of the liquid, and having a short arm attached to a **U** tube containing sulphuric acid. This served to free the entering air from ammonia and organic particles. Another tube, having a short limb, carried off the air which by this contrivance was compelled to travel through the entire depth of liquid. This tube was attached to a Liebig potash bulb containing sulphuric acid, which effectually prevented any amine from passing through and so occasioning loss. Between the absorption bulb and the drop-aspirator, by which a steady air-current was maintained, was fixed another **U** tube holding sulphuric acid, to prevent any gases from decomposing organic matter (which the river water might contain) pushing back into the bulbs. The air current was regulated by means of ground-glass stop-cocks.

As soon as the threads showed any tendency to collect and sink together in the bottom of the flask, the long masses which waved above were carefully lifted out and transferred to a new culture-solution, so that all decomposing cells should be eliminated.

The air current was maintained steadily for three weeks. At the expiration of this time the absorption bulb was removed, the acid transferred to a round-bottomed flask, rendered alkaline with potassium hydrate, and distilled. The volatilized substances were collected in a large quantity of distilled water which was afterward examined for trimethylamine, and also for ammonia, but none could be found. This experiment was repeated three times, and in no case did the amine result. From one experiment the culture solution was poured off through a filter, then distilled, in order to determine whether the amine remained dissolved in the water in spite of the air current. The result was the same—no amine was present.

Having proved that trimethylamine is not given off from the cells when they are exposed to light, the next step was to determine whether it is given off if the plant be kept in darkness.

Accordingly the culture flask was covered by an opaque screen and the gas collected as before. At the expiration of twenty-four hours the plant was de-starched. This culture, starch free, remained in good condition, so far as the morphology of the cells indicated, for seven days. At the end of this time the absorption bulb was removed, its contents made alkaline and distilled as before. The method used for the separation and estimation of this amine was that described by Fleck,* which is based upon the solubility of trimethylamine sulphate in cold absolute alcohol, ammonium sulphate being under such conditions perfectly insoluble. The amine is weighed in the form of its sulphate $(CH_3)_3N.\ H_2SO_4$.

From the culture solution which had been maintained in darkness, very appreciable quantities of the amine were obtained, and the merest trace of ammonia.

It was mentioned above that trimethylamine began to come off almost immediately upon removing the plant from water, and that it was completely expelled by drying

* Journ. Am. Chem. Soc., Vol. 18, p. 670.

at 100° C. After drying the plant, even alkalies caused no further evolution of the gas. This fact was indicated by the low percentage of nitrogen as determined by Kjeldahls made with dry material, and others made with fresh material. To obtain the entire nitrogen content it was necessary to work with fresh threads which had been simply drained. The loss of nitrogen was not very great, hence if it was due to proteid decomposition there was, relatively, only a small amount of the substance which yielded trimethylamine.

To determine whether the loss of nitrogen by drying was due to its exit as trimethylamine only, the fresh plant was drained, weighed, and introduced into a large flask containing potassium hydrate. The substance was distilled until the gases were no longer absorbed, then the amine was estimated as before. In this case, however, considerable ammonia was produced.

From this analysis the plant was found to contain 0.45 per cent. $(CH_3)_3N$, which is equivalent to 0.1 per cent. nitrogen. The nitrogen found in the fresh plant amounted to 2.61 per cent.; that in the dried material, 2.52 per cent. Apparently, then, we have the loss of nitrogen perfectly accounted for by the trimethylamine content.

If, as Loew believes, it is the lecithin only which produces trimethylamine, we should find some agreement between the quantity of phosphorus organically combined, and the quantity of trimethylamine evolved, since they exist in lecithin in the proportion of 1 : 1.

The phosphorus was determined by extracting the material, dried at 30° C. and powdered very fine, with absolute ether until it failed to yield any green coloring matter to the solvent. Absolute alcohol was then allowed to act until all the green substance had been removed. The united extractions were evaporated in a platinum dish, then ignited with calcium carbonate and ammonium chloride, the last traces of carbon being finally oxidized by the aid of ammonium nitrate. The white residue consisted of phosphorus, as calcium phosphate, and alkalies, in the form of sulphates, carbonates, and chlorides. It was taken up with water and thoroughly boiled out, the phosphorus being estimated in the insoluble portion by separating with ammonium molybdate, and weighing as magnesium pyrophosphate.

Loew * states that mono-potassium phosphate is soluble in absolute ether to the extent of 3 mg. in 100 cc. This solubility introduces an error into the estimation of lecithin as determined by the phosphorus content of the ether-alcohol extract, provided this phosphate occurs in the plant. Another, and more general opportunity for error lies in the fact that in the estimation of lecithin the material is preferably dried at very low temperatures. Much water is in this way retained in the tissues, and so carries out the soluble salts during the extraction. Both sodium and potassium were found in the extract in quantities far beyond those required to combine with the phosphoric acid. A trace of magnesium was also detected. This was probably from magnesium sulphate, which is somewhat soluble in absolute alcohol. Sulphuric acid was present, perhaps arising from the oxidation of organic sulphur, perhaps in combination with the alkali as sulphate.

Lecithin contains 4 per cent. of phosphorus and 7.56 per cent. of trimethylamine. Calculating the lecithin from the phosphorus found, we have 0.19 per cent. contained in the plant. If we make the calculation upon the basis of trimethylamine, we have 5.97 per cent, or a quantity over thirty times as great as that indicated by the phosphorus content.

Many attempts were made to isolate crystals of lecithin from the plant, but all were fruitless.

Though these experiments do not absolutely prove that lecithin is entirely absent from the plant, they do indicate that the evolution of trimethylamine is from another

* Pflüger's Arch., Vol. 79.

source, and that it probably plays an important rôle in the synthesis of the plant proteid.

Chemical Changes in the Conjugating Cells.

Having obtained some insight into the chemical character of the vegetating cell, it was considered advisable to investigate the changes in composition, if such changes take place, in the conjugating cell. Loew, in the paper before cited, states that during conjugation a decrease in the starch content takes place, with a corresponding rise in the sugar content. This observation was confirmed during the present investigation—not only does the glucose and starch vary considerably, but the entire cell seems to be fundamentally altered.

It was found impracticable to conduct the analysis ot this material as was done in the case of the vegetating, since the conjugating threads were inextricably mixed with those not conjugating, and even in the individual threads, conjugating cells were more frequently separated by several vegetating cells. The work, therefore, was accomplished by the aid of micro-chemical reactions, and comparisons were made with the normal material. Observations were started when the tubes had just begun to push out, and were continued until the entire act had been completed. The conjugating material was first noticed in the pond in the latter part of April, 1896, after a week of very warm weather had stimulated vegetation.

In the very early stages it was found that the chlorophyll bands, alike in their matrix and ground substance, had very materially altered. If the cells be treated with carbon disulphide or chloroform, a disintegration of the band results, because of the solvent action of the reagent upon the green substance. The reagent first destroys the characteristic contour and arrangement of the pyrenoid centre and starch grains, and collects the green chlorophyll in large drops at the edges of the bands. Ultimately, if the action of the solvent be continued, the green solution is diffused over the whole cell. Before this stage is reached, the droplets at the edges of the bands of conjugating material show more of a yellow tint than the corresponding droplets in the vegetating bands. This difference in color is plainly marked and indicates that we have here, in all probability, a compound which leans toward etiolin rather than toward normal chlorophyll. So marked is the difference, that the masses of conjugating threads have a distinctly paler color than the others.

Not only is the green substance in an unstable condition; the framework of the band seems to have undergone a change also. This framework in the conjugating cells is entirely effaced by continued treatment with carbon disulphide or chloroform, while in the vegetating cells the outline of the band can be plainly seen, even after the chlorophyll has been completely dissolved out. Just what the fundamental difference is has not been ascertained. It is probably closely correlated with another observation which was made at this time. A microscopic examination of those cells which had distinctly developed tubes, showed clear refractive bodies lying on, or closely against, the chlorophyll bands. The diameter of such a droplet was sometimes as great as that of the band, decreasing until it was represented by only a refractive point. The substance was insoluble in cold and hot water, but soluble in the usual solvents for fats. Osmic acid colored it deep brown or black. This test must of course be made after removing the tannin. It was accomplished by immersing the threads for a moment in boiling water, then exposing them for a short time to the vapor of osmic acid.

Because of the resin found in the vegetating material, and which was supposed to be contained in the chlorophyllaceous substance, these droplets were tested for such compounds, following the idea that owing to the high state of activity of the cell, and the marked changes which had taken place, it was possible that the resin had been excreted from the band. Such tests, however, yielded only negative results. The substance corresponds in every respect with a true fat. It persists in the cell through the primary stages, and even after the contents have balled off, dark spots are seen on treating with osmic acid. These show a tendency to collect in the interior of the mass.

The relation of the tannin to the conjugating cell is very complex. The quantity of tannin in the normal healthy cells is extremely variable, and the different amounts observed in the conjugating cells were so wide-spread and so unlooked for, that at first it seemed impossible to formulate them. Close study of the plant at all stages indicates the following history of the tannin content for the conjugating cell.

It has been noticed that rapid division always precedes conjugation. After this has occurred, just previous to conjugation, the quantity of tannin is very great. Iron salts produce an inky-black color, while copper acetate gives large masses of its characteristic brown precipitate within the cell wall. This large amount of tannin does not perceptibly alter during the growth of the first half of the connecting tube. At about this stage it begins to diminish, and by the time the tubes are in close proximity, the tannin has almost entirely disappeared. Usually, until the tubes actually meet, a slight reaction can be obtained *in the tube itself*. Only the merest traces are to be found in cells giving or receiving the contents of an opposite cell. Neither was it possible to demonstrate that one cell of the pair invariably contained more tannin than its associate, though frequently this seemed to be the case.

In the two uniting threads it always happens that some cells are unable to accomplish the act of conjugation, though stored with the required food, and showing the same preparatory peculiarities that the others show. This may be due to a divergence in the direction of the two threads, causing the tubes to be too short, or it may be due to the fact that one thread is frequently composed of a large number of short, almost square cells, while the uniting thread is formed of cells of the normal length. These short cells may alternate with long ones in the same thread, where they generally occur in chains of three or four. As we find *Spirogyra* to be strictly monoecious there are, of course, a number of cells which remain unfertilized.

These stimulated cells, which are unable to conjugate, accumulate the large amount of tannin and retain it. Indeed, proportionately to their size, the amount of tannin stored by them is much greater than in the larger cells. Frequently these cells form rudimentary or even fully developed tubes, which, however, never meet a corresponding tube.

We may ask, does not this tannin behavior approximate to that of malic acid in the fern? The tannin, though a constant constituent of the plant, is formed in much larger quantity immediately preceding conjugation. During the first period of attraction between the cells, it maintains this quantity, but as the cells are drawn closer and closer together we find it disappearing and apparently by way of the tube, since it is there that we detect its last traces. The evidence indicates that it diffuses through the cellulose wall of the tube, and this may account for the fact that we have so marked an alteration in the wall of the cell at this period. (The modification of the cell wall will be again mentioned.) It seems scarcely likely that the tannin formed should act as a food supply.

The presence of a resin so closely united with the chlorophyll would indicate a like origin for this substance. Though the plant synthesis of both classes of compounds is as yet unexplained, the indications are that the tannins are intermediate between the oils and resins. For the pines, at least, it has been established that the young cells are filled with protoplasm, which is partially replaced later by tannin. Then oleo-resins appear, and increase at the expense of the tannin and the protoplasm. According to this view we would expect the resin content of the cells to diminish, since the tannin formed seems to be diffused into the water. Unfortunately this could not be determined by micro-chemical tests, since the resin is so closely bound with the chlorophyll. But the oil drops exuded by the bands probably represent the material which, when the cells are not subjected to such a stimulus as conjugation affords, yield with the tannin the resinous body.

The carbohydrates of the cell show decided modifications. As has been already mentioned the glucose increases, apparently at the expense of the starch. There is always, however, a considerable amount of starch in the cell along with the glucose.

The behavior of a vegetating cell with Fehling's solution has already been discussed, the cell in this case having only a small amount of glucose. In the conjugating cells, even before the tubes have reached any great size, the quantity of glucose has so increased that the cuprous oxide deposit appears quite black under the microscope. When the bands of the cell begin to change their normal position the great mass of glucose is seen to be directly in front of the tube, and to be pushing into it. This mass of glucose persists in the cell, and when the giving cell transfers its contents, the glucose in large quantity can still be detected.

No trace of cane sugar could be found in these cells.

Every one who has handled fresh *Spirogyra* is familiar with the smoothness and apparent sliminess of the mass of threads. This is readily explained by the large amount of mucilage united with the cellulose. In the conjugating material this sliminess has largely disappeared. The threads are far more adherent than at other times, and show a strong tendency to collect and hold the small particles of disintegrated organic matter with which they come in contact. There is here a modification of the cell wall, causing an increase of the gum, hence rendering the cell more adhesive.

The proteid of *normal Spirogyra* gives off very readily trimethylamine. The *conjugating* material did not yield the characteristic fishy odor to the hands of the operator, nor to the vessels containing the air-dried substance, in anything like the quantity usually observed. Some of the threads, as free as possible from vegetating cells, were accordingly heated with potassium hydrate. The odor of trimethylamine was plainly detected, but comparison with a like quantity of vegetating threads, under the same conditions, showed that the amine was relatively in very small amount, and in all probability this was due entirely to the admixture of vegetating cells, from which it was impossible to free the material.

Morphological study has demonstrated that the cellulose wall is intact over the ends of the connecting tubes until after they have met. Watching closely the behavior of the giving cell, it was noticed that after the mass of material had begun to enter the tube a clear, refractive, colorless layer of protoplasm was sent in advance. It was granular in composition and very motile. The dividing wall of the closely pressed together tubes having been reached, the substance remained flattened against it for about one-half minute. The wall then suddenly dissolved, and the transfer of material from one cell to the other began.

This clear particle of protoplasmic material behaves like a cellulose ferment, and doubtless contains such an enzyme. Whatever be its nature it certainly is the active agent in dissolving the septum between the cells. It can be easily seen that a simple rupture does not take place, the passage being clearly cut with sharp boundary lines, and of the same size as the protoplasmic mass which pressed against the cell wall. The dissolved area may be in the centre of the plate or at one side. It is, however, fully formed by the substance above described, and does not increase in size during the passage of the remainder of the cell contents.

Starch passes over as such. Treatment with iodine shows blue masses in the act of transference. Many of these are too large for single grains. It would seem, therefore, that the pyrenoid, with its surrounding starch granules, is only dislodged from its position in the chlorophyll band, and not disorganized.

Chemical Changes in the Cells of Spirogyra Due to the Action of Monochromatic Light.

Since 1864, when Sachs performed his now classic experiments on the relation of blue and yellow light to plant assimilation, many investigators have not only repeated, but also widely extended the work done by him.

To obtain the desired conditions, Sachs used double-walled bell jars containing a saturated solution of potassium bichromate for the yellow rays, and a solution of ammoniacal copper sulphate for the blue. Others, working in this field, have used frames of wood, provided with glass top and sides, the glasses being of the color desired. Frequently light-tight, blackened boxes, having one side closed by a flat bottle filled with the colored solution, are employed. Engelmann obtained monochromatic light by means of the micro-spectroscope, examining an algoid thread in the various portions of the spectrum, and noting the oxygen evolved. But by this method only small quantities of material can be used, and the conditions, other than light, are abnormal.

Preparatory to the work done in this laboratory, a number of colored glasses have been tested spectroscopically, but not one has been found to be monochromatic, even in the broadest sense of the term. Most of the aniline dyes and various inorganic salts, yield impure spectra. A saturated solution of potassium bichromate, which has been accepted as affording yellow light, gives in addition all the red and orange and part of the green. It will be shown later that these individual colors have specific actions on plant growth, hence the light obtained, after passing through bichromate, gives to the plant the combined results of the red, orange, yellow and part of the green. Ammoniacal copper sulphate, if the solution be too dilute, lets through red and green, as well as blue, while if too concentrated nearly all the light is cut out.

For accurate work, then, such conditions will not suffice. Hence it became necessary to devise a means by which such defects as are above mentioned should be remedied. After many trials the method about to be outlined was adopted as most satisfactory.

Description of Color Screens.

White earthenware bowls, having a diameter of 9½ inches at the top, 5¼ inches at the bottom, and 4½ inches in height, served to contain the material to be investigated. Into these bowls were fitted dishes of white glass, two inches in height, and having straight sides. Into these the desired color solution was poured. Tin-foil was fitted over the edge of the glass dish and made to extend some distance below the top of the bowl, all white light being in this way excluded. The dish was covered by a glass plate to prevent evaporation and the entrance of dust. It is advisable to mark the original level of the liquid by a diamond scratch, and see that this level is maintained by adding the proper solvent from time to time. If two layers of the colored liquids were necessary, a second glass dish was placed on top of the first, and the joint made tight as before.

By such a contrivance, all the light reaching the interior of the bowl must pass through the entire depth of colored medium, since the side light is excluded by tin foil. The light intensity is increased by the reflection from the white walls of the bowl.

The colored solutions were tested by a No. 7 Krüss spectroscope, and the limits of the colored band determined as closely as possible. Monochromatic light is, in the strict sense of the term, the light obtained from a single wave length. But it is quite obvious that such light is not practicable for physiological experiments. Hence the term "monochromatic light" has been adopted for a comparatively narrow band isolated from all the other visible rays of the spectrum, and in which the human eye, aided by the spectroscope, can distinguish only one color.

Such a band was isolated from each fundamental color of the spectrum, namely, violet, blue, green, yellow, orange and red. To produce these bands the following solutions and mixtures were found to be the most satisfactory.

Violet.—Dissolve 128 grams of copper sulphate in 1000 cc. of water. Add to this 0.08 grams of Hoffman's violet (blueish) in 40 cc. strong alcohol. A layer one inch in thickness gives a band extending from 449 $\mu\mu$. to 417 $\mu\mu$.

Blue.—Dissolve 35.5 grams of copper sulphate in 1000 cc. of water. 100 cc. of strong ammonia water renders this a clear, deep blue. A layer of one inch gives from 476 $\mu\mu$. to 435 $\mu\mu$.

Green.—Victoria green ($3(C_{23}H_{25}N_2Cl).2ZnCl_2 + H_2O$) was taken as the basis for this color. In pure solution, however, it transmitted some of the blue and some red. Aniline yellow removed the former, and copper sulphate the latter. The quantities used were: 0.32 gram Victoria green in 1000 cc. of water, 0.0454 grams aniline yellow in 22.7 cc. alcohol, 16 grams of copper sulphate in 100 cc. of water. The mixture is used in a layer of one inch, yielding a band extending from 535 $\mu\mu$. to 510 $\mu\mu$.

Yellow.—This band, being so short, and also the brightest color of the spectrum, proved exceedingly difficult to obtain. Yellow dyes and solutions were very imperfect, yielding red, orange and green invariably, and frequently some blue.

It has been seen that copper sulphate cuts out the red end of the spectrum, either wholly or in part, according to its concentration. An aniline dye, "mandarin," having the formula $C_{16}H_{11}N_2O_4SNa$ and showing a deep orange when in aqueous solution, removes the more refrangible rays. If, then, a ray of white light be allowed to pass through both these liquids we have remaining only the yellow rays, provided the solutions be of the proper concentration. This is obtained by dissolving 0.888 grams of mandarin in 1000 cc. of water. A layer of 1⅝ inches is necessary. The copper sulphate is a solution saturated at the ordinary temperatures, and is used in a 1⅝ inch layer.

For this screen, therefore, we require two glass dishes, one above the other. The wave lengths obtained are from 603 $\mu\mu$. to 579 $\mu\mu$.

Orange.—This screen was made much like the preceding one. For the orange, however, a stronger solution of the mandarin orange is necessary, and a weaker copper sulphate solution, since the portion of the spectrum desired now includes rays which are less refrangible than the yellow. These solutions are:

1. 3.333 grams mandarin in 1000 cc. of water. The layer should be 1⅝ inch.

2. 160 grams copper sulphate in 1000 cc. of water. The layer should be one inch.

The light passing through these two solutions is entirely absorbed with the exception of a narrow band which extends from 634 $\mu\mu$. to 599 $\mu\mu$.

Red.—The band in this case may be obtained by the use of an aqueous solution of a scarlet aniline dye. This dye consists of a mixture of equal parts of (1) the soda salt of xylidin-azo-B-naphthol-sulphonic acid, and (2) sodium mono-sulphonate of amido-azo-benzol-azo-B-naphthol. Technically, it is known as "Scarlet, [(SRRB) (BASF)]," and serves as a wool dye. Of this 12 grams should be dissolved in 1000 cc. of water, and the glass dish filled to the depth of one inch. The red band extends from 718 $\mu\mu$. to 643 $\mu\mu$.

It will be seen that, with the exception of the yellow and orange screens, a single layer suffices for the attainment of the desired wave lengths. The yellow and orange, occupying so short a portion of the visible spectrum, have been found to be unsatisfactory unless produced as above described. The wave lengths as given are for the orange from 634 $\mu\mu$. to 599 $\mu\mu$., and for the yellow from 603 $\mu\mu$. to

579 $\mu\mu$. There is here an overlapping of 4 $\mu\mu$., but this is too small a band to make any appreciable difference in the physiological results. In the blue and violet, likewise, the bands overlap somewhat. The blue extends from 476 $\mu\mu$. to 435 $\mu\mu$., while the violet is from 449 $\mu\mu$. to 417 $\mu\mu$., a lap of 14 $\mu\mu$.

After the foregoing work had been completed it was found that Landolt * had constructed what he terms a "color filter," for which he makes use of inorganic solutions almost exclusively, and uses not less than two layers for each colored band. For the yellow which extends from 614 $\mu\mu$. to 574 $\mu\mu$. he finds three layers are necessary, viz.: 1. Nickel sulphate; 2. Potassium bichromate; 3. Potassium permanganate. Landolt does not give an orange band distinct from red and yellow. He fills tightly stoppered, flat, glass bottles with these solutions, standing them closely against one another in metal frames. While this form of apparatus might be constructed on such a scale that it would be available for biological work, it is believed that the simpler scheme above given is more readily adapted to the conditions required for such investigations. The glass dishes and earthenware bowls may be obtained in so many sizes, that large or small objects can be accommodated with equal facility.

Experimental Study of Spirogyra nitida.

Conditions having been obtained, under which the plant could be grown for a long period in light composed of but a small number of wave-lengths, the effect of these narrow bands upon the growth and composition of the individual cells remained to be determined.

To this end *Spirogyra nitida* was placed in the culture bowls and its development watched. The most favorable conditions for the growth of the plant were found to prevail when a layer of clean, washed sand covered the bottom of the bowl, having planted in it about six actively grow-

* Sitzungsber. d. Kgl. Akad. d. Wissenschaften zu Berlin, (1894) Vol. 38.

ing shoots of *Elodea*. This plant grows easily and rapidly, and furnishes, therefore, a good supply of oxygen. Whether it be this fact or some deeper reason there can be no doubt that *Spirogyra* grows more rapidly and makes healthier threads when growing with an actively vegetating plant than when growing alone.

The bowls so stocked were allowed to stand two days in white light before being covered with colored screens in order that possible injurious results from moving the *Spirogyra* might be outgrown. The bowls were then covered as described in the previous section of this paper, and placed in windows facing the south and in close proximity to eastern windows, so that they secured the maximum amount of direct sunlight. A greenhouse was found to be too warm to produce the best results. A temperature averaging about 22° C. gives the most desirable growth. Occasionally the water was siphoned off and a fresh supply introduced in the same manner.

When the experiments were begun the cells were in good condition and well supplied with starch. While they continued a record of the temperature and amount of sunlight was kept. The work was repeated many times, the conditions, as far as possible, being strictly similar. They extended over an entire winter. The results as given here set forth more especially the chemical, but also, to some extent, the morphological changes which the cells undergo when certain rays only are allowed to act.

The special changes induced by each colored band will be given separately, the order being that of the colors in the spectrum, beginning with the most refrangible rays.

Violet.—If the plant be exposed under the violet screen to bright and continuous sunlight, the cells rapidly become abnormal. The first noticeable change occurs in the chlorophyll bands. These, at the end of twenty-four hours, are seen to have a vacuolated appearance, and are of a pale green color. At this time sugar, starch and tannin are still present in the usual quantity. The protoplasmic pellicle appears normal.

By the close of the second day, provided the sunlight continues, the chlorophyll bands are balled together more or less tightly in the centre of the cell. This balling causes the protoplasmic pellicle to recede from the cell wall, so that it can be distinctly seen around the entire cell. When such a cell is treated with a solution of iodine in potassium iodide this pellicle takes on a violet-blue color. The fluid in the cell-vacuole assumes the same tint, and the starch grains, which are in considerable quantity, instead of showing a pure deep blue, incline toward a violet. A test made with Fehling's solution shows the presence of very little sugar. The color which these cells yield with iodine, is intermediate between the true starch blue and the violet of erythrodextrine.

These peculiar phenomena indicate that we are dealing with a cell in which elaboration and metabolism are so reduced, at least in respect to starch transformation, that only a very small proportion becomes soluble, and that little is far from a true sugar. Judging from the coloration produced by iodine it is just beyond the amylodextrine stage. This product does not seem to be utilized by the cell, nor, so far as could be determined, is it carried to the sugar condition.

Ludwig Klein * has proved that the conidial stalks of *Botrytis cinerea* do not grow during the day because of the presence of blue-violet rays. A paper by Ward † on the reduced growth of *Bacillus anthracis* in blue light, hints that the reason may lie in some deep-seated chemical changes, and the work of Macfarlane ‡ on the sensitive plants, would indicate that the chemical equilibrium of the cells is, for the time being, much disturbed.

The absorption spectrum of chlorophyll shows a dark band in the violet: Hence, according to the theory of Timiriazeff and his school, work is done by these rays. Engelmann, too, reports an evolution of oxygen in the

* Bot. Zeitung, 1885. † Proc. Roy. Soc., Vol. 53.
‡ Botanisches Centralblatt, Vol. 61.

blue violet. It may be then, that all the available energy furnished by the violet rays is only sufficient to produce this imperfect hydrolysis. Or, judging from the experimental work cited, the violet rays are so detrimental to the cell that its normal activity is reduced almost to zero. Under the usual conditions, that is the less refrangible rays being present also, their activity may overcome the injurious effects of the violet rays. *Botrytis cinerea*, as shown by Klein, is too sensitive to these rays to have their action overcome by the presence of the red end of the spectrum, and doubtless other plants would show the same phenomenon.

The third day generally finds the cells attacked by bacteria. The very rapid increase of these organisms causes complete disintegration of the cell contents, with the simultaneous production of an inky-black compound which fills the cell cavity. By the sixth day the cells are quite empty save for the black substance.

The bacterial organisms never failed to make their appearance under the violet screen, though the other cultures were quite free from similar growths. They formed an iridescent pellicle over the surface of the water, and caused a foul odor, suggesting butyric acid.

Through the kindness of Dr. Alexander Abbott, Director of the Department of Hygiene, this pellicle was investigated and found to contain four spirilla which did not liquify gelatine, and whose characters do not agree with those of any known form. Unlike other organisms these flourish under violet light. Three of them are chromogenic, producing a pale yellowish-green color.

Having proven that the cell under violet light could not transform its starch into sugar, the question arose, Can the de-starched, but otherwise healthy, cell produce starch when exposed to violet light only?

To answer this query material was rendered free from starch and placed under the colored screen. At the end of twenty-four hours the cells were still quite free from starch, but apparently otherwise unchanged. Later the cell-contents balled together as before, but now treatment with iodine solution did not cause any blue-violet color. The organisms above mentioned promptly attacked the cell, which, weakened from starvation, succumbed to their ravages in about four days. During this time no starch formation could be detected.

Blue.—The phenomena observed, when the plant was grown under blue light, were exceedingly interesting and suggestive, when compared with the results obtained with bands from other parts of the spectrum.

For five days after submitting *Spirogyra* to the action of blue rays the cells were, morphologically, in good condition. The starch grains were slightly diminished in size. Chemical examination showed that sugar was in much smaller quantity than that normally present.

At this time the protoplasm was seen to take on a granular appearance, which grew constantly more marked. By the seventh day the chlorophyll bands had lost their characteristic disposition in the cell and had become somewhat balled, though not to such an extent as those under violet light. The pyrenoid centres, with their surrounding starch granules, were scattered promiscuously over the cell, while here and there the dense granular protoplasm could be seen between the green masses. Treatment with iodine caused the starch granules to become deep blue, while the dense protoplasm assumed a rich red-violet color.

When Fehling's solution is used we find the areas corresponding to the red-stained protoplasm precipitating cuprous oxide.

Exposure to blue light pushes metabolism a step ahead of that obtained under violet light. There is sufficient energy here to produce a reducing carbohydrate, and one also which can be assimilated by the cell. The blue rays, like the violet, cannot produce starch. But starch hydrolysis is possible, though the process is so slow that the granules originally present become from day to day almost imperceptibly smaller, until at the end of the fifth week they have entirely disappeared from many of the cells, and in the others are very few, and so small that strong magnification is necessary in order to distinguish them. After the starch is completely used up the cell contents rapidly disappear, leaving finally only the empty cellulose walls.

Green.—Under the green screens the growth of the threads and the general appearance of the cells is excellent. So far as the carbohydrate of the plant is concerned we have a condition closely approximating that of the normal. The starch granules are somewhat larger than those formed under white light and are very plentiful. Sugar can always be detected and is in the usual quantity. Tannin, likewise, can be observed in the cells, but never in large amount.

Though these green rays have so slight an action upon the carbohydrates of the cell, the protoplasm is strongly modified by their action. The quantity very materially increases, so much indeed that the protoplasmic pellicle is doubled in size. This pellicle is a denser mass than is usually seen and is filled with small, dark granules.

The most striking phenomenon is the exaggerated motility of this protoplasmic layer, soon after placing the plant under the colored screen. In about three or four days after the commencement of the experiment this activity is noticed, and it prevails for five or six days. While actively motile the protoplasm shows a strong tendency to collect at the ends of the cell, either pressing closely against the cell wall, or lying some distance back from it. Frequently protoplasmic currents are seen flowing across the cell. These may run quite straight, or more or less diagonally, or they may take a zig-zag and tortuous path. The large granules are carried along rapidly in this moving mass, while some granules can at times be followed entirely around and then across the cell.

Green light induces the formation of crystals of calcium tartrate, and is unfavorable to the production of calcium oxalate crystals. A very noticeable increase in the number and size of the tartrate crystals takes place by the fourth day, and after this time a rapid decrease in the number of oxalate crystals is observed. Many break into small pieces. The diameter of the tartrate crystals is occasionally quite as great as that of the cell. This peculiar variation prevailed so long as the culture was maintained.

No breaking down of the chlorophyll bands occurs, and the healthy green color remains unaltered when the plant is exposed to green light. But a flattening of the band, with a corresponding increase in width occurs, and the irregularity of the outline is so marked that the term "amœboid" may well be applied to it. In some cases the bands run together so completely that it is difficult to distinguish any boundary line between the individuals. In these bands the pyrenoids are remarkably distinct. They are very refractive and larger than usual.

Yellow.—A comparatively short exposure to yellow light, that is two or three days, causes the green substance to become much paler in color, and the bands show a slight tendency to ball together. Under these conditions the starch rapidly disappears, until by the close of the fifth day it is entirely gone. The sugar, meanwhile, has increased far beyond the normal amount. The cells, when treated with Fehling's solution, become quite covered by the cuprous oxide resulting from the reaction. Although about five days are required to free completely all the cells from starch, many of them are emptied by the second day.

While this conversion of starch into sugar is taking place, there is a simultaneous and very marked growth in the length of the cell. So rapidly does this elongation take place that the chlorophyll bands are pulled out of their spirals, and made to lie quite straight in the cell, which is ultimately three times as long as when grown under white light, though its diameter is not increased.

These cells were tested repeatedly for *tannin*. In the great majority of them none was found, though occasionally a trace could be seen.

Another marked and surprising consequence of the growth under the yellow screen, was the almost total elimination of the crystals normally present in such large numbers. These disintegrate, oxalate and tartrate alike, and finally disappear entirely from the cell. The small fragments into which the crystals break are at first angular, then they become rounded off and gradually smaller until they are quite dissolved. What part these substances play in the nutrition of the cell could not be determined, but there seems every likelihood that a solution does take place.

The protoplasmic pellicle surrounding the cell wall becomes much reduced in size, and is quite clear and refractive. Few granules are to be seen in it. The nucleus, too, with its suspending threads, is very clear. This pronounced refractiveness is most striking, and gives to the cell a starved appearance. Even the chlorophyll bands partake of it, becoming narrow and of a clear pale green tint.

Treating the long sugar-filled cells with a very dilute solution of iodine in potassium iodide caused a sudden rupture of the cell, and the consequent scattering of the cell contents. This rupture was liable to happen to any part of the wall, the cell-plate being quite as frequently pushed out—so breaking up the threads into short lengths, or even single cells—as was the true wall torn. The force was sufficient to break the protoplasmic pellicle, and even to push the chlorophyll bands and the nucleus through the aperture, throwing out the latter, and carrying it for some distance.

We have here a large cell in which the sugar content, and consequently the specific gravity of the cell sap, is much increased. The osmotic pressure of a sugar solution is comparatively small, while the pressure of the inorganic salt, potassium iodide, is almost twice as great. The suddenly-increased endosmosis being greater than the protoplasmic utricle can withstand, it is violently ruptured, tearing also the cellulose wall.

The culture could never be maintained for more than seven days because of the attack of a fungus, which penetrated and completely demolished the cell contents. Soon after the formation of a large quantity of sugar, and the lengthening of the cell, the presence of this fungoid growth could be detected. The conditions in the cell were favorable for its rapid growth, namely, a large quantity of soluble nutritive substance, with a lowered vitality, which permitted the inroads of organisms.

Some investigators, notably Pfeffer, consider the yellow rays most active in causing assimilation. Judging from the experiments just cited, the energy expended in the cell is, indeed, great, but the ultimate growth is very abnormal, there being a tendency toward an extensive production of carbohydrate in a soluble condition. Is this energy such that sugar can be produced in the cell without the appearance, so far as micro-chemical tests can show, of starch? If so, starch-free cells placed for a time under yellow light should have the sugar content increased. After this stage their behaviour should correspond with that described in the previous experiment.

This was found by experiment to be perfectly true. Destarched threads placed under the yellow screen were examined after 24 hours, but no starch had been produced, and the quantity of sugar was not excessive. The cells were of the usual length. Forty-eight hours showed the cells much lengthened, and the sugar content was also greater. On the fourth day the cells had attained to their full length, they contained much sugar, and many of them had been attacked by the fungoid growth. In control experiments, destarched material when placed in white light, showed always a prompt starch formation, and made a good growth.

Orange.—Though following so closely upon one another as do the orange and yellow rays, indeed slightly overlapping in the experiments herein described, the results of their separate action are widely different. The narrowness of these bands makes their dissimilar actions all the more striking.

Two or three days under the yellow screen sufficed, as we have seen, to free the cells from starch, fill them with sugar, and in many ways alter what we would consider to be distinctive characters. On the contrary, five days under the orange made no appreciable differences. The plant's behavior was normal. By the eighth day the number of crystals had greatly diminished. The oxalate crystals suffered more than did the tartrate, the former almost entirely disappearing from the cells, while the latter, though few in number, were in fairly good condition.

An examination for sugar showed this substance to be in larger quantity than in the control threads grown under white light. However, it was still far below the quantity of sugar contained in the culture made in yellow light.

The protoplasmic pellicle was modified in that it had lost its granular structure, and was clear and refractive, though not so much so as in the case of the yellow. The nucleus and its threads partook of this change also. The nucleus stood out clearly in the cell, while the nucleolus was very large and prominent. No change in shape or in the relative positions of these bodies could be observed.

Tannin was always present, and in fairly large amount. Its quantity varied without recognizable cause, just as it does when the plant is exposed to white light.

Occasionally cells were seen which were longer than the normal. These were not very frequent, and were not more than twice the length of the other cells.

The cultures in orange light were sometimes kept under observation for five weeks. At the end of this time they were still healthy, showed very few crystals, contained starch and sugar and tannin, and had made a fairly good growth.

Red.—Under the red screen the plant approached still closer to the normal. Assimilation went on rapidly, so rapidly in fact, that the cells became gorged with starch. At the end of five or six days so many granules, and such large ones, surrounded the pyrenoids that the bands were crowded closely together, almost or quite hiding the nucleus from view. This piling up of starch was not at the expense of sugar, the presence of which was always demonstrable, and in quantities agreeing with the normal.

The tannin formation was excessive. Copper acetate threw down a heavy precipitate in the cells, and ferric chloride colored them inky black.

The crystals, on the other hand, were not so many nor so large as when grown in white light. Eight days caused a breaking down of oxalate, while by the tenth day very few of these remained. Calcium tartrate crystals were not many, but here and there one did survive. These, when solution took place, had the arms dissolved first, leaving behind a square plate which was at first mistaken for another variety of crystal. In time these likewise disappeared.

The protoplasm seemed to be normal in every way. The nucleus, when it could be distinguished in the dense mass of starch-laden chlorophyll bands, was very refractive, but contained dark particles as usual. The nucleolus was also very refractive.

These cultures, like the orange, can be kept for an indefinite period in good condition. *The growth is even more rapid than in white light.*

Growth Under Colored Glass.

Having carefully cultivated and watched the development of the plant under pure light, some experiments carried on under colored glasses may well be compared with them.

The apparatus was the same as that used by Macfarlane* in his "color screen" experiments on the sensitive plants, and consisted of a square wooden frame, into the sides and top of which were fitted glass plates of the desired color. The healthy *Spirogyra* was grown in white glass jars having a capacity of about one litre. These were placed

* Bot. Central. Vol. 61.

inside the box, and the whole apparatus exposed to bright light, either in a green-house, or, as these experiments were made in the early autumn, in a sheltered place in the Botanic Garden.

Three screens were used, viz.: blue, green and yellow-orange. These glasses, tested by the spectroscope, were found to allow the following rays to pass:

1. Blue glass:

Red, from 738 $\mu\mu$. to 703 $\mu\mu$.
Yellow-green, 566 $\mu\mu$. to 552 $\mu\mu$.
Green-blue, blue and violet, 517 $\mu\mu$. to 408 $\mu\mu$.

2. Green glass:

Orange, yellow, green and a little blue, from 629 $\mu\mu$. to 458 $\mu\mu$.

3. Yellow-orange glass:

Red, orange, yellow, green, and green-blue, from 687 $\mu\mu$. to 464 $\mu\mu$.

When grown under such conditions, it is obvious that the plant is acted upon by a considerable part of the spectrum, since these glasses divide it roughly into three portions with much overlapping in the less refrangible rays. Hence the changes observed in the plant are due to a combination of forces, these forces being represented by the rays which pass.

Blue Glass.—The blue light, having a small band of red, some yellow-green, and a little blue-green, in addition to all of the blue and the visible violet rays, acts upon the plant in a much modified form, the red and green tending to overcome the evil effects produced by the blue and violet. As a result of this the plant made a much slower growth than under normal conditions, but a growth far beyond that made under pure blue.

Starch and sugar diminished in quantity, and frequently the starch disappeared entirely, only to reappear in a short time. The tannin fell considerably below the normal amount, but was never completely lost. The chlorophyll maintained its deep green color, and was perfectly healthy. Morphologically, it was modified in that it tended to form dense aggregations over the nucleus, giving the appearance of a protective covering. In this mass it was difficult to distinguish the individual bands. The cells were much *shortened*—being not more than half the usual length, and the spiral bands were wrapped very closely around them.

The threads grew straight upwards, the folding upon itself which *Spirogyra* is so apt to show, and which Mann * ascribes to heliotropic action, being entirely absent. Since the blue-violet rays are those which, more than any others, induce heliotropic curvature, this fact is noteworthy. Further mention will be made of it when the growth under the yellow-orange is discussed.

Green glass.—Under green glass the results were more abnormal. Orange, yellow, green and a little blue cannot, apparently, compensate for the absence of the strong red rays. In twenty-four hours from the time of the beginning of the experiment, the chlorophyll bands had begun to break down, while at the end of forty-eight hours many cells had the pyrenoids connected by only a fine green filament. The spiral position of the bands was quite lost, and the remains lay hap-hazard in the cell. The condition of the cells composing a single thread varied much. Some were quite free from starch, others had unusually large starch grains around clear large pyrenoids. In those cells which were free from starch iodine frequently, though not invariably, produced a violet coloration, closely approaching the color obtained in like manner when the plant was grown under violet light.

Another phenomenon, which was observed only a few times, was the presence of oil droplets, on or close to the chlorophyll. These were blackened by osmic acid, were soluble in the usual solvents for fats, and behaved in every respect like the droplets observed in the plant when pre-

* Proc. Bot. Soc. Edin. Vol. 18.

paring for conjugation. Actual conjugation was not, however, attempted.

The quantity of sugar and tannin is very small, the latter constituent occasionally entirely disappearing from some of the cells. Crystals of both kinds could be detected.

Yellow-orange glass.—This glass, while it permitted the passage of all the orange and part of the red, gave results which were strikingly like those obtained under pure yellow, though the time required to produce them was much lengthened.

The starch disappeared about the ninth day, and the cells were then filled with sugar and were very long. The tannin, unlike the pure yellow culture was in large quantity. No crystals could be seen in the long cells, and the chlorophyll was in rather a bleached condition. The bands here lie straight in the cells just as do those in yellow light. Treatment with iodine in potassium iodide causes the same rupture of the cell wall.

It was stated that under the blue glass no bending of the filaments took place, even though these rays are so positively heliotropic in their action. Under the yellow-orange screen the threads were bent sharply upon themselves, as many as five distinct folds being assumed. Since the rays which this glass transmits are supposed to be almost without heliotropic action it may well be asked, Are not these folds due simply to the weight of the long weak threads? The plant under the blue screen was made up of short, strong cells, and the filaments were short, as compared with the long filaments under the yellow. This may account for the fact that no bending occurred under the blue.

Behavior of the Cells in Darkness.

Some endeavors to de-starch *Spirogyra nitida* by simply placing it in the dark produced rather peculiar results, which led to a more careful study of the behavior of the plant when all light was excluded. It was found in this preliminary work, that the threads did not de-starch readily, even when, so far as could be determined, the plant grew in perfect darkness. A quantity of fresh threads placed in a beaker glass, and covered with tap water, the whole being maintained in darkness, showed in the cells very appreciable amounts of starch even after two weeks had elapsed. The condition of the cells at the expiration of this time was not very good. Here and there the bands had lost their normal positions, and in some a distinct breaking down of the cell could be seen. By the time the starch had been converted into soluble products the cell was so altered in other respects that it was quite useless for physiological experimentation.

In these darkened threads a solution of the crystals was very apparent. They broke down into small fragments, and were finally dissolved as under the action of yellow light. This solution became more rapid as the amount of starch grew less, but in no case were the crystals wholly used up.

Since starch-free material was much needed for experimental work it became necessary to find a method by which this end could be gained, and still have comparatively healthy cells. It was thought that running water might perhaps prevent decomposition and enable the cells to survive until all the starch had been metabolized. Accordingly a small stream from a laboratory tap was led into a jar containing the plant, and the whole covered with a tight box. At the end of twenty-four hours scarcely a trace of starch was found in the cells which were otherwise perfectly normal. Thirty hours will suffice to remove all the starch from *Spirogyra nitida*, while the more slender species react even sooner.

To determine whether this result was due to the plentiful supply of inorganic salts furnished by the running water, a quantity of the plant was placed in distilled water to which a culture mixture was added. The starch was removed very slowly, and the cells behaved as they did in a limited supply of tap water. The inorganic salts, then, are not responsible for this behavior.

Fresh *Spirogyra* was next placed in a flask fitted with a doubly perforated cork carrying glass tubes arranged as in an ordinary wash bottle. The short tube was connected with a suction pump, and by means of the long tube a current of air was drawn through the flask. The air must not be drawn through with such force that it churns the *Spirogyra* in its passage. If the flask is kept quite dark, the plant under such treatment behaves precisely as it does when running water is supplied to it; the starch is rapidly metabolized, and the cells soon become starch free.

From the above facts we are led to believe that in this starch transformation the gases of the air play an important part. Since all experiments have shown that carbon dioxide is acted upon by chlorophyll only when light is present, we must look to the oxygen as the active agent. This element seemed, by its presence, to so stimulate certain functions of the cell that it was enabled to convert starch into soluble products.

An explanation of this peculiar behavior lies in the fact that the simpler nitrogenous substances, such as amides, are built up in the dark, and that these substances there unite with the carbohydrate present, to form the more complex compounds or proteids.

While the absorption of free oxygen by the plant is generally followed by a breaking down of the organic substances, just as in animal respiration, it is probable that being deprived of the nascent oxygen, which results from the decomposition of carbon dioxide in sunlight, and also from the free oxygen of the air or water, the plant is unable to combine the first-formed nitrogenous compounds with the carbohydrate already present. Or, since we know that in time the starch is dissolved, this synthesis takes place so slowly that the equilibrium of the cell is destroyed before all the carbohydrate is used by the nitrogen compound.

The nature of the hydrolytic ferment in *Spirogyra* is as yet unknown. But from the study of this class of ferments we may readily suppose that free oxygen, in greater quantity than is supplied by still water, is necessary in order that it may produce hydrolyzed products from starch.

The Action of Light on Diastase.

A consideration of the foregoing results led to an investigation of the behavior of unorganized hydrolytic ferments in rays of varying refrangibility. The information which we possess upon this point is very limited, and its relation to plant metabolism is quite untouched.

St. Victor and Corvisart * state that sugar is formed from starch more rapidly in light than in darkness. Green † exposed solutions of diastase to the action of electric light and of sunlight. The diastase so treated was then allowed to act upon starch paste, when he found that light exercised a destructive influence upon the ferment, this influence being more marked at the violet end of the spectrum. But the light with which he experimented was polychromatic, and if diastase is affected by light rays, it is probable that the portions of the spectrum affecting plant growth will also influence the rapidity of diastatic action.‡

The relation of light rays to the ferment is, as determined by the previously described color screens, very marked, and in perfect accord with the changes observed in *Spirogyra* when grown under corresponding conditions. An account of the experiments whereby this conclusion has been reached, will make clear the above statement.

Potato starch was purified by washing with very dilute potassium hydrate, then with 1 per cent. hydrochloric

* Comptes Rend., Vol. 49. † Annals of Botany, Vol. 8.

‡ After this investigation had been passed to press another article by J. R. Green appeared in the Proceedings of the Royal Society, Vol. 61, p. 25. Many of his results agree with those above given, but some are strikingly different. In the above investigation narrower, and therefore purer, colored bands were used than those from which Green drew his conclusions. It is noticeable that he fails to give the action of the yellow rays as distinct from the orange.

acid, and finally with distilled water until the washings did not react with silver nitrate. It was then dried in the air, and was preserved for use in tightly-stoppered glass bottles.

A preparation of diastase was obtained from Messrs. Bullock & Crenshaw, Philadelphia. This was found to be only partially soluble in water, yielding when filtered a clear liquid of a pale straw yellow.

The starch paste, made by pouring starch, mixed with cold water, into boiling water, contained 1 gram in 100 cc. It was freshly prepared each day. The strength of the diastatic solution soon changed, hence it was necessary to prepare this daily.

The tests were made by placing the beaker containing the starch and diastase in a white bowl, and covering with a colored screen. These bowls, when a temperature of 45° to 50° C. was desired, were partially filled with heated water. The progress of the reaction was noted by removing from time to time a drop of the liquid, and applying the iodine test. The control experiments under white light were conducted in like manner, except that the glass screens contained only distilled water. The work was done in *direct sunlight*. As it was found that the light intensity caused a very material variation in the time required for this hydration, the experiments were made only on very bright days, and then only in the middle of the day when the sun's rays were most direct. Diastase solutions of varying strength were used, though if too dilute the end reaction was hard to determine.

The experiments were carried on from the middle of February to the end of April.

For the six screens the following ratios were found, the time in white light being taken as unity:

White	1.00	Green	1.14
Darkness	1.28	Yellow	0.76
Violet	2.00	Orange	0.85
Blue	1.21	Red	1.00

A few examples, taken at random from the series of experiments, indicate the time in minutes. Each experiment conducted in colored light was checked by a similar test in white light, the time required in both cases being here given:

DARKNESS.

Exp. 1.	Exp. 2.
White, 10 minutes.	White, 10 minutes.
Darkness, 13 "	Darkness, 12.75 minutes.

VIOLET.

Exp. 1.	Exp. 2.
White, 9 minutes.	White, 22 minutes.
Violet, 18 "	Violet, 45 "

BLUE.

Exp. 1.	Exp. 2.
White, 11 minutes.	White, 9 minutes.
Blue, 15 "	Blue, 12 "

GREEN.

Exp. 1.	Exp. 2.
White, 14 minutes.	White, 10 minutes.
Green, 15 "	Green, 12 "

YELLOW.

Exp. 1.	Exp. 2.
White, 12 minutes.	White, 13 minutes.
Yellow, 9 "	Yellow, 9.5 "

ORANGE.

Exp. 1.	Exp. 2.
White, 15 minutes.	White, 15 minutes.
Orange, 13 "	Orange, 13 "

RED.

Exp. 1.	Exp 2.
White, 9 minutes.	White, 11 minutes.
Red, 9 "	Red, 11 "

The light rays, from the above data, attain their maximum for diastase in the yellow, and in darkness the action is slower than in light. Under orange the change from starch into sugar is slightly slower than with yellow, while red light requires the same length of time as white. Progressing toward the more refrangible end of the spectrum we find the green band a little slower than white light, and the blue still more unfavorable to sugar production, while the violet rays are only one-half as rapid as the red.

In diffuse daylight the action of these rays is much less marked, the ratio between yellow and white being as 1 : 0.92. As diffuse yellow light exercises less influences for good than does bright yellow light, so is the destructiveness of the blue and violet lessened by diffuse light.

In the experiments made by Green, the enzyme was exposed first to the influence of light, then mixed with starch paste and its activity noted. As the conditions in these experiments were slightly different, starch and diastase being mixed first, then exposed to light, it was deemed advisable to expose diastase in solution to light, as did Green, then test its activity under the colored screens. Such tests showed that the solution became rapidly weaker in light, but in colored light maintained its relative strength.

This behavior indicates a protective influence of starch on diastase when exposed to light. It is even more than that, since in the one case light accelerates, and in the other retards its hydrolytic activity.

Interpretation.

The relation of light to plant growth being one of the most interesting and wide-spread of all the many questions with which the plant physiologist has to deal, it has naturally received much attention. And while each portion of the spectrum has been considered by the various workers, the greatest amount of interest centres in the red-orange and yellow, because of the theories which have been built upon the study of the behavior of these rays in regard to plant assimilation. It is the portion of the spectrum containing the less refrangible rays which, from Sach's time onward, has been recognized as best promoting plant growth. According to Lommel, Müller and Timiriazeff this is because the rays, absorbed by chlorophyll, have their energy converted into some other form of energy, which is then capable of bringing about the decomposition of carbon dioxide and water and causing their subsequent combination to form organic products. These writers argue, that only the rays which are absorbed are capable of causing chemical changes in the plant, and therefore the absorption bands of the chlorophyll spectrum correspond to the regions in which growth takes place.

Pringsheim, taking exactly the opposite view, considers that the rays absorbed are those which would be prejudicial to the growth of the plant, and that they are in this way removed. Pfeffer believes that the yellow rays—and there is no absorption of these—are those most active in assimilation. But, the conditions under which he worked being inexact, too much reliance cannot be placed upon his deductions.

Engelmann's experiments tend to confirm the work of the school of Timiriazeff, namely, that the region of most active assimilation is situated at the junction of the red and orange, which region is also that of the densest absorption band in the chlorophyll spectrum.

The theories regarding the action of light have been based upon the rate of decomposition of carbon dioxide and upon the corresponding evolution of oxygen as determined for the different parts of the spectrum. The results obtained with *Spirogyra* show the general condition of the cells, and the changes in quantity and in kind of the substances produced, by the growth of the plant.

The spectrum of living chlorophyll as determined by Mann* gives four absorption bands. The first two, which extend from 678 $\mu\mu$ to 662 $\mu\mu$, and from 654 $\mu\mu$ to 638 $\mu\mu$, are both included in the band furnished by the red screen, which lies between 718 $\mu\mu$ and 629 $\mu\mu$. What are commonly known as the third and fourth bands of Kraus, Mann does not find in *Spirogyra*, but the fifth he places between 531 $\mu\mu$ and 459 $\mu\mu$. This band is partly covered by the blue screen (from 476 $\mu\mu$ to 435 $\mu\mu$.) and a very small portion is covered by the green (535 $\mu\mu$ to 510 $\mu\mu$.) The sixth band

* Proc. Bot. Soc. of Edinburgh, Vol. 18, (1890.)

he finds to extend from 459 $\mu\mu$ to 445 $\mu\mu$., with the centre at 450 $\mu\mu$. The violet screen, from 449 $\mu\mu$ to 417 $\mu\mu$, includes part of this band, which Mann says is not a well-defined one, and also includes the absorption band which we invariably find at the extreme end of the spectrum.

Under the orange screen we have no absorption band; the yellow, likewise, is not absorbed, and under the green screen a few, only, of the rays coincide with those which are absorbed. But plants grown under these screens show striking variations from one another and from the normal, and the orange, where, according to the absorption theory, growth should not occur, gave, next to red, a growth more nearly approximating the normal than did any other.

Such facts cannot be reconciled with either of the theories above given, since it is apparently not so much the absorption of the rays, as the amount of energy which they possess which influences assimilation for either good or evil.

According to Langley the greatest amount of energy, as measured by the bolometer, is furnished by the orange rays. Following this statement, growth should here be at its maximum, but the foregoing experiments with *Spirogyra* gave a more normal growth under red, in which the energy is somewhat lower.

The very peculiar behavior under the yellow screen I am inclined to attribute to the action of these rays on the hydrolysis of starch. This is converted into soluble carbohydrate so rapidly that the nitrogenous products, which normally are in sufficient quantity to combine with it to form higher compounds, are in this case unable to do so. The sugar, therefore, accumulates in the cell, upsetting the perfect balance of power which should prevail. The inroads of the fungus cannot then be withstood, and the plant dies.

If we accept the red, as the region of greatest growth, or the junction of red and orange, we must conclude that the maximum hydrolytic activity is not conducive to the welfare of the plant; and we must also, from the experiments upon the action of diastase on starch paste in the different light rays, place the two centres of activity, the assimilative and the hydrolytic, some distance apart. The activity of the latter decreases, from the yellow toward both the more and the less refrangible end of the spectrum, and it is to be noted, that where the diastatic activity approximates that in white light the plant makes a good growth, if not a perfectly normal one. This condition is seen under the red screen, which in its action on diastase is exactly equivalent to white light.

The green, standing to white light, as measured by diastatic activity, in the relation 1:1.14 has its starch hydrated rather more slowly than in white light, yet the decrease is not sufficient to stop nor to materially injure the growth of the plant.

The strange appearance and unusual activity of the protoplasm produced under this screen suggests that the cell is in a condition exactly the reverse of that induced by yellow light. There, soluble carbohydrate predominated over nitrogenous compounds; here, the speed of production of soluble carbohydrate is slightly lessened. The nitrogen assimilation is then, probably, in excess, and it may be that the proteid formed contains a larger proportion of nitrogen than that formed under the usual conditions.

Mendeléeff, in his "Principles of Chemistry," has called attention to the fact that nitrogen content and protoplasmic activity seem to go hand in hand through all forms of life. Animals, whose tissues are so largely nitrogenous, possess this activity in the highest degree. The higher plants, with their great quantity of stable carbohydrate, have it only feebly. But, on the other hand, in lower plant forms, as for example in the zoospores, where the rapidity of movement is quite comparable with that of animal life, the nitrogen content is high, and remains so until the active period is passed. When the spore fixes down it develops a cellulose wall, loses its high percentage of nitrogen, and becomes in all respects a true plant.

If protoplasmic activity depends upon the multiplication of unstable nitrogen atoms the increased movement of the protoplasmic pellicle may be due to the synthesis of such a product under these abnormal conditions.

By the time we reach the blue rays the diastatic activity has greatly diminished. Yet enough energy still remains to convert the starch grains, little by little, into soluble products, though these seem to differ chemically from those compounds generally obtained by diastatic action. The cell energy, too, has fallen so low that carbon dioxide and water are no longer decomposed to yield starch as the first visible product. When the supply with which the cell was furnished is used up, its resources are at an end and death ensues. Under blue light we may say that metabolism is at a minimum, while carbon dioxide assimilation, so far as we can determine, has ceased. The density of the protoplasm shows that a very pronounced alteration has taken place in its composition, and this is shown likewise by the color which iodine imparts to it. This color would indicate that even though the starch is slowly hydrated the energy is not sufficient to carry it to a true sugar, and cannot link together nitrogenous and carbohydrate substances into the proteid found in the plant under white light.

The violet screen, which furnishes the more refrangible rays, does not seem capable of changing the starch which is already in the cell, into any product which can be used in plant metabolism, though it is indeed somewhat altered, since we find a blue color diffused through the cell after treatment with iodine. Probably both this fact and that of the greatly reduced cell energy combine to produce a condition in which proteid cannot be formed in *Spirogyra*. This same energy, on the other hand, is not only sufficient for, but favorable to, the growth of certain bacterial organisms. The deleterious effects of this screen are seen also in the action of diastase on starch where the time required for hydration is twice as long as the time required when white light acts.

Not only do we find the fundamental constituents of the cell undergoing modifications, but other products, such as the cell crystals, are much altered by different light rays. While there is, in all probability, a direct connection between the formation or disappearance of these bodies and the geneial activity of the cell, I have not been able to formulate it from the above experiments.

In yellow light the obliteration of the crystals is almost complete, while it is less marked in orange and red. When the plant is kept in darkness without a sufficient oxygen supply the same breaking down occurs. As etiolation implies also starvation, it might be supposed that the solution of the crystals provided nutritive material. Yet in orange and red light there is a diminution in the number of crystals, though the cells are well nourished.

Green light tends to promote the production of tartrate crystals, increasing them both in number and size, though here also oxalate crystals were used up. Weber* finds the greatest absorption of ash constituents to take place when the plant is in white light; it is somewhat less in yellow, then follow red, blue and violet, decreasing in activity as the refrangibility of the rays, but green gives the lowest ash content. These results were based upon the action of the light which passed through colored glasses, none of which were monochromatic. One would infer from the large crystals of the green culture that an extensive absorption of inorganic constituents was here taking place, while results from the yellow, showed either very few or no crystals whatever, leading to the opposite view.

A number of observations have been made which show a similarity between yellow light and darkness. Sachs and Kraus have found that etiolation tends to produce long internodes; and rays of low refrangibility do the same. Corresponding to the internodes we have the individual cells of the *Spirogyra* thread, and, as we have seen, these under yellow light attain to three times their normal length. It

*Landw. Versuchstat., Vol. 18 (1875).

is interesting to note in connection with the statements made by these observers that, in the experiments made on *Spirogyra*, it was the yellow only which caused a marked lengthening when the red, orange and yellow rays were separated, though under the orange-yellow glass the action of the yellow rays was not sufficiently retarded by the presence of the others to prevent the cells elongating.

Rauwenhoff * states that less tannin is found in etiolated leaves and plants than in green ones. Here, too, the behavior of the yellow culture accords; tannin is entirely absent.

Looking at the question of the action of light on plant growth, from the chemical changes noticed in *Spirogyra*, we see that assimilation, though in a more or less modified form, can occur when none of the light rays are absorbed by the green coloring matter. Also, that such absorption may or may not be accompanied by assimilation.

The blue and violet rays seem to act as checks to the great activity of the yellow, and perhaps to the orange, preventing the too rapid transformation of starch into sugar, upon which the rapid growth in length apparently depends.

The Action of Palladious Chloride on the Living Cell.

While studying *Spirogyra* micro-chemically palladious chloride was used as a reagent. The action of this substance upon the living cell demonstrated so clearly certain morphological features, that a more careful examination of its behavior was made. It was found that a solution containing 0.1478 grams palladious chloride in 100 cc. distilled water fixed the cell instantly, and with the minimum amount of distortion. The protoplasm was slightly browned, making the nucleus and its threads the more easily seen. If the solution be diluted until it contains only 0.001478 grams palladious chloride in 100 cc., the morphological

* Ann. d. Sci. Nat., Ser. 6, t. v., (1877).

changes are very gradual and show plainly the structure of the nucleus and its contents.

This weak solution of palladious chloride was run gradually under the cover glass, its action on the cell being carefully watched. The first visible result was a sharp rounding off of the nucleus from the cell, though the nuclear threads were not broken. By this rounding off the nuclear membrane became plainly visible, and appeared to be a clear, homogeneous, doubly refractive bounding layer. Even by aid of an oil-immersion lens it was impossible to detect any structure in it. The nuclear substance meanwhile assumed a brownish appearance, which was probably due to a deposit of metallic palladium, and its granular structure became very marked. In many nuclei there appeared to be a mass of tangled threads in the meshes of which lay the more fluid substance. The threads suspending the nucleus could be distinctly traced through the nuclear membrane and into the granular mass of the nucleus.

The nucleolus showed a dark bounding layer of double contour. Its substance remained homogeneous, but became much more refractive than is usual. The dark layer is undoubtedly a true membrane dividing the nucleolus from the nucleus, as stated first by Macfarlane,* and confirmed by subsequent investigators. It was distinctly visible and invariably present.

These changes took place in from 8 to 10 minutes. A continuation of the action of the very dilute palladious chloride caused the suspending nuclear threads to rupture, and in so doing generally displaced the nucleus. Where this happened the nucleus was observed to be incased in a protoplasmic pellicle which was distended until it was much larger than the body which it enclosed. The suspending threads were seen to penetrate this pellicle.

A further treatment of the cell with this reagent caused, at the expiration of half an hour, a complete balling together

* Trans. Bot. Soc. Edin. Vol. 14.

of the chlorophyll bands, the inner layer of protoplasm and the nucleus. The outer protoplasmic layer, however, was unaffected and still adhered closely to the wall of the cell. The balled mass was generally pulled to one end or close to the sides of the cell. The many crystals were in this way left quite free in the unoccupied space of the cell, and could be easily studied. None were seen in the balled material, hence it was inferred that these bodies lie between the two protoplasmic pellicles.

Summary.

1. An analysis of *Spirogyra nitida* shows that the chlorine and sodium content of the ash is comparable with the chlorine and sodium content of the salt-water algæ. The dry matter yields all the usual organic plant constituents, tannin being in specially large quantity.

Micro-chemical analysis reveals crystals of calcium tartrate, as well as those of calcium oxalate, side by side in the cell.

2. The trimethylamine, which is readily evolved from *S. nitida*, is apparently closely connected with, and aids in the formation of a proteid body. It is not evolved when the plant is exposed to light, but is detected in darkened material. This amine accumulates in the de-starched cell, but does not seem to result from the decomposition of lecithin.

3. Conjugating cells show a chemical composition which, in almost every essential differs widely from that of the vegetating cell. The behavior of the tannin, and its marked increase in quantity is now striking; as is also the presence of oil droplets, which are found free in the cells.

4. Under colored screens, furnishing light of definite quality, the chemical composition of *S. nitida* differed according to the light rays which it received.

(*a*) *Violet* rays prevented almost wholly the hydration of starch, and soon killed the plant.

(*b*) *Blue* rays gave an imperfect hydration, but sufficient to preserve life for some time. Starch was not formed in the cells.

(*c*) *Green* rays caused an active assimilation with a continuous growth and unusual protoplasmic motility. The protoplasm was also in increased quantity. Green light favored the production of crystals, particularly of calcium tartrate.

(*d*) *Yellow* rays caused elongation of the cells, which contained abnormal quantities of soluble carbohydrate, but no starch, no tannin, and no crystals. The cells were short-lived.

(*e*) *Orange* rays caused a good growth closely approximating the normal. Crystals were not plentiful, however, and the sugar was in rather large quantity.

(*f*) *Red* rays caused a growth which was even more rapid than that made in white light. Tannin was formed in larger quantities than under the normal conditions.

5. The action of monochromatic light, from the various portions of the spectrum, upon solutions of diastase mixed with starch paste, shows that yellow light causes the most rapid hydration, while violet requires the longest period in which to accomplish this result. The red rays required the same length of time as white light. Wherever a marked difference can be traced between the action of diastase in rays of a certain refrangibility and in white light, there too, the chemical composition and growth of *Spirogyra* is abnormal; when, however, colored light and white light coincide in their effect on diastase, the plant grows also.

6. *Spirogyra* cells de-starch rapidly, and without decomposition, if, while preserved in darkness, a stream of fresh water or a current of air be supplied to them. Cells kept in darkness, without an oxygen supply, show a solution of the crystal content, and a general breaking down before the starch has all been converted into sugar.

7. Palladious chloride, in extremely dilute solution, serves well to demonstrate the morphology of the nucleus and its contents.

On the Structure and Pollination of the Flowers of Eupatorium ageratoides and Eupatorium coelestinum.

By Laura B. Cross, Ph. D.

(With Plate XVIII.)

IN the contributions that are being made to plant pollination, the relative frequency of self and cross pollination has received a considerable share of attention. The fact that various flowers, once regarded as being probably cross-fertilized have, during recent years, been found to be systematically self-pollinated; and also the increasing number of plants that have been shown to bear cleistogamic flowers, both point to the necessity for accurate statistics, not only for the orders, but for the species composing them. No order, probably, has received more attention than the Compositæ; but much remains to be done in the extended study of the different genera and species. The following is a contribution toward the study of *Eupatorium* suggested by Dr. Rothrock in 1891.

H. Müller* has given some details, structural and physiological, of his observations on *Eupatorium cannabinum;* and though the species I have examined differ in specific details, the fundamental points established by him have been confirmed by my observations.

Twelve plants of *Eupatorium ageratoides* and twelve of *Eupatorium coelestinum* were selected and subjected to the same treatment throughout. Four plants of each were protected by thin cotton cloth, and four by coarse Swiss muslin, at a time when the flower parts were immature

* "Fertilization of Flowers," Eng. Ed. 1883, pp. 318–320; 363–364.

and completely covered in by the involucre. The remaining four plants were marked with bits of muslin and left exposed. Six days later, twelve additional plants from each species were selected. Two of these were covered by thin cotton cloth, two with Swiss muslin, two had one-half of each inflorescence protected by thin cotton cloth, and the other half exposed, two had one-half of each inflorescence protected by Swiss muslin, two had single branches of the panicle protected, and the remaining plants were left exposed.

In each lot of plants selected, those remaining uncovered so developed their flowers that the style arms divaricated about three days earlier than those covered with muslin. The muslin-covered plants matured their flowers two days earlier than did those covered with cotton cloth, this difference being probably due to the greater amount of light passing through the open meshes of the Swiss muslin, than through the more closely woven cotton cloth. The difference in the time of maturing was also very noticeable in the plants which had a part of the inflorescence protected and a part exposed, both having similar conditions, except in the amount of light. Uncovered parts were faded, when covered parts were just maturing. Another interesting difference between protected and exposed flowers, whether on the same or separate plants, was that in every instance the protected florets had their style arms developed in a very contorted manner. Those of one floret often touched a neighboring style or dipped into the adjacent corolla. Hildebrand states that the style arms of chicory roll up like a feather, the pollen being thus brought in contact with the stigma. This he considers to occur most frequently in the absence of insects. It was difficult to collect a small amount of pollen from exposed plants, but in protected ones the pollen was so abundant that it covered the inflorescence and the inside of the muslin cover. Indeed, it is difficult to form an adequate conception of the amount of pollen produced unless the inflorescence be protected. There was no marked difference in the time of maturing of the fruits, whether borne on the most vigorous early plants, or on those selected at later periods, the same number of days bringing about, as nearly as possible, the same results in every instance.

Inflorescence of Eupatorium ageratoides and Eupatorium coelestinum: Each capitulum is surrounded, and, in early stages of development, completely covered in by the involucre. *E. ageratoides* produces rather open panicles of capitula with 12 to 17, commonly 15 white florets of delicate texture on a flat disk-like receptacle. *E. coelestinum* bears compactly-clustered panicles, and for the massing of a greater number of florets the receptacle is prolonged upward into a sharp-pointed cone, each of which bears from 46 to 60 florets of a bluish purple color. In both species the pappose rudiment of the calyx (Fig. 8 *m*) consists of a series of long multicellular hairs, the bases of which are surrounded by a very delicate tissue (Fig. 8 *n*) which adheres to the torus when the pappose hair is removed from the margin. The corolla in *Eupatorium ageratoides* consists of a lower tubular portion, expanding into an upper cup-like form and terminating in five corolla lobes. These lobes bear on the outside, and near their bases, multicellular hairs (Fig 1 *h*) longer than the lobes themselves. These hairs occupy an upright position until the corolla is expanded, when, by the recurving of the petals, they are thrown back, become flaccid and wither with the corolla. In structure the corolla exhibits not only the long external hairs just referred to, but the inner—or when expanded, the upper—surfaces of the petals are covered with large, rounded, closely-set, tubular papillæ, (Fig. 1 *p*) which resemble the sweeping hairs on the style, but differ from these in being shorter and in diminishing to slight swellings at the base of the corolla lobes, where they finally disappear. These updirected outgrowths may be of use to insects in affording them a firmer footing when visiting the florets for pollen and nectar.

(*b*) The Corolla in *Eupatorium coelestinum* (Fig. 2) is smaller and less spreading; the lobes are shorter, more rounded and less reflexed than in *E. ageratoides*. On the outside, and near the base of the lobes, are found rounded sessile hairs (Fig. 2 *h*) which in dried specimens are filled with reddish purple pigment. The inner surface of each lobe bears papillæ only around its margin, and not uniformly over its surface, as in *E. ageratoides*. The lower part of the corolla in each species is composed of rather long, straight, thin-walled cells, which extend upward as far as the attachment of the filaments. Above this point the cell walls become slightly waved toward the top of the corolla.

(*a*) The Stamens of *E. ageratoides* are borne on the corolla tube alternate with its lobes. Each filament in cell structure consists of two parts, the lower being composed of long, thin-walled cells extending through two-thirds of its entire length (Fig. 4 *a*). The other part, next to the anther (Fig. 4 *b*) is composed of oval or quadrangular cells bounded by a thickened, beaded, strengthening wall, the same in structure as the wall of the anther. The anther consists of two lobes united by a connective which extends upward between the lobes as an irregular, four-sided structure, broad on its external, and narrow on its internal face. Each connective is expanded above into a transparent deltoid process (Fig. 4 *c*) which unites with its neighbors to form a pyramidal roof over the apex of the style, thus protecting the more irritable parts from external influences and the nectar from rain. The anthers are united by their contiguous margins, and dehisce by introrse longitudinal slits, (Fig. 5).

(*b*) The Stamens of *E. coelestinum* (Fig. 5) differ from *E. ageratoides* (Fig. 4) only in being shorter and less firmly united.

(*a*) The Pistil of *E. ageratoides* is deeply cleft at the top into two long style arms which are covered from their tips downward over two-thirds their length with multicellular hairs, that sweep the pollen from the anther cylinder, hence called sweeping hairs (Fig. 6 *e*). Interspersed among the sweeping hairs are occasional goblet-shaped multicellular hairs. Immediately below the sweeping hairs are the stigmatic papillæ (Fig. 6 *d* and *d'*) arranged laterally in groups of three or four (*d'*) covering almost the entire length of the lower third of the style arms. In this species there is a glabrous area at the base of the style arms. The style is slightly swollen at its base, and surrounded by an annular nectar gland *g*.

(*b*) The Pistil of *E. coelestinum* (Fig. 6) is longer than in *ageratoides* and is frequently twisted. The stigmatic papillæ extend entirely to the bases of the erect style arms which have enlarged club-shaped tips—Fig. 6 *e*. Hildebrand * states that in *E. cannabinum* the stigmatic surfaces remain closely appressed, and that the stigmatic papillæ are not fully developed until after the pollen is matured, shed, and carried away by insects, so that cross pollination is insured. In the dried specimens of *E. coelestinum* examined, the style arms were slightly separated before they protruded beyond the top of the anther cylinder, but the stigma was not fully developed. In the matured flowers the style stands more erect than in *E. ageratoides*. In flowers not fully expanded, and with the anther cylinder closed at the top, the style showed a distinct, loop-like curvature just above the receptacle (Fig. 6 *f*). In fully expanded flowers the style is quite straight.

The five anthers cohere to form a hollow cylinder which is filled with pollen when the corolla begins to expand. In the first stage with its two style arms closely applied to one another, the pistil extends to the base of the anther cylinder and gradually elongates, pushing the pollen before it out of the cylinder by means of the outwardly directed sweeping hairs (Fig. 6 *e*) which cover the upper part of the style arms. When the stigmatic portion, which is smaller

* "Ueber die Geschlechts-Verhältnisse bei den Compositen." Verhand der Leo. Carol. Acad. Dresden. Vol. 35 (1869).

in diameter than the area bearing the sweeping hairs enters the otherwise empty cylinder, the pressure is reduced and a probable transfer of liquid diminishes the turgescence of the filaments which bend themselves at point *a*, Fig. 4, and draw down the cylinder from over the stigmatic area. In *E. coelestinum* (Fig. 6) the stigmatic branches are further carried up by the unfolding of the loop-like curvature in the style. The pollen thus carried out of the anther cylinder falls upon the corolla, and is at once carried away by insects, or by the wind ; this closes the first or staminate stage. The stigmatic surfaces readily develop their papillæ and secrete stigmatic fluid. When by frequent observations the pistillate stage was determined in the first lot of plants selected, two of the first four plants were carefully cross-pollinated by hand, and two were close pollinated in the same manner. The second four plants were left undisturbed until put in press, as were also those exposed. In the second lot selected, two of the first four plants were cross-pollinated, and two were close pollinated. The second four, in which half the inflorescence was protected, and half exposed, were left undisturbed until put in press, when ninety-five per cent. of the fruits grown on exposed parts were well developed, while sixty-two per cent. of fruits grown on protected parts were apparently good—showing an increase of over fifty per cent. in favor of exposed plants. The plants with separate branches protected were also cross and close pollinated ; while the last two of the second choice were left exposed, to compare with the last four of the first choice. Ninety-four per cent. of the fruits were matured in each case.

The immature condition of the stigma at the time the pollen is swept out of the anther cylinder clearly indicates cross-pollination, whatever the agency may be. The pollen is carried from the corolla by nectar or pollen-feeding insects, or by the wind. If removed by insects, as seems most probable, they carry it from flowers in the staminate stage, to those in the pistillate as they pass over the capitulum, or from one plant to another. The results throughout show that fertilization under these conditions did occur. If the pollen be carried by the wind, it will as in the case of insect agency, be deposited upon the fully matured pistils —but the results recorded in the following tables do not show that fertilization by means of wind did occur; for though the pollen was abundantly distributed over the entire inflorescence and the inside of the covering of the protected heads, the seeds could not be made to germinate under the same conditions as those grown upon unprotected plants. Moreover, the colors of the flowers and the abundance of nectar secreted, would indicate entomophilous fertilization, while the anthers are shorter than the corolla, united in a tube and dehisce introrsely—conditions unfavorable to wind pollination. From the time of pollination to the time when the fruits are ripe, a period of eight to ten days elapses. Previous to pollination the ovarian wall is clear, pale, and delicate in appearance. In surface view it shows very long cells, each containing a row of transparent, circular areas at irregular intervals—Fig. 9. Cross-section —Fig. 10—shows five layers, each of which is composed of cells of uniform size, except the innermost—Fig. 10 *i*— which shows smaller cells. Soon after pollination the fourth layer from the outer surface has pigment deposited in it, which gives a most delicate ecru tint to the wall. As the fruit matures the pigment is gradually deposited in the fourth layer between the circular areas, whose perimeters are much thickened, forming chimney-like openings (Fig. 10 *k*). The wall passes through every shade of brown, until at maturity it is very dark brown. During the period from pollination to maturity, no change occurs in the circular areas. H. M. Ward * suggested in a recent publication that the pigmenting of the maturing fruit is a provision intended to act as a color screen against the blue violet rays, "as these rays would otherwise

* "Further Experiments on the Action of Light on *Bacillus Anthracis*," by H. Marshall Ward.

destroy the reserve substance by promoting its rapid oxidation."

E. AGERATOIDES. Table of Statistics showing comparative results of cross, close and natural pollination	Number of Capitula examined.	Total number of flowers developed.	Average number of flowers in Capitulum.	Number of Achenes matured.	Number of Achenes not matured.	Average number of matured Achenes.	Number of days under observation.	Number of days elapsed bet. pollination and maturing of Achenes.	Percentage of good fruits.
Plants matured under natural conditions, Aug. 29 to Sept. 20.	8	117	14.5	110	7	13.7	23	—	94
Protected Sept. 3, cross pollinated Sept. 19, gathered Sept. 27.	8	108	13.5	66	42	8.2	23	9	61.1
Protected Sept. 3, close pollinated Sept. 19, gathered Sept. 27.	8	106	13.2	43	63	5.25	23	9	39.6
Protected Sept. 3, gathered Sept. 26.	16	245	15.3	10	235	.62	23	—	4.1

E. COELESTINUM. Table of Statistics showing comparative results of cross, close and natural pollination.	Number of Capitula examined.	Total number of flowers developed.	Average number of flowers in Capitulum.	Number of Achenes matured.	Number of Achenes not matured.	Average number of matured Achenes.	Number of days under observation.	Number of days elapsed bet. pollination and maturing of Achenes.	Percentage of good fruits.
Plants matured under natural conditions, Aug. 29 to Sept. 20.	8	448	56	352	96	44	23	—	78.5
Protected Sept. 3, cross pollinated Sept. 19, gathered Sept. 27.	8	381	48	255	126	32	23	9	66.9
Protected Sept. 3, close pollinated Sept. 19, gathered Sept. 27.	8	424	53	102	322	13	23	9	24
Protected Sept. 3, gathered Sept. 26.	8	456	57	50	406	6.2	23	—	10.9

Referring to the preceding tables, it will be seen that eight capitula grown under natural conditions produced 117 fruits in twenty-three days, 110 of which were black and swollen and contained well-developed embryos. Eight capitula, selected from a portion of a panicle protected September 3d, cross-pollinated by hand September 19th, put in press September 27th, produced 108 fruits. Of these forty-two were white, shrivelled and imperfect, and sixty-six were black and promised to be fertile. Plants protected September 3d, close pollinated by hand September 19th, the product gathered September 27th, produced 106 fruits from eight capitula, forty-three of which were black and swollen, and when dissected showed well-developed embryos, while sixty-three were pale and shrivelled, with immature embryos. Plants protected September 3d, left undisturbed till gathered on September 21st, produced 245 fruits from sixteen capitula, only ten of which appeared well-developed and fully matured. In order to test the fertility of the embryos, I selected seeds showing the best development, from plants grown under the four conditions mentioned in the tables, and planted them January 7th, in a large germinating dish between pieces of white felted flannel. On March 31st radicles were seen protruding from fruits grown under these conditions. This continued until the middle of May, when at least seventy-five per cent. had germinated. The radicle in germinating protruded from the side of the fruit—Fig. 11—just above the point of attachment to the stalk 1. Twenty of the seedlings were potted, and made vigorous growth. None of the seeds from plants cross or close pollinated by hand, or seeds from plants protected and left undisturbed, germinated; although subjected to the same conditions as those grown naturally. Reviewing the above observations, it seems clear that self-pollination in the species of *Eupatorium* is very rare indeed; and that even when it does occur, the resulting fruits are of weak germinating capacity. When close pollination by hand is effected, a slight increase in the production of good fruits is obtained; but when covered flowers are cross-pollinated the increase is very striking, and decidedly points to the conclusion that the artificial method adopted is an imperfect imitation of the action of insects, whose visits assure the large percentage of good fruits indicated in the table of statistics.

The foregoing brief observations point to important lines of inquiry, which the writer may in the future be able to follow out more fully.

DESCRIPTION OF FIGURES IN PLATE XVIII.

Illustrating L. B. Cross' paper on *Eupatorium*.

Fig. 1. Longitudinal section of the corolla of *E. ageratoides*, showing the external surface of two lobes of the corolla bearing papillæ, *p*, on their inner margins, and multicellular hairs, *h*, on their outer surface. × 65.

Fig. 2. Longitudinal section of the corolla of *E. coelestinum* showing papillæ, *p*, over the margins of the lobes and oval sessile hairs, *h*, on the external surface. × 65.

Fig. 3. Stamen of *E. ageratoides*; *a*, junction of long, thin-walled cells with *b* oval, quadrangular, beaded cell wall; *c*, process of expanding connective.

Fig. 4. Cross section of stamen of *E. ageratoides*. × 65.

Fig. 5. Four of the stamens of *E. coelestinum*, showing connection and dehiscence. × 65.

Fig. 6. Pistil of *E. coelestinum*; *g*, nectary; *f*, loop in the style; *d*, stigmatic surface; *d'*, high power view of stigmatic papillæ; *c*, sweeping hairs. × 65.

Fig. 7. *g*, nectary enlarged. × 150.

Fig 8. Longitudinal section of fruit, showing, *l*, receptacular stalk; *ov*, ovule; *n*, transparent tissue surrounding base of the pappus; *o*, base of corolla; *g*, nectary in section; *r*, base of style. × 65.

Fig. 9. Surface view of seed coat showing brown, elongated cells, with pitted areas. × 350.

Fig. 10. Cross section through the seed coat showing, *i*, innermost layer of small, thin-walled cells; *k*, pigmented layer with pitted markings. × 350.

Fig. 11. Germinating seedling with fruit wall attached; *g*, shrivelled nectary; *r*, remnant of style. × 35.

Contributions to the Life History of Amphicarpæa Monoica.

(*WITH PLATES XIX-XXXVI.*)

BY ADELINE F. SCHIVELY, PH.D.,
Assistant Teacher in the Department of Biology, Philadelphia Normal School.

THE Genus *Amphicarpæa* was established by Elliott[1] in 1817. An account of his observations may be found in the Journal of the Academy of Natural Sciences of Philadelphia. He mentions in "The Botany of the South"[2] two species—*A. monoica* and *A. sarmentosa*.

In the "Genera Plantarum" are enumerated seven species inhabiting North America, Japan and the Himalayas.

The Genus is stated to contain fifteen species in "Die naturlichen Pflanzenfamilien." These are distributed as indicated above, except that two additional are mentioned as occurring in Tropical America. These are *A. pulchella* and *A. angustifolia*—both found in Mexico, the latter also as far south as Peru.

Both publications give *A. Edgeworthii* in the Himalayas, also *A. monoica* in North America. Neither records *A. sarmentosa* and *A. Pitcheri*, which are mentioned in some of the leading American Manuals of Botany.

The investigation of *A. monoica* was undertaken at the suggestion of Professor Macfarlane, who studied the sensitive movements of the plant, and also the production of cotyledonary buds. My work has progressed under his supervision.

The scientists who have worked upon *Amphicarpæa* will now be mentioned in chronological order.

Darwin[11] experimented upon the movements of the leaves and also upon the shoots producing subterranean legumes.

A very short account appears in "The Power of Movement in Plants."

In 1878, Farlow[15] reported investigations upon *Synchitrium fulgens*—var. *decipiens*—which badly infests the plant in some localities.

During 1886 and 1887, Meehan[16] studied the flowers and fruit. The account of his investigation is found in the "Proceedings of the Academy of Natural Sciences (Philadelphia, 1887)." The results of his observations are summarized at the close of his paper. The statement given below is not an exact quotation; the arrangement of facts, however, is that used by him. His conclusions are as follows:

1. Climbing as well as trailing stems bear apetalous flowers.

2. These produce a third form of legume.

3. Petaliferous flowers under suitable conditions of nutrition produce legumes as freely as leguminous plants generally.

4. Petaliferous flowers are adapted to close fertilization; the apetalous are fertilized from these.

In 1890, Huth[17] published a paper, entitled, "Uber geokarpe, amphicarpe, und heterokarpe Pflanzen." He classes *Amphicarpæa* under the second heading indicated in the above.

Macfarlane[19] reported to the Botanical Section of the Academy of Natural Sciences (Philadelphia), his observations upon the production of cotyledonary buds. About the same time (1893), in a lecture delivered at the Woods Holl Marine Biological Laboratory,[20] the sensitivity of *Amphicarpæa* was compared with that of *Mimosa*, *Cassia*, *Oxalis*, etc.

This list comprises the known contributions to Botanical Literature concerning *Amphicarpæa* up to the present time.

General Conditions of Life.

Amphicarpæa monoica is a plant quite widely distributed throughout the eastern United States. It is, indeed, one of our most common weeds. Its favorite habitat is the woods, where its fresh, green foliage presents an attractive appearance during the spring and summer. It seems to grow more luxuriantly, if it obtains a considerable amount of sunlight, and if the roots receive abundant moisture. Continued exposure to the sun's rays has an injurious effect upon the delicate leaves. It thrives best in a rich loam, but vigorous plants grow in clay or gravel, provided the water supply is fairly plentiful.

The roots are fibrous and copiously branched. Upon these occur singly or in clusters, the tubercles that are characteristic of the Leguminosæ. They are nearly spherical, but slightly flattened, varying in diameter from one to five millimeters. They are found when the plant is but a few inches high. The number varies according to the character of soil, and whether the plant is grown in a pot or in the open. (Plate XIX.) The comparative production of the tubercles in different soils has not been studied experimentally; but they seem to be more numerous, as well as larger, if the plant is grown in a pot.

Wood, Gray, and other botanists refer to *A. monoica* as "perennial." In this latitude there is no evidence of this being typically the case. The plants appear in the spring as the result of the germination of the seed. A very few instances which indicate variation from this rule have been found. While gathering underground seeds in the autumn of '95 I collected a plant possessing long thickened roots, which could be described as tuberous. Unfortunately the fact was not noticed, until too late to ascertain whether the plant would really have perennated or not. In the spring of '96, several specimens were obtained, in which, from thickened root and lower stem region, arose the new plant; at one side persisted the dried remains of last year's stem. (Plate XXXII., Fig. 1.)

The stem is herbaceous, but often becomes very woody toward the end of the season's growth. It is usually green, though often it may be quite purple. In habit, the plant is a twiner, but in the manifestation of twining, great differences are observed. A vigorous plant will ascend rapidly to the top of any weed, whose firm stem offers a sufficient support. If no such sturdy neighbors are near, several plants may twine around each other, forming a thick coil, which for a long time may assume a procumbent position. So delicate is *Amphicarpæa*, and the stem so weak, that the protection of other plants seems a necessity. In attempting to grow specimens out of doors, either in the ground or in pots, it was noticed that they suffered markedly from even slight winds. Though provided with a stick, the twinings were uncoiled; finally shoots and even leaves were injured.

Legumes and Seeds.

Legumes are produced both above and below ground. A description of these and of the seeds is essential to assist in explaining the accounts of germination.

Terrestrial legumes vary much in size, shape and thickness. They are ellipsoidal, much flattened laterally, and might best be described as irregularly pyriform. Mature specimens are on the average three-quarters of an inch in length, and about three-eighths of an inch in thickness. They vary greatly, measuring, however, from a half inch to occasionally an inch in length. (Plate XIX.)

There is considerable diversity in color. Some are pale, others are rich pink-purple, and still others are dark purple or reddish brown. It is suspected that the character of the soil exerts an influence in this respect. Those found in a very moist locality are usually darker than those found in a dry situation.

The entire surface of the legume is very hairy. For a long time the calyx persists (Plate XX., Fig. 1), but in the larger and older legumes, it is scarcely discernible. It is probable, therefore, that it gradually decays. Usually there is a single seed, filling the entire cavity; but a two-seeded condition is not uncommon (Plate XX., Fig 2). The walls of the legume are at first comparatively thick, but the tension consequent upon the growth of the seed causes them to become quite thin. Histological peculiarities will be described later in this paper.

The seed is smooth, of a mottled pink purple color, and varies in size and shape; the statements made concerning the legume, practically applying here. The coat consists of the following layers: a row of strongly indurated cells, prismatic in shape, with long diameter lying at right angles with the outer surface of the coat (Plate XX., Fig. 3, *a*). These cells merge externally into a homogeneous layer of similar tissue—the cuticle. Purple coloring is diffused throughout many of the cells of the prismatic layer. Immediately underneath these, are several rows of parenchymatous cells, many of which contain chloroplasts (Fig. 3, *b*). In the neighborhood of the hilum the layers are increased to form a chalaza, though there is no change in character, nor are new types of element introduced. In that portion of the coat, directly bordering upon the cotyledons, a row of flattened elongated cells is seen, forming the inner epidermis. (Fig. 3.)

The seed is exalbuminous, and contains a large proportion of starch; the granules measure 6 μ, their prevailing form being ellipsoidal. The cotyledonary cells contain numerous refractive protein granules, the nature of which has not yet been determined.

The *aerial legumes* for the present will be referred to as (*a*), (*b*) and (*d*); (*a*) resulting from purple flowers; (*b*) from green inconspicuous ones, produced in late summer; and (*d*) from somewhat similar green, inconspicuous ones produced in winter only.

(*a*) Legumes of this type are about one and a half inches long, stipitate, and decidedly tapered toward the apex, where the remains of the style persist. The shape might be described as falcate; the surface is smooth, excepting the dorsal and ventral sutures which are hairy. The calyx persists and remains quite conspicuous until dehiscence. (Plate XX., Figs. 4, 5.) The seeds vary in number from two to four; three, however, are generally found. The walls of the legume are firm, resisting and quite thick.

(*b*) The legumes of this type are about an inch in length, and are not stipitate, or but very slightly so. They are not tapered, their shape being nearly oblong; the style extends from the apex of each as in (*a*), and its calyx is smaller than that in (*a*), but like it persists. The surface is slightly hairy; the sutures resemble in condition those of (*a*). Usually there are two seeds, but the number varies from one to three. (Plate XX., Fig. 6.)

(*d*) The legumes of this type are still smaller than those of (*b*), and are sessile. They are oblong, the style remaining as a hook which often lies close to the suture. The surface as well as sutures are noticeably hairy. The seeds number one or two, the latter being most common. (Plate XX., Figs. 7, 8.)

Histological features will receive attention toward the close of the paper.

In the aerial types (*a*, *b*, *d*) the seeds are reniform, varying from one-quarter to three-eighths of an inch in length. When ripe the color is grayish green, flecked with dark purple. Upon exposure to the air they become dark brown, with purple black spots; quite often the coloring is a uniform purple brown or black. Type (*d*) bears the largest seeds; (*a*) and (*b*) bear seeds of about the same size. In the general aspect of these but little variation is seen. Those of (*a*) seem darker, but it is doubtful if this distinction will hold.

The structure of the coats of the aerial seeds will be described according to the sequence adopted for those of the terrestrial. No histological differences in the three types of aerial seed have been observed. The outer indurated layer of cells resembles in shape, arrangement and general coloration, that seen in the terrestrial, but the depth of the layer is nearly twice as great as that in the terrestrial (Plate XX., Fig. 9, *a*). Beneath is a row of curiously shaped cells, that are strongly thickened and possess flanges abutting upon each other. Six or eight rows of cells lie below this, showing a gradual or sudden change from indurated to parenchymatous type, according to the region of the seed from which the section is taken. In the region of the hilum all of the above layers increase remarkably in size and thickness. Forming the chalaza are numerous pitted and reticulate tracheids, of the character usually found toward the termination of vascular areas. In this part of the seed, lying between the tegmen and the cotyledons, is a narrow tapering band of sclerenchyma, limited in extent. Bordering directly upon the cotyledons is the inner epidermis of the coat; this consists of narrow elongated cells. Immediately above these epidermal cells are two, occasionally three, layers of strongly indurated elements (Fig. 9 *b*).

The seeds of the three aerial types, like those of the terrestrial, are exalbuminous. In the aerial seeds the prevailing shape of the starch granules is spherical; they are smaller than those of the terrestrial. The proportion of proteid seems greater in the former than in the latter.

Weight.

Equal numbers of terrestrial and of aerial seeds were weighed, and then dried in the oven for from two to four hours at a temperature of about 80° C. The results have been arranged so that comparisons of the weights of a single seed of each class may be made.

Small terrestrial seeds weighed about .345 grammes; after drying, .181 grammes. *Medium sized seeds* weighed 1.143 grammes; after drying, .605 grammes. In a certain locality near Burmont, several exceedingly large specimens were found. The weight of one of these was 2.601 grammes; after drying, 1.1711 grammes. Thus it will be seen how great is the proportion of water present in this class of seed; certainly from forty to fifty per cent. of the entire weight is lost in drying.

The *aerial seeds* do not contain so much water as the preceding. Seeds of type (*a*) weighed before drying, .0291 grammes; after, .0274 grammes. Specimens of type (*b*) weighed .0611 grammes; after drying, .0564 grammes, while those of type (*d*) weighed .0741 grammes, and afterwards .0726 grammes.

In the "Fertilization of Flowers" (Müller, Eng. edit., page 214), a reference is made to some of Darwin's results. These were published in a certain edition of "Different Forms of Flowers in Plants of the Same Species." As a copy of this could not be found, no more exact information can be given. He found the weight of the aerial seeds to be $\frac{1}{75}$ that of the terrestrial form. There is no statement as to the size of the terrestrial ones—whether small or medium. The figures above will give a much larger fraction.

Germination.

Such remarkable differences in size, weight, and structure of seed-coats prepare us for more or less striking peculiarities attendant upon germination. When the investigation of *Amphicarpæa* was begun in the autumn of '94, a quantity of both aerial and terrestrial seeds was collected, and placed in boxes to be used as occasion required. The terrestrial ones became exceedingly hard, almost horny in texture. Both varieties were soaked for twenty-four hours previous to planting. Very few aerial seeds germinated; and only a few terrestrial ones, which had been placed in pots of earth almost immediately after gathering. Upon investigation it was found that those which had been dried and later soaked, had decayed. The same result was obtained each time the experiment was repeated. No germination records were possible during the succeeding winter.

In the following autumn, all terrestrial seeds were put in pots of earth, slightly moistened and kept in a cool place. As quite satisfactory results were obtained in germinating these, this method of preserving the seeds is recommended. All experiments described, were conducted in the greenhouses of the Botanic Garden of the University of Pennsylvania. The temperature ranged from about 20° C. to 36° C., probably averaging 27° C.

Upon October 14, 1895, twenty terrestrial seeds and the same number of aerial were planted. Several aerial appeared in the course of three weeks, but no terrestrial. All of the latter germinated, however, during January, 1896.

Upon December 16, 1895, thirty-two seeds of each kind were planted. An aerial seed first appeared within ten days; about December 30, several terrestrial seeds showed themselves above ground. By January 18, 1896, twenty-six terrestrial and four aerial seeds had developed. After this, at irregular intervals, the remainder of the terrestrial germinated. Result, 100 per cent. terrestrial; 12½ per cent. aerial.

On January 4, 1896, twenty terrestrial seeds were planted as follows: Ten, one inch below the surface; ten, two inches below the surface. On the same date, twenty-five aerial seeds were planted, ten, one inch below the surface; ten, two inches below the surface, and five, one-half inch below the surface. On January 18th, one aerial (1 inch) had appeared above ground; investigation showed that one terrestrial (1 inch) had germinated, though no shoot was visible above ground.

After this results were as follows:

Plants above ground.
Jan. 21st.

1 Aerial (1 inch).
1 Terrestrial (1 inch).

Plants above ground.
Jan. 29th.

1 Aerial (1 inch).
4 Terrestrial (1 inch).
2 Terrestrial (2 inches).

Plants above ground.
Feb. 1st.

2 Aerial (1 inch).
5 Terrestrial (1 inch).
6 Terrestrial (2 inches).

Plants above ground.
Feb. 5th.

2 Aerial (1 inch).
6 Terrestrial (1 inch).
10 Terrestrial (2 inches).

Plants above ground. Feb. 8th.	*Plants above ground.* Feb. 11th.
3 Aerial (1 inch).	3 Aerial (1 inch).
6 Terrestrial (1 inch).	10 Terrestrial (1 inch).
10 Terrestrial (2 inches).	10 Terrestrial (2 inches).

Results, 100 per cent. terrestrial, 12 per cent. aerial.

Keeping aerial seeds in water at a temperature of 35° to 40° C. did not materially increase the rate. Considering the results obtained from filing *Canna* and other seeds with hard coverings, I concluded to try the method here. The percentage then increased to 50, sometimes 70.

About February 18th, seedlings from terrestrial seeds began to appear above ground ten to twelve days after planting, and this time-interval between the planting and germination decreased as spring advanced.

In the autumn of '95, a pot containing one hundred seeds was buried out-of-doors a foot below the surface, where it remained during the winter. April 1st the weather became quite warm. April 10th the pot was dug up; every seed had germinated, and within three or four days all plants came above ground. From the middle to the end of April is the time for the appearance of *Amphicarpæa* seedlings in their native haunts.

It would seem, however, that terrestrial seeds require a certain period of rest even if the requisite heat and moisture are provided. For instance, seeds taken upon April 19th, from plants grown in the greenhouse during the winter, were planted immediately, but failed to germinate until early in June. While collecting seeds, on October 13, from plants grown in the greenhouse during the summer, it was impossible to gather all; many remained among the cinders. Notwithstanding the favorable conditions to which these seeds were exposed, no indications of plants were seen until the latter part of December.

Similar results to those obtained in the autumn of '95 were got in '96. Again, after the latter part of December, germination proceeded rapidly.

Having learned by the autumn of '96 that there was more than one variety of aerial seed, efforts were made to ascertain their respective powers of germination. In the case of type (*a*) the percentage ranged from naught to twenty. With seeds of type (*b*) the same percentage variation was obtained. But filing in each case raised the percentage to seventy. Seed of type (*d*), (found only during the winter) all germinated within six weeks, if planted immediately after being removed from the pots. If allowed to dry, results were no better than those previously mentioned, but with these also, filing raised the percentage.

Very satisfactory results have been obtained by germinating between layers of moist flannel, kept near steam pipes (temperature of course quite high). Within four or five days many had germinated; at the end of two weeks there was a well-formed stem and root. All terrestrial seeds responded quickly to this treatment, whether legumes or seeds only were used. Unfortunately this method was not tried until after January 1, 1897, so that I cannot say whether it would be possible to shorten the supposed resting period or not, had the experiment been made in the early autumn.

With all seeds a temperature of 28° to 30° C. is essential for rapid results.

It would seem from the above data, that it is rare indeed for terrestial seeds to fail to reproduce the species.

Aerial seeds were likewise placed under the above conditions; germination was much slower than for terrestrial ones. Type (*a*) gave 2 per cent.; but with 90 seeds of type (*b*), not one germinated.

Some aerial seeds gathered in '94, gave results but little different from those of '95, when subjected to similar conditions at the same time.

Doubtless the peculiar structure of the seed-coats of the aerial ones is an obstacle to their more general germination. In nature, few, if any of these are likely to produce plants in the succeeding spring.

The seeds of type (*b*), while in general appearance and histological structure not distinguishable from type (*a*), do not seem to possess the same capacity for responding to conditions suitable for germination if both sets are planted without filing. It may be that (*b*) requires a longer resting period than (*a*).

An interesting feature has been noticed in the behavior of the cotyledons, of both terrestrial and aerial seeds, but particularly the former. Normally these, as has been stated, remain below the surface; if however, the seeds happen to be in such position that the cotyledons are wholly or partly exposed to the light, chlorophyll is developed with astonishing rapidity. Nor does it seem that much light is required; seeds which were germinated between layers of flannel, in a deep box placed under the shelves near the floor of the greenhouse showed this phenomenon well within three weeks. Aerial and terrestrial seeds behaved similarly in this respect.

During the winter a plant raised from a terrestrial seed, whose cotyledons remained half above the soil, attained the height of two and a half feet, and produced numerous legumes. The size of the cotyledons was but little reduced; they were firm and not at all shriveled in appearance. The exposed portion of the cotyledons was an intense dark green, really deeper than that seen in the leaves; the subterranean half was quite white; a sharp demarcation showed plainly how the seed had been placed.

Sections through the very green portion showed chlorophyll granules, closely crowded around the cell walls; in the deeper tissue of each cotyledon, these granules were seen, sparingly scattered. Still deeper, no granules were found. The iodine test revealed the presence of the large starch granules characteristic of the terrestrial seed. These were most numerous in the colorless portion, but were not by any means absent in other parts. In addition, minute starch centres were detected in the chlorophyll granules themselves.

Seeds planted in normal position soon develop a small shoot in the axil of each cotyledon. The main stem of the plant at this time is eight or ten inches high. If, however, the cotyledons are placed, so that they are exposed to the light, longer shoots, four in number—two for each axil—are developed by the time the plant reaches the height mentioned above. Cutting off one of the cotyledonary shoots caused the production of two more buds of unequal strength. This operation has been repeated three times in succession, upon the same plant, with a like result. I am not prepared, however, to state how frequently there will be similar response.

It is true, that the cotyledonary shoots developed in normal position give somewhat similar results, when experimented upon in this manner, but the response to the operation of cutting is not so rapid.

In the capability to develop such a quantity of chlorophyll, *Amphicarpæa* seems unique. The cotyledons of *Vicia Faba*, normally hyopgean, when exposed to the light, do behave similarly; but the depth of color is not so pronounced.

Edwardsia chilensis is the only seed mentioned by Lubbock,[18] having subterranean cotyledons, which are greenish. Nothing more explicit is stated; one cannot tell whether that is the natural color, or whether it is produced by accidental exposure to light.

At present no other member of the Leguminosæ is known to exhibit such a marked tendency to form chlorophyll in the cotyledons, unless those organs naturally arise above the surface of the ground.

Young Plants.

As has been stated, the cotyledons of both terrestrial and aerial seeds remain underground. The radicle has grown quite long, and the petioles of the cotyledons have elongated considerably, before the bent epicotyl issues from their protection. For some time the epicotyledonary region remains in this position. From the moment of germination, the contrast between the seedlings of aerial and terrestrial seeds is evident, and becomes more pronounced as growth increases (Plate XXI.) The stem from *the terrestrial seed*, as it appears above ground, is of a deep purple hue; it is strong, vigorous and grows rapidly, soon carrying the first pair of opposite green leaves to a height of four or six inches. After this, compound leaves are produced; the internode between the simple leaves and the first compound leaf is short. When the stem is about ten inches in height, it exhibits an inclination to twine; if a support is within reach, the plant soon becomes a vigorous twiner and the internodes increase in length. The stem of the plant from *the aerial seed* is slender, feeble and is usually green. It grows during the first ten days almost to its full height, which is much below that attained by the preceding plant. The simple and compound leaves are about half the size of those of the first described. Twining does not take place; even tying to a stick failed to induce twining movements. During the winter variations from such types were seen. A terrestrial was found which was low growing, although it still twined. (Plate XXXV., Fig. 1.) Occasionally an aerial grew taller, or more strictly perhaps, longer; but reclined upon the ground. *This striking dimorphism continued through the winter.* Plants produced from filed seeds behaved as the others. In the late spring a good many of the aerial seedlings twined; their general appearance was feebler than that of the terrestrial form. Reference to these facts will again be made toward the close of this paper.

In the descriptions which follow, plants produced from terrestrial seeds are intended, for they furnished specimens apparently most normal in behavior.

Below the first pair of green leaves the stem is nearly smooth, above these, the stem exhibits all degrees of hairiness. The hairs are always retrorse, and vary from a rather scanty growth to a thick brown felt. The vigor of the plant and the place of its growth seem to exert an influence upon this characteristic.

Cotyledonary Buds.

The germination of seeds of *Amphicarpæa* by Macfarlane[19] had been interfered with by mice; and the same difficulty confronted the writer. Even the raising of plants out of doors was not without serious draw-backs. More than one plant several inches high was visited by rabbits or by sparrows, which found the fresh green herbage agreeable. The main shoot was often removed close to the ground. Upon examining the plants a few days later, in nearly every specimen several cotyledonary buds had developed and were manifesting apogeotropic tendencies. The number varied from two to five; they were thick and white. It is not usual for more than two to appear above ground, but occasionally three have been observed. It was found that plants from three to six inches in height that were thus injured sent up within ten days two shoots arising in the manner described.

These occurrences suggested experiments in which the plant was deliberately injured by cutting off the main stem close to the ground. Many of these experiments were performed with results exactly as given above. A plant fifteen or more inches in height, so treated, either never developed cotyledonary shoots, or else after many weeks one appeared above ground—a tiny feeble thing.

If four or five cotyledonary buds have developed, and a vigorous shoot resulting from one is then cut off, the immediate result seems to be the formation of two more. For example, one so treated had finally ten buds.

These experiments were not a success when plants produced from aerial seeds were used. Sufficient vitality seemed to be lacking.

It is worthy of notice for comparison with statements soon to follow, that these cotyledonary shoots never bear simple leaves, but compound only. They soon begin to twine, however, and the growth of the cotyledonary shoots in all respects is about equal.

Axillary Shoots.

Let us now turn attention to the cotyledons of a plant which has developed without accident. Examining the conditions below the soil, it is found that from two to five runners arise in the axils of the cotyledons. These usually remain underground, and are therefore white, bearing stipules, but no leaves. For a time their growth is comparatively slow. Plants in the woods, developing from seeds in the spring, showed about July 1st, cotyledonary axillary shoots from three to six inches long. Those raised in pots were not so long, but were more branched. As the summer advances, these runners elongate rapidly, and eventually may become twenty to fifty or even sixty inches in length.

In the axils of the green leaves both simple and compound, arise branches, which may be referred to as axillary shoots (Plate XXII.). In the case of the simple leaves, two to four, occasionally six, of these are found. Possibly here the term "runner" may be more appropriate. The compound leaves show one, often two axillary shoots. All of the axils of leaves upon these original branches possess similar possibilities. One may easily imagine therefore the mass of vegetation resulting from a healthy plant, from which axillary shoots three or four feet in length are actively growing.

This development in the axils does not begin until the plant reaches the height of ten to fourteen inches. Sometimes their increase is so rapid, that growth of the main stem is evidently retarded.

Apogeotropic and geotropic tendencies.

Plants resulting from terrestrial seeds twine more or less vigorously—and the main stem is decidedly *apogeotropic.* The axillary "runners" are *geotropic;* as soon as the bud develops, this tendency becomes manifest. When the ground is reached the tip does not seem to penetrate the soil, but growth takes place and the shoot may extend along the surface for some distance. Many of these runners are quite leafy; others are devoid of those organs, and show stipules only. From the axils of the stipules grow numerous branches of varying length which exhibit *geotropism* in beautifully curved tips.

The extremity of the runner is often turned upward in the most curious manner. In order to ascertain if these runners possessed any *apogeotropic* tendencies, many of them were given an opportunity to twine. A support was placed for them, they were even assisted by being artificially twined around the stick and then tied to it. In all cases they persistently refused to twine, gradually turned so that the tip inclined downward, and as growth continued they finally reached the soil and behaved as previously described.

Experiments, made upon the runners when about four inches long, consisted in carefully cutting a sixteenth of an inch, and also an eighth from each apex. The shoots were then supported and inclined upward. In the course of two days, they had grown an inch and showed a decided geotropic curve.

It has been noticed that these runners from the simple leaves appear to be *negatively heliotropic*. No special experiments have been made which positively prove that this characteristic is stronger than the *geotropic* one. These axillary runners and their branches continue their growth, finding now a crevice, now a space under a flower-pot—both of which are suitable places for the maturing of terrestrial fruits. In the green-house, the plants were placed upon a shelf about a yard in width, raised several feet from the floor. Many runners from the plants finally extended across the shelf either directly or diagonally, and continued their growth in the dark space below, many of them maturing fruit.

In the woods some of the best developed and most fruitful specimens of axillary runners have been those growing among the dead leaves, which excluded nearly all the light.

All axillary shoots from the axils of compound leaves exhibited for a time geotropism. Plants which were inverted gave proof of this. Care was taken that plants selected for this experiment should have short axillary shoots (not more than an inch and a half). Within twenty-four hours, the portions of the specimen had adjusted themselves to their altered relations; the shoots were geotropic.

Ordinarily this condition does not last long, for as growth increases, a great curve is noticed near the tip, sometimes extending for several inches. All that is needed is the placing of a support near the apex. In a few hours twining begins, and consequently apogeotropic tendencies are manifested. If no support is given, the shoots will twine around any neighboring support, or indeed around some adjacent individual of the same species.

We may now recapitulate briefly. Axillary runners from simple leaves are *geotropic* and *negatively heliotropic*. In the young condition, the axillary runners from compound leaves are *geotropic;* this characteristic is usually lost quite soon, for they become *apogeotropic* and twine readily. The last mentioned shoots usually appear to resemble the main stem in their habits of growth.

Occasionally exceptions to this last statement are seen in certain plants that, differing in no apparent particular from others in their early life, exhibited later the peculiarities which will be described below. The axillary shoots from compound leaves, as well as the branches from these, were purplish, rather than green, and leaves were very few; often entirely absent. Such shoots seemed always geotropic. I have now in mind, one plant which grew in the greenhouse during the summer; it became fully five feet high; the main stem twined vigorously. The long purple shoots were numerous, but they did not exhibit the slightest inclination to twine, even around neighboring shoots; they grew directly downward. Yet just beside this specimen were plants with many leafy branches which twined upon any available support.

Truncation Experiments.

Having observed these phenomena, a series of what may be termed "truncation experiments" were made. These consisted in cutting off the main stem at different levels, and noting the result upon the future development of the axillary shoots. Nearly all of these were performed in the green-house during June and July, a few, however, during the winter months. The results of some of these are stated below.

I.

Cutting off Main Shoot above Simple Leaves.

On June 6, 1896, the main shoot was cut off above the simple leaves; in the axil of each was a branch one inch long.

On June 16, both branches had lengthened considerably; they formed almost a right angle, and were growing upward.

On June 29, the axillary runners were about eight inches long, and although growing upward, had not yet twined. Sticks were placed for them.

On July 6, the runners were over a foot long, and both were twining. (Plate XXIII.)

On June 19, the main stem of a plant was cut above the simple leaves; also all buds from the axils.

On June 29, additional accessory buds had developed, and the shoots were one inch, and one and one-half inches respectively. Another bud was appearing in the next axil.

On July 7, the branches had turned upward, and were three and six inches respectively. The bud remained in about the same condition.

On July 15, the branches were ten and fourteen inches.

As no support had been given to them, they twined around each other.

On July 1, the main stem of a plant was cut off above the simple leaves. One of the axillary branches was taken away; the other about ten inches long was left.

On July 15, it was seen that the runner had increased to fifteen inches, and in the axil of each small leaf upon it had appeared a little branch. The main runner did not twine nor exhibit any inclination in that respect. An accessory bud was seen in the axil of the simple leaf.

In some cases the shoot declined for some distance out of the pot, then twined feebly around some support that was near. It did not take the one provided in its own pot. The results obtained in this series bear a direct relation to the age of the shoot at the time when operations are begun. One may readily see, then, that if the true stem is destroyed, its place is taken by the axillary shoot, and *that which in its normal condition possessed pronounced geotropic characteristics, now exhibits apogeotropic ones.* Yet, if the injury takes place after the shoot is tolerably long, it is impossible to change its strongly-impressed habits; its inherited tendency remains.

Cutting off Main Stem above First Compound Leaf.

On June 6, the main stem of quite a tall vigorous plant was cut off above the first compound leaf. Axillary branches were removed from the simple leaves. A single bud remained in the axil of the compound leaf.

On June 29, the branch which had developed in the axil of the compound leaf was vigorously twining. The plant was about two feet high. Axillary runners from simple leaves were ten inches in length.

On July 8, the plant was two and a half feet in height; the axillary runners, eighteen inches.

On June 12, the main stem of a plant was cut off above the first compound leaf, and all the axillary buds from the simple leaves were removed.

On June 29, the plant was one foot high, and the newly-developed shoot in the axil of the compound leaf was twining.

On July 8, the plant was one and a half feet high, and twining well. Axillary runners had developed.

On July 13, the new twining shoot was cut off above its first compound leaf. A bud remained in its axil. All other axillary buds and branches were removed.

On July 15, the bud had developed into a branch an inch long.

Unfortunately the last date has been omitted from my notes, but in a short time this new branch twined and continued the upward growth of the plant.

Cutting off Main Stem above Second Compound Leaf.

On June 6, the main stem of a vigorous plant was cut off above the second compound leaf. One bud remained in the axil of this; all others were removed.

On June 29, the plant was two feet high. The new shoot was twining; the internodes were rather longer than those on main stem. One axillary shoot ten inches long arose from the axil of the first compound leaf. Along the twining shoot a bud was seen in the axil of every leaf.

The plant continued to increase in height, and the axillary shoots developed rapidly.

Experiments with Cotyledonary Shoots.

Roots of young plants were carefully washed, then replaced in pots, so as to bring the cotyledonary shoots above ground. Occasionally they were found already appearing above ground. Usually they were white and finely pubescent; then they soon acquired a green color. For some days they grew slowly; they were supported by small bits of wood, and inclined upward, in order to prevent a continuation of their tendency to return to their natural abode. A record of a few of these is now given.

On June 27, a plant was arranged so that the cotyledonary shoot was above ground. The shoot was short and white.

On July 8, the cotyledonary shoot was quite green, and was about six inches long. It had branched, and was growing out in a horizontal direction. It was turned up and tied to a stick.

On July 15, the shoot was about twelve inches long, possessed branches and leaves. It was longer than the original stem, but no twining had taken place.

On June 27, a plant was found having the cotyledonary shoots above ground. There were two about four inches long.

On July 6, the shoots had increased in length. One was tied to a stick (the other was accidentally broken). The main stem of the plant was twining.

On July 15, the plant was eighteen inches high, the shoot about fifteen inches, but did not twine.

On July 22, no twining had occurred.

On June 27, two small cotyledonary shoots, already green, were supported as described above.

On July 8, the shoots were four inches in length, and had made a decided right angle, for they were now growing upward.

On July 15, the main plant stem was cut off. The shoots five and seven inches respectively bore tiny green leaves. They were tied to a stick.

On July 22, no twining had occurred.

About this time, a plant having four cotyledonary shoots above ground was noticed. It was observed again early in September. Extensive growth had taken place, but no twining, although the shoots varied in length from twelve to eighteen inches. The main stem had grown but little.

When plants much older than these (about three feet high) were similarly treated, no results were obtained. The shoots remained white and did not seem to increase in length, and finally died.

Another experiment was as follows: A vigorous plant was truncated just above the simple leaves; every axillary bud was removed, and this process was repeated, no bud being allowed to develop. The result was that in the course of about ten days two cotyledonary shoots had arisen from the soil. Later on twining took place.

Referring for a few moments to the paragraphs upon the development of cotyledonary buds, (p. 284) it will be found that when the main stem is destroyed, and the developing shoots take its place, twining becomes their habit. Yet if the stem persists, and they are brought above ground, their growth is more or less horizontal.

Thus the cotyledonary shoots, and the axillary runners, which under normal natural conditions are geotropic, may acquire apogeotropic tendencies, if necessity places certain responsibilities upon them.

Illustrations need not be multiplied; enough has been said to indicate the deep resources of the plant. In the "struggle for existence" many, if not all, of the conditions artificially produced, no doubt do occur. Very beautifully does *Amphicarpæa* show its ability to cope with adverse circumstances, and by various growth-compensations to prolong its existence, and even to continue its accustomed habits of twining.

Circumnutation Experiments.

In his writings, Darwin includes under the term circumnutation, the movements of heliotropic organs, those of geotropic organs, as well as those of the twining stem. Under the last heading, belong the principal experiments to be described in this section.

It is not the intention to discuss here in detail, the various theories which have been advanced concerning the behavior of the twining stem, the phenomenon of its circumnutation, and their probable relations.

Von Mohl, Palm, Darwin, Dutrochet, De Vries, Pfeffer, Sachs, Kohl, Noll, and other authorities have contributed to the literature dealing with these problems. To a certain extent most of them believe that the peculiar manifestations of the movement are due to variations of turgescence in the growing cells. Numerous hypotheses have been advanced to explain the movement.

Dutrochet suggested that twining stems possessed properties peculiar to themselves, but his efforts to theorize concerning their activity are not particularly lucid. Von Mohl, and later, Kohl, asserted their belief that twining plants are endowed with irritability. More recent authors concur in this opinion. The stimulus afforded by contact with the support is of vast importance in causing the continuance of the normal twining activity, and the health and vigor of the plant is doubtless dependent upon the successful manifestation of its habit of growth. External conditions too have a decided influence upon the behavior. The force of this statement will be evident as the results of experiments are presented.

Plants of the species under investigation twined readily around a rough or smooth stick, varying from one-quarter to three-quarters of an inch in diameter; also around glass rods, string, or wire, and if nothing else was available, they utilized each other. *Amphicarpæa* twines in dextrose fashion—against the sun.

Darwin's experiments recorded in "Climbing Plants,"[12] though numerous and embracing many plants and representatives of many orders, seem to the writer to lack certain essential requisites of information. Much of the movement exhibited is unquestionably due to the innate characteristics of the species. This again is modified by the height and vigor of the individual under observation.

These facts to a certain extent are considered by Darwin.[12] He distinctly refers to the increased amplitude of the circumnutation, noticeable by comparing the young plant with the older stage, although the height of the specimen is not always recorded in his tabulated results.

May not the varying periods of movement be due to the environment? Is it not due to certain external conditions that the manifestations of activity are now quickened, now retarded?

Various writers, among whom is Dr. Macfarlane,[20] have shown in reference to experiments made upon *Oxalis*, *Cassia*, *Mimosa*, etc., how important is the temperature alone. Quick response to stimuli cannot be obtained, unless care is taken to see that the thermometer registers from 75° to 105° F., according to the species. While this kind of irritability is not here considered, we may rightly extend the truth taught in this special case, to all phenomena which may be classed under the manifestations of irrito-contractility. To none are the above words more appropriate than the species now under consideration.

If we watch the tip of the long stem passing through space, as if reaching for a support, we may actually see it move. Hour after hour it proceeds steadily onward like "the hand of a clock." If we are fortunate enough to see it touch a stick, we notice in a few hours a change in the manifestation of its activity. It continues its course now in a "beaten path," as it were, the influence of the action still felt below, and being seen in the tightening coils which clasp the stick.

If the support be removed, the upper part at least of the plant, slowly straightens and repeats the same searching movements. My reader may say, "This is inherent in the plant." True; these statements have only been repeated in order to make very plain the exceedingly active protoplasmic conditions that exist in a climbing or twining plant. Then, how much more easily does the physiological equilibrium change with the variations in environment.

Judging only from what has been learned of one plant, I conclude that in addition to height of specimen, information concerning temperature, conditions of moisture, exact time of day at which the experiment was made, and also light intensity should be stated.

A few items of detail may not be out of place here. *Amphicarpæa* positively refused to circumnutate if exposed to a temperature of 15° C. for any length of time. If retained at such a temperature for a day or two, the effects of the injurious environment remained for some hours after the plant was placed under more favorable conditions.

On the other hand, a temperature of 38° C. or over seemed to have a similar paralyzing effect. If supported, the plant remained almost stationary, and often drooped. If free, the movements were irregular and spasmodic, partly due to the plant's adjusting its equilibrium, which is more or less disturbed by the para-heliotropic position of the leaves. Upon one occasion, a plant behaved as above indicated, temperature 40° C.; it was carried into a cooler greenhouse, the temperature there being 24° C. Apparently undisturbed by being moved, in a few moments the plant recovered from the heat, and proceeded in its usual circular path.

Many of the diagrams given by various authors to illustrate circumnutation, indicate that an erratic or sometimes a sinuous course, has been taken by the plant. It is possible that these results are due to a temperature which is too high for the species. The exceedingly long time required by certain plants may partly be caused by an injuriously low temperature.

The most favorable temperature for *Amphicarpæa* is from 26° to 32° C.; good results are obtained with the thermometer above and below these figures, but the most rapid circumnutation usually occurs within these limits.

If a plant is taken from the moist greenhouse and placed in a dry room, marked retarding of movement occurs, though the temperature is about the same.

Placing a lighted lamp or candle during night, before a plant which has been circumnutating well, though perhaps slowly, will cause it to become stationary and remain so for a time. The last two statements have not been put to the test of many experiments.

Some of this work was done during the winter in the greenhouse. Difficulties were encountered in the varying temperature and moisture of the greenhouse, also the supply of fresh air; but on the whole, results were very satisfactory. Experiments were continued during May, June and July, when the greenhouse was not artificially heated. Out of doors, even a slight wind was a disturbing factor. The greenhouse being well ventilated, the temperature varied little from that outside. As the glass above was very lightly white-washed, the shade produced a condition similar to that in which the plants normally grow.

Specimens under observation were placed as close as possible (without touching) to the glass upon which records were made. No special effort was made to obtain a continuous path traversed by the plant, though all records are fairly accurate. The time in which the revolution might be completed was the information desired. Few observations were made as to the number of internodes circumnutating at one time. Two or three seem to be in activity at the same time; no difference in the rates could be distinguished; the movement seemed uniform.

Plants under eight inches exhibited slow, irregular movements, rarely forming a circle. When nine to ten inches long the curving of the tip became more evident, and from this time on, as the twining inclination increased, the path described became circular. The rate of elongation is rapid—from one to two inches a day.

There is a certain marked periodicity. Beginning with the early hours of morning there is a gradual acceleration until 11 or 11.30 A.M. The greatest rapidity occurs from this time until 2 or even 3 P.M. After that time there is a gradual decrease in the rate, until several hours after midnight. The maximum period may be much extended, beginning earlier and continuing until 4 or perhaps 4.30 P.M., if the day is very hot.

The quickest rate obtained was 51 minutes; the longest 3 hours 36 minutes. In the former case, the specimen was unsupported and was 14 inches high. It was observed upon February 8, the temperature being 26½° C.; it completed a circle 7¾ inches in diameter between 11.42 A.M. and 12.33 P.M. In the latter case the specimen was 9 inches high. The observation was made upon June 30 between 1.32 A.M., and 5.08 A.M. The temperature was 16°–14° C., and the circle but 2½ inches in diameter. Both days were bright and clear.

It is true that the smaller plant had not yet exhibited a twining inclination. But from the two extremes may be gained some idea of the varying conditions under which these experiments with *Amphicarpæa* have been performed. From what I have observed, I am confident that so long a time would not have been required by the second plant, had the records been made under conditions similar to those of the first. It may be best, therefore, to state the longest time noted for an unsupported plant whose height was twelve or fourteen inches.

A plant, 14 inches high on February 14, completed a circle from 6 P. M. to 8.15 P.M., temperature 21° C. The time was 2 hours 15 minutes. On July 2, another specimen 12 inches high, completed a circle in 2 hours and 10 minutes, the temperature being 23° C. The time of day was 6 35 P.M. to 8.45 P. M.

The series which follows is selected as showing average rates of circumnutation and also the periodicity to which allusion has been made. The specimen was 22 inches high, and supported, 9 inches being free; the observations were made during February. Beginning at 9.30 A.M., a circle was completed in 1 hour and 20 minutes; another immediately followed and was completed at 12.01 P. M., in 1 hour and 10 minutes. An interval of a few moments unfortunately occurred; at 12.30 P. M., it was placed in position again, and each circle was completed at the expiration of 1 hour and 10 minutes. The next period began at 1.45 P.M., and was completed in 1 hour and 20 minutes. The date was February 5; weather was clear and sunny. The temperature was 26° during the greater part of the time; it began to decrease during the last one recorded. The last circle required 2 hours and 1 minute, and during this time watering of greenhouse took place; the temperature having fallen to 21° C. Observations ceased at 5.21 P.M.

A plant was observed June 20; the height was 16 inches and it was not supported. From 6.21 A.M. to 8.10 A.M. a circle was completed in 1 hour and 49 minutes; temperature 23° C. At 9.13 A.M. observations began again; in 1 hour and 27 minutes another circle was made, then followed another in 1 hour and 7 minutes. The slight increase of time required for the circle made from 11.49 A.M. to 12.59 P.M., is probably due to a fall of 11° in the hygrometric conditions; since at this part of the day, a more rapid movement should have resulted. The temperature averaged 29° C. The circle was 12 inches in diameter; observations could not be continued, as the plant after this, became caught in the frame. The main stem of this plant had been truncated, and the actively circumnutating shoot was one which had developed in the axil of a compound leaf.

One plant on a hot July day, interested me greatly. It was about 14 inches high; before daylight it required 2 hours and 15 minutes for a revolution, the temperature being 21° C. At 12.47 P.M., I observed it once more; from that hour until 4.49 P.M., four large circles were made; the first in 55 minutes, the remainder in 60 minutes each. The temperature was very regular, 31° to 32° C., but it fell a little, just before the close of the last period.

In some cases, I have been able to study one plant through several successive days, at least for a portion of the time. Thus the varying phases of individuality, growth, time of day and temperature, are more emphatically shown. Watering the greenhouse always retarded movement. In the middle of the day, I feel sure great heat, and want of fresh air affected the rapidity, even when moisture was sufficient.

The above may serve to indicate general conditions. For further information, the reader is referred to the tables on succeeding pages, where have been recorded the results of some of the experiments with necessary details.

On July 22, a clear, sunny day, four plants were carefully observed in the greenhouse for twenty-four hours.

Plant 1 was supported; it was 15 inches high, 8 inches being free. At the close of the twenty-four hours the height was 17½ inches.

Plant 2 was unsupported. It was 12½ inches at the beginning and 15 inches high at the close of the series.

Plant 3 was supported. It was 18½ inches high on July 22, and 21½ inches on July 23. Nine inches were free.

Plant 4 was unsupported. It measured 10½ inches at the beginning, and 12½ inches at the close of the series.

The necessary handling for measuring, arranging, etc., probably affected the results of the first circumnutation. The time records for the night hours show a gradual increase until about 2.04 A.M.; after that a steady decrease. The temperature, it will be noticed, varied very little for nearly twelve hours, and yet the length of time required was longer at 3 A.M. than it was at 7 P.M. The free portions of these plants frequently curved, so that the time of movement was remarkably increased at some times, perhaps diminished at others. This is the only explanation of those results which tend to depart from the beautifully graded series. The size of circle increased rapidly, with elongation of the stem, but as the preceding table gives an idea of the varying sizes, together with the time required for their completion, I have omitted those details here.

During the hours between 9.30 A.M. and 12, it will be noticed that several results of less than an hour have been obtained.

TABLE OF CIRCUMNUTATION RESULTS.

Date.	State of weather.	Temperature, C.	Hygrometer.	Height in inches.	Free or supported.	Time begun.	Time completed.	Time occupied. hrs.	min.	Approx. size of circle.	
*1/29/'96	Clear and sunny.	26—31	——	12	Free.	2.56 P.M.	4.12½ P.M.	1	16½	6 inches.	Same plant.
1/29/'96	Clear and sunny.	31—26½	——	12	Free.	4.13½ P.M.	5.47 P.M.	1	33½	6 inches.	
2/1/'96	Cloudy and rain.	21	——	20	Supported (free end 7 in.)	12.3 P.M.	2.1 P.M.	1	58	5¾ inches.	
2/1/'96	Cloudy and rain.	21	——	20	Supported (free end 7 in.)	2.13 P.M.	4.20 P.M.	2	7	5¾ inches.	
†2/8/'96	Clear and sunny.	26½	——	14	Free.	11.14 A.M.	11.39 P.M.		25	——	
2/8/'96	Clear and sunny.	26½	——	14	Free.	11.42 A.M.	12.33 P.M.		5	7¾ inches.	Same plant.
2/8/'96	Clear and sunny.	26½	——	14	Free.	12.34 P.M.	1.40 P.M.	1	6	7¾ inches.	
2/8/'96	Clear and sunny.	26½	——	18	Supported (free end 6 in.)	11.13 A.M.	12.28 P.M.	1	13	5 inches.	At the close of this experiment plant was tied up.
2/14/'96	Clear.	21	——	14	Free.	6 P.M.	8.15 P.M.	2	15	8½ inches.	
2/15/'96	Clear.	28—31	——	16	Supported (free end 4 in.)	9.20 A.M.	11.15 A.M.	1	55	4 inches.	
2/15/'96	Clear.	29—32	——	16	Supported (free end 4 in.)	11.25 A.M.	12.55 P.M.	1	30	4 inches.	Same plant.
5/4/'96	Clear.	30—27	80—88	10	Free.	5.40 P.M.	7.16 P.M.	1	36	3 inches.	
5/8/'96	Clear.	25½—24	90—88	14	Free.	7.45 P.M.	9.15 P.M.	1	30	9 inches.	
5/15/'96	Clear.	37—38	90—80	9	Free.	12.55 P.M.	1.58 P.M.	1	3	Very irreg	
6/20/'96	Clear.	26—23	90—85	14½	Free.	6.21 A.M.	8.10 A.M.	1	49	7½ inches.	
6/20/'96	Clear.	26—29½	90—88	16	Free.	9.13 A.M.	10.40 A.M.	1	27	12 inches.	
6/20/'96	Clear.	30—29	90—88	16	Free.	10.40 A.M.	11.47 A.M.	1	7	12 inches.	
‡6/20/'96	Clear.	29—30¼	85—74	16	Free.	11.49 A.M.	12.59 P.M.	1	10	12 inches.	
‖2/4/'97	Clear.	17½—22	——	20	Supported (free end 7 in.)	9.45 A.M.	11.25 A.M.	1	40	6 inches.	
2/4/'97	Clear.	22—24	——	20	Supported (free end 7 in.)	11.30 A.M.	1.20 P.M.	1	50	6 inches.	
2/4/'97	Clear.	23—24	——	20	Supported (free end 7 in.)	1.38 P.M.	2.56 P.M.	1	36	6 inches.	
2/4/'97	Clear.	24—19½	——	20	Supported (free end 7 in.)	3.25 P.M.	5 P.M.	1	45	6 inches.	Same plant.
2/5/'97	Clear.	21—26	60—55	22	Supported (free end 9 in.)	9.30 A.M.	10.50 A.M.	1	20	10 inches.	
2/5/'97	Clear.	26	55	22	Supported (free end 9 in.)	10.51 A.M.	12.1 P.M.	1	10	10 inches.	
2/5/'97	Clear.	26	55—52	22	Supported (free end 9 in.)	12.30 P.M.	1.40 P.M.	1	10	10 inches.	

* Hygrometer was not used in these experiments; but the Greenhouse was quite moist.
‡ Plant was too tall for further experiment.

† The tip caught in the frame.
‖ The hygrometer was broken.

TABLE OF CIRCUMNUTATION RESULTS, Continued.

Date.	State of weather.	Temperature, C.	Hygrometer.	Height in inches.	Free or supported.	Time begun.	Time completed.	Time occupied. hrs.	min.	Approx. size of circle.	
2/5/'97	Clear.	26—21	52—58	22	Supported (free end 9 in.)	1.45 P.M.	3.05 P.M.	1	20	10 inches.	Same plant.
2/5/'97	Clear.	20—17	68	22	Supported (free end 9 in.)	3.20 P.M.	5.21 P.M.	2	1	10 inches.	
2/6/'97	Rain.	19—20	60—65	13½	Supported (free end 5½)	9.45 A.M.	12.8 P.M.	2	23	6 inches.	Same plant.
2/6/'97	Rain.	20—21	68—65	13½	Supported (free end 5½)	12.10 P.M.	2.18 P.M.	2	8	6 inches	
2/6/'97	Rain.	19—20	68	14	Supported (free end 7½)	9.50 A.M.	11.55 A.M.	2	5	6½ inches.	Same plant.
2/6/'97	Rain.	20—21	68—65	14	Supported (free end 7½)	12 M.	1.55 P.M.	1	55	7 inches.	
2/6/'97	Rain.	21—25	65	14	Supported (free end 7½)	2 P.M.	3.40 P.M.	1	40	7 inches.	
2/6/'97	Rain.	20—21	68	16	Supported, 8 inches free.	10 A.M.	11.25 A.M.	1	25	8 inches.	Same plant.
2/6/'97	Rain.	21	68	16	Supported, 8 inches free.	11.30 A.M.	12.45 P.M.	1	15	8 inches.	
2/6/'97	Rain.	21—22	68	16	Supported, 8 inches free.	1 P.M.	2.25 P.M.	1	25	8 inches.	
6/29/'96	Clear.	23—18	85—88	8½	Free.	7.10 P.M.	10.20 P.M.	3	10	2 inches.	
6/29/'96	Clear.	18	90	8½	Free.	10.21 P.M.	1.30 A.M.	3	9	2 inches	
6/30/'96	Clear.	16—14	90	9	Free.	1.32 A.M.	5.08 A.M.	3	36	2½ in. irreg	
6/30/'96	Clear and sunny.	27	85	9	Free.	1.15 P.M.	3.08 P.M.	1	47	3 inches.	
7/1/'96	Clear and sunny.	28	85	10¼	Free.	1.45 P.M.	3.28 P.M.	1	43	3 inches.	
7/1/'96	Clear and sunny.	28—27	85	10¼	Free.	3.31 P.M.	4.58 P.M.	1	27	3 inches.	
*7/2/'96	Clear and sunny.	23—26	88	11¾	Free.	9.10 A.M.	10.48 A.M.	1	38	6 inches.	
7/2/'96	Cloudy and hazy.	26	88	11¾	Free.	10.56 A.M.	12.30 P.M.	1	34	6 inches.	
7/2/'96	Clear.	23	90	12	Free.	6.35 P.M.	8.45 P.M.	2	10	7 inches.	
7/2/'96	Clear.	22—21	90	12	Free.	8.45 P.M.	10.55 P.M.	2	10	7 inches.	
7/3/'96	Clear.	21	90	12‡	Free.	10.58 P.M.	3.28 A.M.	4	30	7 inches.	
†7/3/'96	Clear and sunny.	31—32	85	14	Free.	12.47 P.M.	1.42 P.M.		55	9 inches.	
7/3/'96	Clear and sunny.	31—32	85	14	Free.	1.43 P.M.	2.43 P.M.		60	9 inches.	
7/3/'96	Clear and sunny.	31—32	85	14	Free.	2.44 P.M.	3.44 P.M.		60	9 inches	
7/3/'96	Clear and sunny.	30—28	88	14	Free.	3.49 P.M.	4.49 P.M.		60	9 inches.	

* The atmosphere was very close and oppressive.

† Two circles are included in this time.

‡ A record was taken between 3.30 and 6 A.M.; but was unfortunately lost.

The results are given in separate series for each plant, so that comparisons of time periods may readily be made. The reader will appreciate, too, the favorable character of the temperature of the day and night, and the slight variability in the moisture of the air.

TABLE II.—PLANT I.

Thermometer.	Hygrometer.	Time begun.	Time completed.	Time occupied. hours.	min.
28—29	72—68	10.46 A.M.	12.1	1	15
29—31—29	68—70	12.1 P.M.	1		59
29—30	70	1 P.M.	2.4	1	3
30—31	68—67	2.4 P.M.	3.7	1	3
31—28	65—70	3.7 P.M.	4.14	1	7
28—26	70—76	4.14 P.M.	5.22	1	8
25	76—78—72	5 22 P.M.	6.35	1	13
25	72	6.35 P.M.	7.55	1	20
24—23	70	7.55 P.M.	9.15	1	20
22	70	9.15 P.M.	10.50	1	25
22	70	10.50 P.M.	12.20	1	30
22	70	12.20 A.M.	2.3	1	43
22*	70	2.3 A.M.	2.37	1	34
22	70	3.37 A.M.	5.20	1	43
23	70	5.20 A.M.	6.35	1	15
23—24	70	6.35 A.M.	7.52	1	17
25—27	68	7.52 A.M.	8.54	1	2
28—29	66—60	8.54 A M.	9.50		56
29	60—55	9.50 A.M.	10.45		55
30	55	10.45 A.M.	11.40		55

PLANT II.

Thermometer.	Hygrometer.	Time begun.	Time completed.	Time occupied. hours.	min.
28—29	72—68	10.47 A.M.	11.55	1	8
29—31—29	68—70	11.55 A.M.	1.2	1	7
29—30	70—68	1.2 P.M.	2.9	1	7
30	68—66	2.9 P.M.	3.20	1	11
30	66	3.20 P.M.	4.35	1	15
28—27	72—75	4.35 P.M.	5.55	1	20
26—25	78—72	5.55 P.M.	7.32	1	22
25—24	72—70	7.32 P.M.	9.10	1	38
23—22	70	9.10 P.M.	10.55	1	45
22	70	10.55 P.M.	12.37	1	42
22	70	12.37 P.M.	2.25	1	48
22	70	2.25 P.M.	4.16	1	51
23—24	70	4.16 P.M.	6	1	44
25	70	6 P.M.	7.20	1	20
25—26	70	7.20 P.M.	8.37	1	17
26—28	70—65	8.37 P.M.	9.45	1	8
28—29	65—55	9.45 P.M.	10.40		55
30	55	10.40 P.M.	11.40		59

* Peculiar curving of free portion.

TABLE II.—PLANT III.

Thermometer.	Hygrometer.	Time begun.	Time completed.	Time occupied. hours.	Time occupied. min.
28—29	72—68	10.48 A.M.	12.15	1	27
29—31—29	68—70	12.15 P.M.	1.20		55
29—30	70—68	1.20 P.M.	2.37	1	17
30	68—66	2.37 P.M.	3.44	1	17
30	66	3.44 P.M.	4.58	1	14
28—27	72—75	4.58 P.M.	6.20	1	32
26—25	78—72	6.20 P.M.	7.50	1	30
25—24	72—70	7.50 P.M.	9.20	1	30
24—22	70	9.20 P.M.	10.55	1	35
22	70	10.55 P.M.	12.37	1	42
22	70	12.37 A.M.	2.25	1	48
22	70	2.25 A.M.	4.10	1	45
23—24	70	4.10 A.M.	5.55	1	45
25—26	70	5.55 A.M.	7.20	1	25
25—26	70	7.20 A.M.	8.55	1	35
26—28	70—65	8.55 A.M.	10	1	5
28—29—30	65—55	10 A.M.	11.6	1	6

PLANT IV.

Thermometer.	Hygrometer.	Time begun.	Time completed.	Time occupied. hours.	Time occupied. min.
28—29*	72—68	10.49 A.M.	11.51	1	12
33—37†	45	11.51 A.M.	1.3	1	12
37†	45—50	1.3 P.M.	2.30	1	27
34	50—55	2.30 P.M.	3.41	1	11
33	55	3.41 P.M.	5.1	1	23
29—27	55—72	5.1 P.M.	6.24	1	23
27—25	72—70	6.24 P.M.	8.5	1	43
24—23	70	8.5 P.M.	9.50	1	45
23—22	70	9.50 P.M.	11.45	1	55
22	70	11.45 P.M.	1.50	2	5
22	70	1.50 A.M.	3.50	1	45
22	70	3.50 A.M.	5.35	1	45
23—24	70	5.35 A.M.	7.9	1	32
25—28	68—65	7.9 A.M.	8.34	1	25
28—31	50—55	8.34 A.M.	9.41	1	7
33—34	55	9.41 A.M.	10.38		57

* Changed to another greenhouse. † Irregular movement.

For the species, the average time occupied is about 1 hour and 20 minutes. Darwin[12] records as his most rapid circumnutator among climbing plants—*Scyphanthus*—which performed a revolution in 1 hour and 17 minutes. *Amphicarpæa monoica* must be awarded the palm; as repeatedly the results of 1 hour, and quite frequently 55 to 51 minutes have been obtained.

Among tendrils, however, there are more rapid rates reported by Darwin[12]. However, he does not note the length of the circumnutating portion. With *Passiflora gracilis*, circles are made in as short a period as 57 and 58 minutes; others require longer time; the average is a little over an hour. A footnote on page 154 in "Climbing Plants" calls attention to *Passiflora acerifolia*, whose tendrils according to Gray complete a circle in 46 and even 38½ minutes.

Plants of *Amphicarpæa* often exhibited a tendency to curve the apex downward, forming almost a complete circle with the part of the stem below. Observations were frequently stopped by this occurrence. After remaining stationary, sometimes for several hours, the apex would straighten out and continue its revolutions. No cause could be assigned for this behavior. At times, the circumnutating tip would describe a path, in which the dot recording the place last occupied, would be internal to the continuation of the circle, instead of in line with it.

The axillary shoots from simple and compound leaves have both been studied. When examined in a normal unsupported condition, they swayed to and fro in wide irregular ellipses, which rarely were complete in form. It was not difficult to discover that circumnutation was very active, particularly with shoots from the compound leaves. As soon as they were six or eight inches in length, their inclination to twine was manifest, and the apex visibly moved through space. When gently supported, the results were fairly rapid, but the circle was small. The shoots from the simple leaves were not expected to show so much movement; but really there was little difference in the rapidity. All formed irregular small circles in an hour or an hour and a quarter. I do not feel thoroughly satisfied with the methods adopted in observing the axillary shoots, and I trust in future studies to remedy these defects.

Histology of the Stem.

In general the stem exhibits the structure of a typical Dicotyledon. Plate XXIV, Fig. 1, shows the transverse section of a very young stem of a plant about six inches high; the epidermal cells have the outer walls slightly cuticularized. Numerous rows of cells constitute the cortex. Next may be distinguished one row of flattened, slightly thickened cells which form the bundle sheath. About ten vascular bundles surround the central fundamental tissue; the protoxylem is well marked. Among the protoxylem cells and spiral tracheæ are found tannin canals. In the phloem numerous sieve cells with comparatively large plates are seen; here, too, among the companion cells appear tannin canals; usually one in the phloem of each bundle. Small areas of hard bast are seen forming in the region bordering directly upon the bundle sheath.

In sections of an older stem (Fig. 2), we find that the hard bast has developed considerably, forming an almost complete ring. The xylem appears to push down into the phloem, forcing it aside into two nearly distinct patches. Tannin canals are now more numerous than in the young phloem, three or more being present in each area. From study of longitudinal sections the component elements of the secondary xylem are found to be wood cells, pitted vessels and tracheids with reticulated walls. In the cells of the bundle-sheath, just outside of the hard bast, are found prismatic crystals of similar appearance to those met with in the leaf and other portions of the plant. Their appearance will be described more minutely in later pages. At present their position and development in the plant demand attention.

If a transverse section is taken from the stem of a plant about fifteen inches high, there will be seen a single row of cells in the inner cortex, in which may be distinguished small crystals. Just how soon after germination this formation begins has not been definitely ascertained, but evidently it occurs quite early in the plant's career. The increase in size and number of crystals in these cells is rapid. Finally a distinct crystal sheath (Plate XXIV., Fig. 4,) surrounds the vascular area. It is considered that this crystal sheath is equivalent to the original bundle sheath; the position occupied by the former seems to correspond exactly to that of the latter. These crystals seem to be surrounded by a protoplasmic film of considerable thickness, as this area stains very deeply. This condition is plainly shown in a section taken from a plant stem three months old (Fig. 2). In Fig. 3, is seen a transverse section of a stem, a little older than the preceding, but which, having grown during the summer, was much more vigorous. There is a marked increase in the xylem and also in the phloem. The hard bast appears to have undergone some transformation, very few of the cells are visible and these are in scattered groups. The crystal cells referred to above have greatly increased in number, and are abundantly present in the outer expanded ends of the medullary rays. As yet no reagent that will dissolve the crystals has been found; but it is possible that treatment by several chemicals in succession will accomplish it.

A transverse section of stem of a plant raised from an aerial seed shows, when three months old, a condition similar to that seen in Plate XXIV., Fig. 2; but the diameter of the section is about 1/8 of that represented in Fig. 2.

Yet one more feature of interest is found in the section Fig. 3, when studied with high power. In the xylem and to some extent in the phloem, are noticed sack-like bodies whose contents are refractive, and gelatinous in appearance —some protoplasmic substance possibly: Chlor-iodide of zinc colors these a deep purple-red: iodine test gives no reaction. No starch is found in the section, nor have tannin canals been located.

During the life of this plant some marked physiological changes seem to occur, the character of which is not yet understood. Nor can it yet be stated whether there is any connection between fruit production and the progress of the changes or not. Further investigation may elucidate the meaning of what has been observed.

General Appearance of Leaves.

As has already been stated, the first green leaves of *Amphicarpæa* are simple and opposite. They are netted-veined, broadly ovate, with rounded apex, hairy upon both surfaces, and also upon the margin, which is entire; the stipules are interpetiolar. At the base of the petiole, and also at the base of the blade is a pulvinus. The petiole is about one and a half times the length of the blade, and both it and the pulvini are retrorsely hairy. The remaining leaves are compound, provided with stipules, and are arranged alternately. They are pinnately trifoliate, petiolate and stipellate. The primary pulvinus is usually very well developed, being at least four times the size of those belonging to the leaflets. The terminal leaflet possesses a petiole of its own—a continuation of the main one, also a pulvinus and two stipels. The petiole of this leaflet makes, with that of the main leaf, an obtuse angle; thus its blade lies in the same plane as the remaining leaflets. Each lateral leaflet is attached by a pulvinus only, and is provided with a single stipel. All leaflets are ovate, with an acute apex, the blade being longer than those of the simple leaves; but the terminal is larger than its fellows. The lateral leaflets are rarely symmetrical, the outer side being much wider. In other characteristics the compound resemble the simple leaves. All leaves are remarkably thin, and of delicate texture. The petiole forms with the stem an angle of 45° to 60°. The pulvini of the leaflets stand up at an angle of 30° with the petiole, so that the surface of the blades lie about in the same plane.

Histology of the Leaf.

The epidermal cells are irregular, stomata occur upon both surfaces of the leaf, but are much more numerous upon the lower than upon the upper. Large firm unicellular hairs are placed at regular intervals upon both surfaces and are exceedingly numerous upon the margins, particularly of young leaves. These hairs are thick-walled and bear tubercle-like markings. On the midvein, on some of the larger veins, and on the margin are found small bladder-like hairs.

The vascular bundles branch extensively; but frequently there is no evidence of anastomosing. This is often seen with the more delicate branches, which suddenly terminate in the mesophyll. Embedded in the larger vascular areas (probably in all, however) have been seen crystals similar to those occurring in the clearly defined crystal sheath, previously described in the stem. Possibly, however, because they are not so massed up on one another, their distinct twin-like structure is much more easily distinguished, the partition, whether apparent or real, being easily located. (Plate XXIV., Fig. 5.)

The transverse section shows thin upper and lower epidermal layers, while the mesophyll consists of irregular, but tolerably uniform cells, so that a differentiated palisade tissue is absent.

Simple and compound leaves correspond in the above details.

Leaf Positions.

In common with many other members of the Leguminosæ, *Amphicarpæa* is exceedingly susceptible to changes in temperature, moisture and light. Because of the delicate foliage, many difficulties arise, and constant watchfulness is necessary to explain the condition of each plant.

a. Normal Position.—In diffuse daylight, in early morning, or when shaded from the sun's rays, both simple and compound leaves assume a position which will here be alluded to as "normal." The dorsiventral relation is shown; leaflets present a flat position, though occasionally the terminal is slightly elevated. The angle of the petiole with the main stem varies from 45° to 60°.

b. Paraheliotropic Position.—If exposed to direct action from the sun's rays or to a strong reflection, the lateral leaflets turn the outer edges gradually upward, the upper surface being inclined toward the terminal leaflet. As the intensity of heat and light increases, the pulvini are stimulated more and more, the angle assumed by the margin is 90° with a line drawn through the surfaces in their normal position. The terminal pulvinus rises about 45°, thus elevating the leaflet. The lateral pulvini rotate the leaflets at this stage; but there is little change in the angle they make with the main petiole.

A further increase of the sun's action causes the lateral leaflets to incline more toward the terminal, which rises usually 90°; frequently the upper surfaces of the leaflets are in direct contact, the under surfaces being outward. The lateral pulvini have risen slightly; but their angles are difficult to estimate, as these blades have been so much rotated. (Plate XXV, Fig. 1.)

Often the terminal does not assume a perpendicular position, but the apex points either right or left. It is noticeable too, that the terminal leaflets on opposite sides of the plant do not incline in the same direction, even if the sun's rays are vertical.

A series of questions which must yet remain unanswered are suggested. Are these movements of advantage to the plant? Are the pulvini protected? Is too rapid transpiration retarded? Are the movements due to heat, or to certain rays of light?

For the present, a partial answer at least may be given regarding the last. Plants were studied in the greenhouse where the temperature often was 90° F. While there was no sunlight, para-heliotropic positions were not assumed. Certain it is that sunlight has a direct influence; it has been found that leaflets toward the east, for instance, may be visibly affected by the rays falling upon that side of the plant, while those toward the west still remain normal.

A plant whose leaves have taken the para-heliotropic position, if shaded, or lifted to a shady spot, will show the ordinary position in from three to seven minutes.

The simple leaves rise slowly; in a very young plant they rise 90° and bend over toward the tender shoot. (Plate XXV, Fig. 2.) In older plants they rarely rise more than 75°.

In all of the above movements, the angle of the petiole seems unchanged; leaflets and their pulvini alone being concerned.

A very hot sun causes the under surface to turn completely uppermost, the leaflets appear limp and droop. In some species of plants, where this condition is seen, the blades are firm at least when they are handled; but in *Amphicarpæa*, I think the expression used, best describes their peculiar appearance.

This movement is not apparent in all the leaves, usually only the three or four nearest the upper part of the plant. This behavior was noticeable upon hot days in the greenhouse as well as out of doors. Macfarlane[21] first drew attention to the above condition, as occurring in numerous other plants, some of which are not at all sensitive according to the ordinary application of this word. After the intensity of illumination subsides, the leaflets gradually assume the para-heliotropic position, or may even return to the normal without the above transition.

c. Nyctitropic position. In preparing to assume the nyctitropic position, the terminal leaflet falls slowly, the lateral do likewise, gradually turning their upper surfaces toward the terminal leaflet at an angle of 45°. The complete deflexing may not take place until an hour after preparations have evidently begun. Sudden changes in environment may accelerate movements, or indeed may cause plants to take the sleep position even in the day-time. Carrying a plant from the moist atmosphere of the green-house into the dry air of a heated room having about the same temperature, produced a shock, which resulted in the assuming of the nyctitropic position. Often complete recovery did not take place until the plant was returned to congenial, moist surroundings, or some time thereafter.

Exactly what may be designated as a complete nyctitropic position is still perhaps a matter of doubt. About sunset the following condition may be seen: The leaflets have fallen 90°, the terminal one points perpendicularly downward or inclines in the direction of the petiole, the surfaces of the laterals approach; often the apices touch each other.

Simple leaves also deflex 90°. When the plant is quite young, after thus deflexing, the blade turns and lies with its under surface below the petiole, nearly parallel with it, and almost in contact with it. Thus, at this time these leaves pass through 180°. (Plate XXV, Fig. 3.) This remarkable movement disappears in plants having four or five compound leaves, and frequently before this number is reached.

Within two hours after all leaflets have assumed the position described above, the terminal one rises slightly, the pulvinus forming an acute angle with the petiole. The blade stands out, as shifting toward the right or left has taken place. Gradually, though constantly, the leaflet turns its upper surface, the pulvinus changes its angle, the leaflet inclines again toward the perpendicular until about 11 P.M.; as a result of this continuous movement, the upper surface of the terminal leaflet lies in the same plane as the surface of a lateral leaflet, and faces outward (that is toward the observer or directly away from him—according to his position in relation to the plant). (Plate XXVI.)

The petiolar angle most commonly assumed is nearly

90° ; obtuse and acute angles have also been noted. Out of seventy-five leaves upon eight plants, the petioles of eleven showed obtuse angles, six, acute, and the remainder were right angles. Upon one plant two different angles may be observed ; usually, however, uniformity exists. Certain leaves showing each of the angles were marked and watched upon several successive nights; each night the customary noted angle was regularly assumed. There seems to be no reason for this difference; but in the numerous sets of plants studied, it was always seen. The right angle, then, appears to be the prevailing one. As the *normal leaf position* showed an angle varying from 45° to 60°, there would here be a fall of 45° to 30°.

Darwin[11] states that the petiole may fall through about 57°. From the facts given, he must have studied one which assumed an obtuse angle. No others are mentioned by him. Those which did assume this angle seemed to the writer to fall much more than the number of degrees estimated by Darwin; certainly 75° is nearer the correct amount.

In the passage above referred to, the circumnutation of the leaf was traced by Darwin[11]. He is not himself, satisfied with the method employed, but his object was, he states, "to ascertain if the leaf moved after it had gone to sleep." A diagram of his results is given, but they do not give an exact idea of what may be observed during the night hours. First, the apparatus used would seem to me to have a deflexing effect upon the entire leaf. Secondly, it records movements of the terminal leaflet only, and even the results for it are questionable. Thirdly, his observations ceased at 10.50 P.M. What is to be seen after that hour will be described presently. However, it may be indicated that so great and varied is the activity of leaflets, that no idea is given by the tracing nor by the description in Darwin's work.

The movements until 11 P.M. have already been described. From that hour till daylight, leaflets are constantly in motion. Observations were made every half-hour. Those recorded below were made during the last week of June and early in July. I cannot speak exactly for night movements earlier in the year, but the behavior at that season until 10 P.M. would indicate during the remaining hours decided similarity to that described for the summer months. Between 11.30 P.M. and 2 A.M. the terminal leaflet re-assumed gradually a nearly perpendicular position, turning again, so that the margin instead of the surface was more in the plane of the surface of the laterals, but it still stood out from the remaining leaflets, the apex inclining away from the petiole. The laterals had rotated upon the pulvini, so that their upper surfaces inclined somewhat inward.

Between 2 and 3 A.M. the terminal rose slightly, and the laterals shifted so that their upper surfaces faced in the normal direction. All leaflets were deflexed about 45°, but the spreading apart of leaflets was marked.

From 3 A.M. the general attitude of a plant might be described as that of expectation. About 4 A.M. the petioles had arisen, and the day position was rapidly being assumed. By 4.30 some few leaflets had completely expanded; many at 4.45 A.M.; nearly all at 5 A.M. These records are of green-house plants, temperature 20°–25° C.; the hygrometer, 85°–90°. During this month the sun rose at 4.35 A.M.

Those out of doors varied greatly—clouds, winds, low temperature retarded the assuming of the day position, although during the night the leaflets showed similar activity to that just described (unless it was very windy). On a moderately warm morning, some were found in day position at 5 A.M.; on a cool morning there was a delay until 6 A.M., and even later.

In this connection it may not be out of place to allude to the Mimosas which were in the green-house. While *Amphicarpæa* was in agitation half the night, the leaflets of *Mimosa* were quietly folded. When the time arrived for the day position, the leaflets expanded in a very short time, no indications of movement being visible before 4.45. *Mimosa* assumed day position about a half hour later than *Amphicarpæa*.

Observations were made to ascertain what relation the time of assuming nyctitropic position bore to the hour of sunset. Until the early part of May, records were made from plants in the green-house only; after that time comparisons could be made with those growing in the Botanic Garden. During the time the green-house was artificially heated, the temperature frequently fell late in the afternoon, and, as the final watering for the day occurred about that time, the hygrometer record was high.

Previous to April no data of value were obtained. During that month, upon clear, warm afternoons, the nyctitropic position was assumed about nine minutes before sunset (6.24–6.54 P.M.).

During May, ten to twelve minutes before sunset (6.55–7.21 P.M.) was the general time. May, 1896, was a most unfavorable month, as there were but few clear, warm days.

After that—in June and July—plants in the green-house were often completely nyctitropic, fifteen or twenty minutes before those in the garden, which quite often, although showing indications of nyctitropic position for some minutes, did not assume it completely until sunset hour or a minute or two before (7.30 P.M.).

These differences may be attributed to the following circumstances:—the humidity of the green-house, and closeness of the air, and comparatively, the more rapid approach of darkness, caused by shading of the green-house by certain adjoining walls. In June the position of the sun was such that these conditions were quite noticeable. Those out of doors had the advantage of all the light at that time as well as fresh air.

Dark, rainy days caused rapid assuming of the nyctitropic position from thirty to fifty minutes previous to sunset.

On such days, the plants out of doors gave no exact results as to time of taking nyctitropic position, for usually the leaves remained more or less deflexed during the entire day. Even on a clear day, a brisk wind or a fall in temperature would induce the nyctitropic position at an earlier hour.

Electrical disturbances of the atmosphere seem to have an effect upon *Amphicarpæa*. On one hot July day a heavy thunder-storm occurred about 5 P.M.; the clouds were unusually heavy. Within an hour, the sky had cleared, and the sun was shining brightly. Yet the plants did not recover their normal position, but retained the nyctitropic, which had been assumed on the approach of the storm. This statement applies equally well to those plants which had not suffered from the force of the rain. The sunset hour was 7.30.

So many conflicting conditions make it difficult to state a general rule. As far as I am able to gather from these observations, there seems to be but a slight difference between the time of taking nyctitropic position and sunset hour in the summer months. On the other hand in the winter season, the leaflets close from fifteen minutes to a half hour before sunset. The rapid approach of darkness in the latter case; the long twilight in the preceding certainly form important factors.

Plants in an open space, upon a clear warm day, are late in taking the nyctitropic position—just about the sunset time. But this statement can not be correct for the individuals growing in the woods. From the few studied in their native haunts, the period in August (sunset about 7,) is from fifteen to twenty minutes earlier than this hour.

The above facts lead to the conclusion that there is not a definite time-relation between the time of nyctitropic position and the exact time at which the sun sets.

Pulvinus Structure

The pulvini are much more pubescent than the other portions of the petiole. Both the long, unicellular hair and the bladder form are abundant; the former is tuberculate in character.

In a transverse section of the pulvinus the flattened portion indicates the dorsal region. The epidermis is strongly cuticularized; in the many celled cortex there are few chlorophyll granules. Numerous crystals of the character previously mentioned as occurring in the stem are found; the number is variable, but nearly all exhibit the twin arrangement more plainly than is usually seen in other parts of the tissue. In the secondary and tertiary pulvini the crystals are comparatively more numerous.

In the fundamental tissue, lying next the central mass, the cells are similar, and possess somewhat thicker walls.

The cells of the bundle-sheath resemble in appearance those in the centre of the pulvinus, and show clear collenchymatous walls. Chlor-iodide of Zinc produces a violet coloration. Next to the sheath lies the phloem; then the xylem which occupies a relatively large area. Chlorophyll is very abundant just within the bundle sheath.

All the usual reagents reveal the presence of tannin cells in the xylem.

Continuity of protoplasm is best demonstrated in the phloem region and the central mass of collenchyma.

Clear refractive globules have been observed in the cortex; these do not consist of oil, nor of tannin, for treatment with special reagents to demonstrate the presence of either substance, yields no satisfactory results. Their composition has not yet been ascertained. They are not always seen, and from a few observations which have been made, I think their presence has some connection with the position of the leaf at the time when the study is made; but whether they are most abundant during the normal, the para-heliotropic or the nyctitropic position can not yet be definitely stated.

These globules which appear to be absent in the secondary and tertiary pulvini, may be distinguished in the primary.

Flowers of Amphicarpæa.

Before stating observations as to the flowers and fruit of *Amphicarpæa*, it may be well to give a brief outline of the facts to be found in the principal Botanical Manuals.

In the "Botany of the South," Elliott[2] describes pale purple flowers found in racemes. These are complete, but he says they are "generally sterile." Indeed when, in his report to the Academy of Natural Sciences, he describes the shape and appearance of the legume, he quotes Walter as his authority, stating that he himself had never seen one.

Peduncles from the root bear flowers without petals. Near the surface of the earth racemes are produced, the flowers of which are furnished with a calyx and rudiments of a style. "The fruit here" he says, "is a one-seeded ovate pod."

The preceding account refers to *A. monoica*. In addition he mentions *A. sarmentosa*. It bears filiform racemes which are three-flowered and apetalous. The calyx alone is described. The fruit is an oblong pod.

Darlington[3] agrees with the above statements in regard to complete flowers, and also as to fruit. On the radical peduncles he finds apetalous flowers, which "are often merely pistillate." Peduncles arise from the base of the stem; and a solitary legume develops at the extremity.

In the "Flora of North America"[4] (Torrey and Gray) the descriptions are much more detailed and indicate more careful observation of the floral parts. The purple flowers are described, the shape of legume also, though no reference is made as to the fertility of the flower.

The imperfect flowers are located as the preceding authors have done. It is stated, however, "Stamens wanting or often five or ten, shorter than the ovary; three or four with perfect anthers, the others rudimentary—the filaments are distinct. The ovary is nearly sessile, tipped with a short recurved style. The legume is obovate, hairy, one-seeded, usually maturing below the surface of the ground."

The accounts given by Wood, Chapman, and Gray[12] are similar to those given above; but none are so minutely descriptive as that of Torrey and Gray.

In a communication to the Academy of Natural Sciences by Meehan[16], quite a different statement is made. The purple flowers, the imperfect flowers above alluded to, and the fruit in each case are described. A legume differing in shape from that usually described was noticed by him and figured. The following is quoted from the paper: "In what may be termed the more vigorous racemes, the two lowermost flowers, either have but a small vexillum projecting beyond the calyx, or none. The next half dozen flowers are perfect in every respect and fall without perfecting a legume. The apetalous flowers can scarcely be classed as 'cleistogamous,' for there is no pollen. A few undeveloped stamens are found here and there. In absence of positive demonstration, I should regard these as pistillate flowers receiving pollen from the petaliferous one."

Summing up the previous statements, it is found that there is a general agreement regarding the structure of the purple flowers, and their position on the plant. Their fertility, however, is questioned.

There is no unanimity as to the structure of the imperfect flowers. No doubt seems to exist as to their presence upon the plant, but the location is not definitely stated.

Excluding the observations of Meehan, and for the present, Elliott's statement regarding *A. sarmentosa*, there have been given but two kinds of flowers, and the same number of pods.

Amphicarpæa monoica, however, possesses no less than four distinct varieties of flower, and as many legumes. These may be enumerated as *a*, *b*, *c* and *d*. (*a*) Evident aerial flowers of purple color may fairly be distinguished as the normal type. (*b*) Aerial cleistogamous flowers, possessing no corolla or a very rudimentary one, are intermediate between the purple aerial and the subterranean. (*c*) The subterranean is much reduced in structure, and may be regarded as derived from the normal through (*b*). (*d*) This form is produced during the winter months, and is a compound of (*b*) and (*c*); it might be called a transition type.

Purple Aerial Flowers.

The lavender purple, often almost white flowers are produced in pendulous simple, occasionally compound, racemes. These are borne in the axils of cauline leaves (from about half the plant's height upward), and also upon the upper axillary shoots. Buds appear during the last week of July and bloom from August 10 into September. These statements are made from observations in the neighborhood of Philadelphia. At Woods Holl, Massachusetts, blooming occurred from five to eight days later. The number in a raceme varies from ten to twenty-four, occasionally more. There are frequently two buds, certainly one, in the axil of a broadly ovate, partly clasping, striate, pubescent bract. (Plate XXVII., Fig. 1, 2).

Careful study has led to the conclusion that there are originally two buds in each axil. Very young as well as more advanced racemes showed this condition. As elongation takes place, some of the buds fall off; frequently when most of the flowers are in bloom, there is but one in many of the axils. No histological investigation has yet been completed regarding this. It may be proper to state here, that if this supposition is correct, there may be some foundation for the statement given in Torrey and Gray that these bracts are formed by a "union of a pair." However, it is elsewhere stated by these authors in regard to the imperfect flowers that the bracts are distinct. No bracts are found with these latter flowers; the stipules certainly have been mistaken for them. Therefore the previous statement would not be of value.

Some observations in reference to the number of buds occurring in the axil of each bract of the raceme have been recorded as follows:—

Specimen.	Entire number of buds in raceme.	Number occurring by twos in bract axil	Number occurring singly in bract axil.	Remarks.
1	8	8	0	Young.
2	11	10	1	Young.
3	10	8	2	Little older.
4	7	6	1	Much older—still unopened.
5	13	10	3	Lower three had opened.
6	{ 12	10	2	} Compound raceme, lower
	{ 14	10	4	} flowers had opened.
7	11	10	1	Young.
8	12	12	0	Young.
9	11	10	1	Nearly all open.
10	7	6	1	Young.
11	15	14	1	Young.
12	20	18	2	Young.
13	20	20	0	Young.
14	11	10	1	Young.
15	11	10	1	Young.
16	17	16	1	Young.
17	14	12	2	Young.
18	14	14	0	Young.
19	13	10	3	Lower open.
20	16	16	0	Lower.
21	{ 22	18	4	} Compound raceme.
	{ 13	12	0	
22	22	22	0	Young.
23	20	20	0	Young.
24	10	8	2	Young.
25	17	16	1	Young.
26	14	12	2	Young.
27	16	14	2	Young.
28	11	8	3	Young.
29	15	12	3	} A branch and a bud in the axil of 1 bract.
30	7	0	7	Young.
31	6	2	4	} Compound raceme.
	15	10	5	
32	13	10	3	Young.
33	18	14	4	Young.
34	13	10	3	{ Lower bract has in axil 2 buds and a branch bearing 2 buds.
35	17	16	1	Young.
36	11	10	1	Young.
37	10	8	2	Young.
38	10	8	2	Young.
39	13	10	3	Branch and bud in 1 bract axil.
40	9	8	1	Young.

More observations are needed on this point. At present it cannot be stated in which portion of the raceme, reduction is most likely to take place, as the blooming season approaches.

The seasonal conditions and the general environment exert a marked influence upon the number of purple flowers produced. A hot, dry season is very unfavorable. The summer of '95 showed but few racemes; in '96 the plants were covered with them. In the shaded portion of the woods purple flowers are rarely produced; on the other hand, too much sun does not seem favorable. *Amphicarpæa*, grown in the Botanic Garden in two places where there was constant sunlight, showed but a very few flowers, although the plants were provided with a fair supply of water.

The *calyx* is greenish-white, if the corolla is pale, otherwise purplish-white, flecked with deep purple; in both cases it is pubescent. It is four-parted, the teeth acuminate and dissimilar. Thus far nothing has been seen to indicate the presence of a fifth vascular bundle. It is possible in younger buds, some evidence may yet be found. In the bud the calyx parts are valvate, the tips being spirally twisted. The calyx is about half the length of the corolla, it is swollen at the base in the posterior region, and, as the flower-parts expand, the appearance is that of inflation. It persists at the base of the legume.

The *corolla* is pale purple, but may vary to pure white. The æstivation is that of a typical member of the Papilionaceæ.

The anterior margins of the *carina* cohere but for a short distance. The upper portion of each is shaped like a rounded triangle, and narrows abruptly into a long slender claw. In the inferior region of the triangle occurs a marked depression. The *alæ* are rather oblong in the upper portion, otherwise they resemble the carinal members in general outline. In each of these is seen an invagination pointing posteriorly; the floral parts are so arranged that the pouches thus formed upon carina and alæ inter-digitate, and thus these petals are held firmly together as described by Müller for other forms. On the superior margin of the broad portion of each wing occurs a sack-like process or short spur whose opening is upon the exterior. The curious auricled appearance of the petal is due to the presence of this contrivance.

In the bud the *vexillum* encloses the remaining petals almost completely, but, as the flower expands, it is pushed posteriorly. This petal is obovate, tapering gradually; there is no true claw. It is marked transversely about half way down, by an irregular, imperfectly semi-circular band of deep purple hue, which may possibly be interpreted as a "path-finder." The most deeply pointed portion of the calyx is opposite the anterior petals (carina); the remaining three are around the standard.

The *stamens* are ten in number, five long, five short; they are diadelphous and the insertion is perigynous. The staminal tube is united for three-fourths of its length; the superior stamen is free. The anthers are two-celled, small, almost spherical, versatile and introrse; they are of a deep orange color, and well filled with pollen. In young flower-buds, the anthers are found to be well-developed, but the filaments are short; for some time the style and stigma extend for a distance above the stamens.

Plate XXVII, Fig. 3, is a transverse section through a bud, showing the anther lobes and a portion of the connectives of the five shorter stamens, also filaments of the five longer.

In a transverse section of an anther belonging to a purple flower, the following condition is seen: the epidermis (exothecium of authors) is a single row of small delicate cells; the hypodermal layer (endothecium of authors) consists of much thickened, columnar cells.

In developing anthers the pollen is normal. Some, perhaps all, of the anthers dehisce when the bud is about one-half inch long, and showing no indications of unfolding. At that time the pollen is pale yellow, powdery, and under the microscope appears as a shriveled husk. Upon the addition of water it becomes slightly granular, and swells immediately. Differentiation into exospore and endospore is noticeable now, and a small quantity of oil is seen. The size of the pollen grain will be discussed later on by study of a comparative series.

The monocarpellary *pistil* arises from a slender gynophore. The ovary is free, superior, unilocular, and contains from two to four ovules. The style in a mature state is exceedingly long, the stigma small, capitate, and quite hairy. Microscopic examination reveals the presence of beautiful tufts of hairs surrounding the base of a rounded surface, smooth and having a rather sharp contour; this is evidently the stigmatic area. The hairs project outwards and upwards. The margins of the ovary are clothed with long unicellular hairs, also small bladder hairs. The latter are numerous upon the style. Stomata are present upon both style and ovary.

Extending around the carpel and passing up both dorsal and ventral sutures onward into the style are strongly marked bundles. Their behavior with reagents, when the carpel is entire or sectioned, leads to the conclusion that tannin canals are located here.

Histological study has also demonstrated the nature of "the sheath at the base of ovary" mentioned by various authors. It is without doubt a nectary. A transverse section of this is seen in Plate XXVIII., Fig. 1, to possess ten vascular bundles. The upper portion, not figured here, possesses numerous pits or cells of glandular appearance, which are particularly noticeable around the free margin of the structure.

In a young bud, the style is short, hooked, and the stigma though capitate, shows an undeveloped condition of the hairs, which are as yet closely appressed. For some time after, while the style is elongating, the bent appearance is retained, and thus the stigma inclines downward. Finally the style straightens and also the stigma, the brush of hairs having gradually assumed the characteristic appearance. The early condition of style and stigma is seen in Plate XXXI., Fig. 8, and the later one in Fig. 9. These drawings are made to the same scale.

Fertilization.

It will be seen from the previous description of the structure of *Amphicarpæa* that the purple flowers are well provided with those devices which are associated with insect fertilization. It is probable that this is not the method here, though there are strong grounds for believing that the plant may be a descendant of types that were insect-pollinated. If insects visit these flowers, the writer has not seen them, nor has any indication of such visitors been discovered.

As has already been stated, in the tiny bud, not more than one-quarter of an inch in length, the style has already grown some distance beyond the stamens, and curves the stigma toward them. After this both stamens and pistil elongate and finally are about the same length, the stigma protruding a short distance beyond the anthers. Upon opening a bud about a half inch long, but that is still closed, it will be found that the anthers have dehisced, and usually some pollen is found upon the stigma.

It is quite certain that the majority of the purple flowers do not produce fruit; a number, however, are productive. Perhaps the stigma is not in condition when the pollen is mature. Should this be the case, the question naturally arises, how is fertilization accomplished in any case? For the present it can only be stated that it is possible that the ten stamens may reach maturity at different times. It is also suspected that there may be some explanation yet to be discovered in the long-continued curving of the style towards the stamens.

Aerial Cleistogamous Flowers.

Not until the former blooms are fairly well developed is this variety seen. They appear in the axils of cauline leaves, lower down than the purple, and also upon numerous axillary shoots. Frequently they are solitary ; sometimes they are found in a short, closely clustered few-flowered rudimentary raceme. Occasionally one or two flowers develop at the base of the purple raceme. Again they are found upon a long shoot resembling that upon which the subterranean pods develop—that is, we see a slender axillary branch upon which at intervals, occur solitary legumes, often to the number of three or four. This special shoot frequently branches and occasionally appears to terminate in the production of two pods growing from opposite sides of the apex. The last described structures will be discussed in connection with the underground type of legume.

When once recognized, the two varieties of aerial flower need never be confused, either in flower or fruit.

The calyx is four-parted, as in the preceding, but is smaller and the teeth are not so pointed nor so long. It is pubescent, but the color is always greenish white.

Even the tiny bud, an eighth of an inch in length, possesses a flattened appearance quite different from that of the purple one.

Upon dissection a comparatively large ovary is seen, bearing recurved style, whose stigma is not usually capitate. This ovary is nearly sessile, and is somewhat hairy, particularly upon both anterior and posterior margins.

Occasionally a rudimentary vexillum is present, but practically the flower is apetalous.

The *stamens* are typically ten, and show a small filament-tube, or they may be distinct. They are quite small and all transitions of perfection in the anthers exist. Plate XXIX, Fig. 1, shows the pistil surrounded by the anthers, varying in the degree of perfection indicated. In Fig. 2, a well-developed anther, found in this kind of flower, is much magnified.

The rapidity with which these flowers pass into fruit is quite startling. One must examine a very small bud to ascertain that fertilization takes place early, that the anthers do not dehisce, but send forth numerous pollen tubes toward the stigma. The anthers then shrivel, the ovary presses out of the calyx and within a few days a good sized legume has developed.

The study of these microscopic flowers has been rewarded by the discovery of a beautiful series of transitions in the shape, size and structure of the style and stigma. This is probably a suitable place in which to allude to them, although it may be anticipating slightly. The green aerial flowers without doubt are reduced purple forms. The styles and stigmas, shown in the nine drawings (Plates XXX, XXXI) are enlarged in the same proportion. In each form represented here, pollen tubes were seen passing toward the stigma, if not already in contact with it, and there is no doubt that the series figured in these Plates represents a set of mature organs.

Fig. 1 (Plate XXX) belongs to a terrestrial flower, and is yet to be described, but is here mentioned to show a very rudimentary condition. Fig. 2 is occasionally found in the green aerial, but belongs especially to the underground form. In Figs. 3–7 inclusive, green aerial styles only are represented. The curving and extension downward is marked, but in Figs. 3, 4, 5, there is no indication of a capitate stigma. Along the inner surface, just beyond the rounded apex of some of these, are seen, by careful focusing, thickened areas where the cells appear different from those of neighboring parts. Here is probably the stigmatic surface. Although there is a great difference in the aspect of Figs. 6 and 7, we have present the brush of hairs, still however, appressed. Figs. 8 and 9 have previously been mentioned; they belong to the purple flower and complete the series drawn. The immature specimen in Fig. 8 bears a striking resemblance to the mature one in Fig. 7. In Fig. 9 the style has the characteristic erect position and the perfect capitate stigma.

Plate XXVIII, Fig. 2, is a transverse section through the ovary of the green aerial flower. The macrosporangium, with the enclosed macrospore, may be readily studied. Other sections which were examined showed variation in height and perfection of the stamens.

These flowers have been seen upon plants bearing purple blooms, but appear about a month later. Some of these were in the green-house, others out of doors, alike in the Botanic Garden and in the country. As late as the first week in October, the aerial green flowers were found in bud condition. There is no doubt they would have matured fruit, had the weather continued favorable.

Plants grown in poor soil, or where there was too much sun, or in too much shade, never produced any but cleistogamous aerial flowers.

Meehan[16] calls attention to the two kinds of aerial flowers; but he does not describe their location upon the plant, nor their structure correctly. He regards the apetalous flowers as pistillate, "receiving pollen from petaliferous blossoms." He denies the presence of pollen in these imperfect flowers, and therefore does not wish to call them cleistogamic. He does not note the time when this latter type appears.

Subterranean Flowers.

Some weeks before *Amphicarpæa* blossoms above ground, the cotyledonary axillary runners have already formed buds. It has been already stated that the runners from the axils of simple leaves are geotropic, and the secondary branches upon these also exhibit the same physiological characteristic. While the cotyledonary shoots mentioned are colorless, those from the simple leaves frequently are deeper purple-green than the remainder of the plant. As they lie upon the ground, often the main branch thickens for a distance of an inch or two behind the tip, sometimes becoming etiolated; tips of the secondary branches were often beautifully curved downward.

Before discussing the peculiarities of growth manifested by these runners, it may be well to describe the flower borne by them. The writer does not consider that there is a raceme-like arrangement of the inflorescence, although there seems to be; the plan of inflorescence is somewhat puzzling. Below each flower is a pair of stipules, never a bract. It is easier to explain the arrangement by referring first to one of the runners which we find arising from the axil of the simple leaves. Now, this shoot grows to a great length, producing leaves with stipules at their bases, frequently each leaf is reduced to a pair of stipules. Each new axil possesses the possibilities of one or more buds, each of which may be similar to the parent. In this part of the plant the reduction of the leaves becomes the rule, and in the axil of the stipules appears a small branch terminating in a flower-bud. Here may arise two—even three—branches (rarely at the same time), each bearing flower-buds. The main shoot may increase in length indefinitely, and likewise branches may develop from the apical buds hidden between the stipules at the base of the flower-bearing branch. It may be said that the flowers are solitary; and when occasionally two are found terminating a shoot, it may be inferred that in the axils of that special pair of stipules, two flower-bearing branches arose at the same time. This condition of affairs is more easily studied when the fruit begins to form. It often happens in the subterranean flowers that the buds are very close together. This is because great reduction in length of the shoot has taken place; but the stipules may usually be found even then, and are always readily seen upon the longer cotyledonary branches.

The *calyx* is four-parted, but the teeth are more rounded than in either of those described. As yet no evidence of an original five-parted calyx has been seen. In this case very young flowers *have* been studied, for it is only when in that condition that the facts which follow may be discovered. These flowers are apetalous.

The *stamens* are distinct, the number varying from six to two. From two to four bear fertile anthers, all others are rudimentary. The filament is short, the anther flattened, and fairly well-filled with pale yellow pollen. Often a stamen is seen, bearing but one productive anther lobe. In Plate XXIX., Fig. 4, is represented a series, showing the variations in the character of the stamens. The first is but a filament, in the second the microsporangia are clearly defined, but no microspores are developed. In the third, only one anther-lobe is perfect, while in the fourth, the normal condition is seen.

Transverse sections made through the same flower-bud at different levels are very instructive. That seen in Plate XXVIII., Fig. 3, is taken from a tip which had not yet succeeded in concealing itself in a dark place. The ten filaments are seen in section, but the ovary has not been reached in cutting.

Examination of other sections show that the number of filaments becomes gradually less. No one of the other sections belonging to this series showed more than three perfect anthers.

There is one *carpel;* the ovary is nearly oblong and sessile, possessing long hairs upon the sutures; it is also finely pubescent, though this condition is much better seen after it emerges from the calyx. It is usually one-, but often two-ovuled. The style is short, curved, but extends outward and very slightly downward; the stigma is not capitate.

The relation of pistil and stamens is indicated in Plate XXIX., Fig. 3.

When fertilization takes place the flowers are about a millimeter in length, or even less. Considerable care is required to obtain just the right stage in which the pollen tubes may be observed passing from the fertile stamens which are located just below the style. Sometimes a stamen, with a well-formed anther is found upon the other side of the ovary away from the style. It is probable that this does not take part in the work of fertilization.

Subterranean fruits may result from the flowers originally formed under ground, and from others, which result from flowers produced by shoots above ground, and eventually covered by soil, or succeed in reaching a dark place where they mature fruit.

Darwin[11] (page 503), refers to the actual penetration of the flower-bearing apex into the soil. Repeated observations have been made, but the writer has not been able to satisfy herself that this occurs unaided. In the green-house, a thick layer of loose soil was placed over the cinders covering the shelf, but the shoots simply spread over the surface, sometimes for a distance of several feet. If a small hole were made a short distance from the tip of a shoot, it would soon turn down into it.

Often a favorable spot for concealment would be under a flower pot. In their efforts to seek darkness, some runners extended over the sides of the shelf, upon which they were placed in the greenhouse, and continued to grow to the floor, a distance of at least four feet. They matured fruit here, some hiding among cinders; upon others soil was placed. If the tips do not find a place suited to their liking, they either dry up or produce a tiny flat green legume.

It seems probable, that in nature, earthworms assist in burying the flowers; there are, too, crevices, stones, or leaves which afford the desired protection; the beating of the rain, perhaps, may cause the tip to become covered. Having once secured a proper place, growth in length will continue, for some time, even in the soil, if that is loose in character.

Indications of the presence of subterranean flowers, produced upon cotyledonary shoots, may be seen on a plant six or eight weeks after its germination. Those upon the over-ground branches are much later in appearing. The possibilities of production upon the former seem unlimited. As long as the plant exists, development continues; for branching and re-branching do not cease. As late as October, all stages may be found from the tiny bud to the large legume. In August, a number of shoots were taken from plants growing in a moist spot, with plenty of dead leaves lying upon the ground. Most of these were cotyledonary shoots, but some may have been runners from the simple leaves, which long ago had disappeared. The number of buds and small legumes then present were as follows: thirteen, sixteen, twenty-two, forty, fifteen, thirty, twenty-seven, twenty-one, twelve, seventeen, respectively. An astonishing series, truly; it is probable, too, that most would have matured fruit.

Observations were made to ascertain approximately the length of time necessary for the maturing of these legumes.

On February 15, an axillary runner from the first pair of leaves was buried. It was 18½ inches long, and was buried for about half its length. It bore one compound leaf, a small runner in the axil of this leaf, and a runner nearer the plant, in the axil of stipules. Each of these had two tiny buds. Beyond these the main runner divided into two.

On February 22, the runner was 19 inches—there was no apparent change in buds.

On February 29, the runner was 19½ inches long and the changes in pods were as follows:

Pod 3 was ⅜ inch long, and ¾ inch in circumference, and was becoming rounded.

Pod 4 was ¼ inch long, and was flat.

On March 3, pod 3 was ½ inch long, and quite rounded. Pod 4 was ⅜ inch long—also becoming rounded. The others had been injured in an unexplained manner.

On March 14, pod 3 was ⅞ inch long; pod 4, ¼ inch; both quite full and round.

On March 7, an axillary runner 30 inches long, from the first pair of leaves, was buried for half its length. It bore four compound leaves, and in the axil of each a small branch having minute buds. Beyond the last leaf was a shoot 9 inches long, bearing three buds.

On March 14, the shoot was 32 inches long, and there was a very slight increase in size of buds.

On March 21, the length of shoot was 32½ inches. From the axils of the second and third leaves there were two axillary buds each. That from the fourth leaf had two tiny flat green legumes ⅜ inch long. Upon the terminal portion, pod 1 was ⅝ inch long, 2, $\frac{3}{16}$ inch, 3, ⅛ inch long; all were still rather flat.

These and similar notes seem to indicate that the maturing of the terrestrial legume is comparatively rapid. In the second, certainly the third week, after fertilization, they assume good proportions. After this, the increase is very steady, and growth would be likely to continue during the life of the plant, though the seed is probably mature early.

Then came the question: Will shoots from other leaves than this first green pair, produce these subterranean legumes?

On July 23, shoots from simple leaves, also from first, second, third, and fourth compound leaves were buried in separate pots. All were long, bore leaves, but as yet showed no indication of flower buds.

Circumstances prevented examination until September 3. Finally all were removed September 25. Every one of the shoots had branched extensively both inside and outside of the pots. The tips which were thin and green when placed in position had thickened, formed, even roots had developed. Legumes of all sizes were here; well-developed ones one-half to three-quarters of an inch long were taken from each pot, in number from two to six; while smaller ones were numerous. In regard to productiveness of axillary shoots, those from simple leaves gave the greatest yield; those from compound leaves differed little in fruitfulness; not one failed to develop some.

Structure of Winter Flowers.

During the winter of 1895–96 plants raised from terrestrial seeds produced minute green flowers which resembled the subterranean flowers previously described. They are indeed almost counterparts of those found in summer upon the tips and upon the branches of axillary runners, and which do not become covered with soil. They differ in the resulting legume, as well as in their physiological behavior. While the summer ones, failing to obtain a suitable spot for development, either produced a tiny, flat, one-seeded legume, or else dried up, the winter-type seemed unaffected by its surroundings and usually matured a good-sized two-seeded legume. On the other hand, this winter-form might be regarded as a degenerate type of the green aerial flower of late summer, as it is much reduced in several particulars.

The *calyx* is about the same size as that found in the terrestrial flower, is more pointed in its lobes, but is generally much larger than that of the green aerial. The *corolla* is entirely absent. Ten *stamens* are generally present; they are distinct. Four of these are unusually fertile, the remainder being mere outgrowths from the receptacle. The pistil has a short curved style, the stigma is not capitate; the ovary is sessile and typically two-ovuled. The stamens in number suggest resemblance to the green aerial, while the appearance of style and stigma causes our thoughts to turn to the terrestrial, for no such variations of style and stigma as previously described for the green flowers of summer are seen here.

Plants raised from aerial seeds during winter rarely produced any fruit above ground; if they did, it was a tiny, flat, one-seeded legume, of the character alluded to in a previous paragraph. An additional reason this, for considering the winter type of flower to be most closely related to the terrestrial form.

Within four weeks after germination, flowers were evident; legumes were ripe at the end of two months. Not the slightest indication of purple flowers was seen upon any plants during the winter and spring.

Summary of Views on Floral Variation.

To recapitulate, *Amphicarpæa* presents the case of a plant bearing at least *three*, probably *four* distinct types of flower; and these not occasionally, nor spasmodically, but simply following regular laws of development.

In summer, purple flowers may be expected to appear upon the upper main stem, and the upper axillary branches. A certain intensity of the sun's rays seems necessary, for these are not found upon plants growing entirely in the shade. Neither do they develop extensively upon plants constantly exposed to the sun. Here the water supply may be insufficient; plants grown in such a situation are not apt to reach a fair height.

But later the same plant, having, we will suppose, as is often the case, produced an abundance of purple flowers, now proceeds for a month or more to bear aboveground a cleistogamous form.

Frequently, too, plants which have not developed a single colored flower, may, late in the season, produce this last type.

Similar cases of this method of development are not unknown. Among the Violaceæ it is quite common, but all of the cleistogamic forms are produced close to the ground, hiding among the leaves, and only occasionally upon special short branches.

Specularia perfoliata bears inconspicuous flowers late in the spring; in June the bright purple ones are found.

Henslow[13] mentions the finding of flowers of *Linaria* and *Potentilla* in the autumn, in which he discovered pollen tubes passing to the stigma. These specimens, though imperfect, however, still possessed color.

Amphicarpæa certainly bears its cleistogamic flowers in great abundance, some of them in a very conspicuous position upon the plant. The aerial cleistogamic form occurs persistently and for a long period.

As for the underground flowers, from the middle of June until October, unceasingly *Amphicarpæa* is adding to the number. No average environment seems to prevent their production: but there is marked difference in the size and number of legumes produced.

Among the Oxalidaceæ the special underground shoots do not develop until the summer months are far advanced.

Epiphegus Virginiana shows a similar behavior to *Amphicarpæa*. During the summer of 1896 Dr. Macfarlane observed at Woods Hole *Polygala polygama*, which grows there abundantly. Early in the summer he found this plant to produce subterranean flowers, many of which ripen fruit before the aerial flowers have opened. After the purple flowers have almost ceased blooming, colorless flowers appear above ground, upon elongated shoots which develop below those bearing purple flowers. A study of these is now being made by Mr. C. H. Shaw.

Is the behavior of *Amphicarpæa* in winter not due to absence of intensity in the sun's rays? High temperature and abundant light and moisture were provided, still plants in the green-house from January to end of April showed no purple blossoms. Yet others placed in the same part of the green-house in May were covered with these flowers in August.

Linnæus relates a similar experience with plants taken to the Gardens of Upsal [5,6]; they produced inconspicuous flowers only. Gray,[9] too, reports similar experiences with certain plants in the Cambridge Garden. Insufficient temperature might be adduced as a cause for this non-production of colored blooms; but from my experience with *Amphicarpæa* the light intensity is without doubt an important factor.

Microspores and Macrospores.

Little has been said concerning the pollen; it seemed best to compare all flowers in this particular at one time. When young the anthers of the *purple flowers* are quite well filled. The appearance of pollen after the anthers have dehisced has already been described. Dr. Macfarlane informs me that it resembles the inefficacious pollen of certain hybrids. It measures when dry, 13 μ, upon addition of water it measures 16–18 μ.

The anthers of the *green aerial* flower do not contain so much pollen as those of the purple flower; it resembles in appearance the pollen of the latter when water has been added. It is pale yellow, granular, and measures 11 μ.

The pollen of the *terrestrial flowers* is less abundant than that of the last; but the appearance is similar; it measures 8–9 μ. Two nuclei are frequently seen in this pollen grain. (Plate XXIX., Fig. 5.)

I can not state so certainly the comparative size of the macrospores, as I do not feel sure that those measured were absolutely at the same stage—namely, ready for fertilization. From specimens which have been examined, the macrospore in the *purple flower* measures 5 μ; that of the *green aerial* 6 μ, and that of the terrestrial 4 μ.

Before turning attention to the legumes, it may not be out of place to refer to the comparative size of the pistils of the three types of flowers, as shown in Plate XXXII., Figs. 2, 3 and 4.

Histology of Legumes.

The macroscopic appearances of the legumes have already been described, and reference to illustrations will convince the reader that it is not easy to mistake the products of the different flowers. It is possibly not scientifically correct to apply the term "legume" to the fruit of the terrestrial flower, as there is no dehiscence; but considering it as a modification of the others, the expression may, perhaps, be allowed to stand. For the present, laying aside the winter type, *Amphicarpæa monoica* presents in nature, three distinct kinds of legume. A striking series of transitions is readily made from the purple to the terrestrial, including those tiny flat forms which are not successful in reaching a suitable maturing place. If again we place the winter-type in our list, the series is unusually complete.

With the purple, and green aerial, the fruit is green, turning brown when ripe, the style persisting and forming a characteristic feature in each, as does also the region just toward the apex. In the winter type, the same remarks as to color change will apply; usually the style disappears; if it remains, it either stands out at right angles to the legume, or it is appressed to the ventral suture.

The terrestrial form is white, but is soon tinged with pink purple. When ripe, the style has disappeared, the sutures are often scarcely discernible, the color is purple of varying vividness and density.

Appropriating a word used—possibly introduced—by Huth,[17], we may properly class *Amphicarpæa monoica* among *heterocarpic* plants. In his paper, however, he places it among *amphicarpic* forms.

The histological structure of purple, green aerial and winter-type legumes is similar. Numerous stomata alike in size and shape are found; these are surrounded by several subsidiary cells. The epidermal cells are irregularly isodiametric. (Plate XXXIV., Fig. 1.) Just beneath the epidermis, lie one or sometimes more layers of sclerenchymatous fibres, closely arranged, tapering so that they fit together to form a mechanical device for producing the inflation of the pod. In transverse section, in addition to what has been mentioned, we find cells resembling mesophyll and containing chlorophyll. The inner epidermis is thin, and has no stomata. The glistening, somewhat opaque appearance of the interior of the legume is probably due to air spaces under the epidermis. The mesophyll tissue in the winter type appears of looser texture than the others.

When young, all are somewhat pubescent, but the purple, and green aerial when mature, bear hairs upon the sutures only; those elsewhere have disappeared. The winter-type possesses these epidermal structures through life and also when ripe. Both long unicellular hairs and the bladder forms, previously described, occur here.

The terrestrial form presents several peculiar characteristics. The purple coloring is due as elsewhere in the plant, to a liquid either in the epidermal cells or just below them. Stomata are quite as numerous comparatively, as upon the surface of the overground legumes, but they are here placed upon the apex of a small papilla raised conspicuously above the surrounding epidermal cells, which resemble in size and shape those of the other legumes (Plate XXXIV., Fig. 4). Certainly three kinds of hair occur; one of these has a base suggestive of a glandular function. The others are of the same character as those seen upon the aerial legumes, but are much more numerous. A fourth kind may be the shorter unicellular seen in the drawing. (Figs. 2, 3.)

But instead of these walls being firm and unresisting, they are thin and delicate. No sclerenchymatous fibres exist, but there is present the parenchyma corresponding to mesophyll in texture, whose cells also contain chlorophyll. The seeds occupy all the space within the legume, and the result of the tension is seen by the final thin covering, as increase in size of the seed takes place.

Remembering the great contrast in legumes produced upon the lower axillary runners, due apparently entirely to the special environmental conditions under which they were allowed to mature fruit, an experiment was undertaken. Some of the winter aerial legumes (not located upon the lower runners) were buried, after they had become quite long, but were still flat, the seeds being small and green. At intervals during the course of a month they were examined; at the end of that time a remarkable transformation had taken place—the counterpart of a terrestrial presented itself. The whole structure had swollen enormously; its thickness was four times that of its former state; its color was now pink purple. Instead of firm walls, their appearance was now thin and tightly stretched; even the color of the seed-coats had changed. Various accidents destroyed some of these fruits before the observations were completed.

Experiments are now being carried on to ascertain more regarding this remarkable physiological change, and also what histological changes, if any, result. Winter forms in varying stages of development, and from all portions of the plant, have been buried in specially prepared receptacles, containing soil and sphagnum, and these have been suspended from the roof of the green-house.

It is hoped, too, that some information may be obtained as to the possible function of the long hairs with glandular base, whose presence was mentioned above.

As soon as possible a similar series of experiments will be tried with legumes of purple, and green aerial flowers.

(*a*) Legumes from Aerial Purple Flowers.

In order to ascertain the amount of fruit resulting from purple flowers, racemes were tagged while yet in the bud; others were gathered and examined after legumes had developed, or were mature. Several localities were then studied, and some of the records are given below. As there is at least one flower in the axil of every bract, results are fairly accurate. It is not possible to state the definite position upon the raceme, where fruit may occur. This as well as the number is exceedingly variable.

Observations upon Plants Growing along Wissahickon near Chestnut Hill.

Number of flowers in raceme.	Legumes present.	Remarks.	Number of flowers in raceme.	Legumes present.	Remarks.
11	1		24	4	
12	1		18	4	
12	2		44	8	Compound raceme.
18	4		15	0	
22	3	Compound raceme.	18	0	
12	1		14	0	
8	1		11	1	
17	1		6	1	
20	8	Compound raceme.	13	2	
25	1		14	2	
9	1		6	3	
9	2		9	8	
18	1		18	3	
11	3		30	4	Compound raceme.
10	3		13	5	
10	4		24	4	
17	3		18	4	
11	1		10	2	
16	3		20	4	Compound raceme.
17	4	Compound raceme.	21	6	
12	3		20	5	
60	1	Compound raceme.	28	5	Compound raceme.
12	3		13	3	
14	5	Compound raceme.	13	5	
17	3		19	3	
22	10		11	2	
16	4		10	0	
18	9		27	0	
11	8		13	0	
20	7				

OBSERVATIONS UPON PLANTS GROWING NEAR BURMONT AND LANSDOWNE.

Number of flowers in raceme.	Legumes present.	Remarks.	Number of flowers in raceme.	Legumes present.	Remarks.
24	0		10	6	
22	0		10	2	
9	0		7	5	
23	0		12	5	
24	0		6	4	
11	9		7	3	
12	8		20	6	
5	2		7	5	
7	5		13	6	
10	9		20	7	
11	6		6	5	
5	3		14	3	
17	11	Compound raceme.			

Many other racemes noticed in the latter locality yielded no legumes.

These statistics are quite sufficient to prove that *Amphicarpæa monoica* produces legumes from purple flowers in as large proportion as the Leguminosæ generally, though not at all equal to some well-known genera. As is the case with all plants, however, some years yield better returns than others. The legumes are neither few nor difficult to find. Certainly the statements found in all the Manuals concerning the usually sterile condition of the flowers, are erroneous.

(*b*) LEGUMES FROM OTHER FLOWERS.

Rarely do the green aerial (*b*) fail to produce fruit, these exceptions being due to the appearance of the flowers so late in the season, that the temperature does not permit their maturing. (*c*) For the terrestrial flowers the results are practically as given above.

Comparative Productiveness of Flowers.

The following records show the comparative productiveness of all these flowers, as obtained from plants cultivated in the green-house in pots during summer. They were twenty in number and placed some distance apart. Any intertwining shoots were carefully separated; but the results are not absolutely accurate in the case of the number of terrestrial legumes for each plant, as many which were fair-sized, though still flat, were dried by the heat in the green-house in the latter part of September. Many of the runners had no means of hiding the flower-bearing portion, except among the cinders, and it was impossible to avoid breaking these from their attachment, when pots were lifted. The numbers, however, will give an idea of the possibilities of productiveness in the case of single plants; this could not be ascertained from growth in the woods.

The number of flowers producing terrestrial legumes is not given, nearly always there were numerous tiny ones which were yet undeveloped; mature fruits only were considered.

Plants were placed in position late in May and early in June; examination of results was made in the last days of September. Many specimens reached a height of five feet, and developed axillary shoots abundantly, some of the latter being six and eight feet in length.

Plant I. was raised from a terrestrial seed produced upon a small (non-twining) plant in late winter.

It bore 66 purple flowers resulting in 3 legumes.

14 green aerial flowers resulting in 14 legumes.

7 + terrestrial flowers resulting in 7 legumes—2 of them large.

Plant II. was raised from a terrestrial seed produced upon a small (non-twining) plant late in the winter.

It bore 66 purple flowers resulting in 3 legumes.

14 green aerial flowers resulting in 14 legumes.

6 + terrestrial flowers resulting in 6 legumes—3 of them large.

Plant III. was similar to I and II. It bore

30 purple flowers resulting in 0 legumes.

13 green aerial flowers resulting in 13 legumes.

3 + terrestrial flowers resulting in 3 legumes—2 of them large.

Plant IV. was similar to III. It bore

38 purple flowers resulting in 0 legumes.

12 green aerial resulting in 12 legumes.

3 + terrestrial flowers resulting in 3 legumes.

Plant V. was produced from seed of a winter type legume. It was rather feeble, and bore

0 purple flowers resulting in 0 legumes.

8 green aerial flowers resulting in 8 legumes.

6 + terrestrial flowers resulting in 6 medium sized legumes.

Plant VI. was similar to V., and bore

0 purple flowers resulting in 0 legumes.

16 green aerial flowers resulting in 16 legumes.

5 + terrestrial flowers resulting in 5 legumes; 1 of them large.

Plant VII. was similar to V. and VI., but was stronger, it bore

6 purple flowers resulting in 1 legume.

21 green aerial flowers resulting in 21 legumes.

10 + terrestrial flowers resulting in 10 legumes (small and medium).

Plant VIII. was produced from terrestrial seed upon a plant raised from terrestrial seed. It bore

73 purple flowers resulting in 0 legumes.

8 green aerial resulting in 8 legumes.

7 + terrestrial resulting in 7 legumes, small and medium.

Plant IX. was similar to VII. It bore

4 purple flowers resulting in 1 legume.

24 green aerial flowers resulting in 24 legumes.

6 + terrestrial flowers resulting in 6 legumes.

Plant X. was similar to IX. It bore

(Number lost) purple flowers resulting in 1 legume.

26 green aerial flowers resulting in 26 legumes.

18 + terrestrial flowers resulting in 18 legumes, 5 of them large.

Plant XI. was produced from an aerial seed gathered in '95, whether it was from purple or green aerial flower was not known. It bore

43 purple flowers resulting in 2 legumes.

30 green aerial flowers resulting in 30 legumes.

14 + terrestrial resulting in 14 legumes, 3 of them large.

Plant XII. was similar to XI. It bore

11 purple flowers resulting in 1 legume.

25 green flowers resulting in 25 legumes.

11 + terrestrial flowers resulting in 11 legumes.

Plant XIII. was similar to XI. It bore

13 purple flowers resulting in 1 legume.

13 green aerial flowers resulting in 13 legumes.

13 + terrestrial flowers resulting in 13 legumes.

Plant XIV. was similar to XI. It bore

17 purple flowers resulting in 1 legume.

23 green aerial flowers resulting in 23 legumes.

13 + terrestrial flowers resulting in 13 legumes.

Plant XV. was produced from a terrestrial seed raised upon plant from growth of terrestrial seed. It bore

64 purple flowers resulting in 0 legumes.

37 green aerial flowers resulting in 37 legumes.

13 + terrestrial flowers resulting in 13 legumes (small).

Plant XVI. was the same as XV. It bore

165 purple flowers resulting in 0 legumes.

29 green aerial flowers resulting in 29 legumes.

7 + terrestrial flowers resulting in 7 legumes.

Plant XVII. was the same as XV. It bore
90 purple flowers resulting in 0 legumes.
37 green aerial flowers resulting in 37 legumes.
18 + terrestrial flowers resulting in 18 legumes.

Plant XVIII. was the same as XV. It bore
0 purple flowers resulting in 0 legumes.
31 green aerial flowers resulting in 31 legumes.
28 + terrestrial flowers resulting in 28 legumes.

Plant XIX. was the same as XV. It bore
232 purple flowers resulting in 0 legumes.
36 green aerial flowers resulting in 36 legumes.
12 + terrestrial flowers resulting in 12 legumes.

Plant XX. was the same as XV. It bore
40 purple flowers resulting in 1 legume.
21 green aerial flowers resulting in 21 legumes.
30 + terrestrial flowers resulting in 30 legumes.

The underground legumes were then collected from the pots and stage cinders in their immediate vicinity. As it was almost impossible to avoid breaking some of their attachments, the space was carefully examined and yielded ninety legumes of varying size. Thus from these twenty plants the grand total of terrestrial legumes was three hundred and twenty.

In a plot of ground where plants were separated as much as possible, there was a large yield of terrestrial legumes, but comparatively few aerial, none of which resulted from purple flowers. Although the soil was quite rich, it was constantly exposed to sun, and moisture was not abundant. All of the plants were low, wound somewhat around each other, but rather trailed on the ground. This may have been partly due to the winds which blew quite usually over the special part of the Garden where these grew.

Three very vigorous plants deserve notice, and were so arranged that each could be lifted out with the mass of soil still clinging around the roots. Careful examination revealed the remarkable results of twenty-nine, thirty-five and fifty legumes respectively. These were developed fairly close to the original cotyledonary region. Axillary shoots could not well produce fruit, as the soil was rather clayey on the surface, and no leaves lay upon it.

As the legumes were being collected from a certain plant, the curious branched appearance of the cotyledonary axillary runners attracted attention. Investigation proved the presence of no less than two hundred and fifty-one hypogean flowers and legumes in varying stages of development. (Plate XXXVI, Fig. 1).

An interesting incident which occurred while raising *Amphicarpæa* in a small city yard, is not without value here. In the autumn the space four feet by two which had been used for this purpose was examined carefully, and a number of terrestrial legumes gathered. So diligently was search made, that the writer felt sure that all were removed. Imagine then the surprise, when, in the following spring, one hundred and fifteen plants appeared. The explanation was that the bed in which they were grown was beside a board fence underneath which the runners had matured the fruits. An asphalt pavement in the next yard prevented their growth in length. Several of the plants were examined as to place of origin, and showed a long white, rather crooked stem which had struggled upward. It was not easy to find the seed, only its evident location could be determined.

One certainly doubts the possibility of such a species being exterminated.

Attention should be called, however, to one more set of statistics. On April 18, plants which had been growing since the beginning of February in particularly rich wood soil, which had been kept very moist, were uprooted, and yielded as recorded below. The only aerial fruit was the winter type previously referred to.

PLANT 1.	17 aerial. 3 underground.	PLANT. 2.	13 aerial. 1 perfectly formed terrestrial. Indications of 24 others 1/8 inch long.
PLANT 3.	2 aerial. 3 terrestrial.	PLANT 4.	20 aerial, mainly one-seeded. 1 terrestrial.
PLANT 5.	20 aerial. 2 terrestrial.	PLANT 6.	5 aerial. 9 terrestrial.
PLANT 7.	21 aerial. 5 terrestrial, 2 of these two-seeded.	PLANT 8.	10 aerial. 5 below, 1 of these two-seeded.
PLANT 9.	20 aerial. 8 terrestrial, 2 of these two-seeded.	PLANT 10.	10 aerial. 6 terrestrial, 1 of these two-seeded.
PLANT 11.	7 aerial. 6 terrestrial, 2 of these two-seeded.	PLANT 12.	10 aerial. 7 terrestrial, 2 of these two-seeded.
PLANT 13.	10 aerial. 11 terrestrial, 4 of these two-seeded.	PLANT 14.	7 aerial. 6 terrestrial, 2 of these two-seeded.

Total of terrestrial legumes (perfectly developed) 64, of which 16 were two-seeded. In Plate XXXV, Fig. 3, a view of the cotyledonary region of Plant 8 in this series may be seen.

Having now presented some notion of the relative fertility of each kind of flower, several conclusions may be stated.

1. Plants of *Amphicarpæa* growing under suitable condi-

tions of sunshine and shade, and having abundant moisture, will produce all three varieties of flower. Tall, vigorous plants, with such environment, seem to excel in quantity of purple flowers.

2. Plants growing in almost perpetual shade, or those exposed to constant sunshine, even if well supplied with moisture, rarely produce purple flowers, and but few green aerial ones. The subterranean fruits are quite abundant; but the quality and quantity depend upon the character of the soil. Loose, rich, forest soil, with many decaying leaves, gives excellent results, for the terrestrial fruits may then develop from overground as well as underground runners.

Along the banks of the Wissahickon, not far from Chestnut Hill, lies a certain strip of land about a quarter of a mile in extent. It is an open space, not shaded by trees, and is a perfectly luxuriant mass of vegetation, abounding in tall weeds of various kinds, also a few shrubs. The stream is narrow, and the high banks upon the opposite side give a due amount of shade in the afternoon. The soil is loose, very wet and sandy. Plants of *Amphicarpæa monoica* growing here are most vigorous specimens, rising to the height of six and eight feet, and are densely covered with ferruginous hairs. The best supply of purple flowers was found here, and the racemes were often compound. Strange to say the underground legumes were comparatively few, and most of them small.

Does, then, the number of purple flowers affect the production of underground cleistogamic ones? Or is it due to the character of the soil? It has also been noticed that those plants giving abundant results in the way of subterranean fruits, possessed more tubercles upon the roots. These were quite insignificant, both as to quantity and size upon the Wissahickon plants. Whether this is a mere coincidence, or whether there is a real physiological connection, can not now be definitely decided.

One need, however, pass but a short distance up the rocky hillside, covered with a dense growth of trees, to find in certain localities, plants of *Amphicarpæa* in abundance, twining around each other and trailing over the soil, or occasionally rising higher. Only glimpses of sunlight through the thick foliage of the trees ever reach these plants. No purple flowers are borne here; sometimes a few green aerial ones; but the number of terrestrial flowers must be truly striking. If these localities are visited in spring the young plants form a close bed of green; later a dense tangled mass of vegetation results.

Character of Plants Resulting from Special Seeds.

As previously stated there are four types of seed—(*a*) from purple flowers, (*b*) from green aerial, (*c*) terrestrial, (*d*) winter type.

Any of the above seeds will give rise to a plant capable of producing terrestrial seeds.

The terrestrial seed will, in summer, give rise to a plant which may bear *a*, *b*, *c*. This is equally true, if the terrestrial seed has been derived from a plant produced from a purple, a green aerial, or a winter type seed.

What possibilities lie in plants raised from the other seeds can not yet be confidently stated as a sufficient number of experiments has not been performed. It is likely that the seed of the winter type produces all three kinds of flowers.

The sharp dimorphism referred to in the early portion of this paper, seems to disappear as the sunlight increases in intensity, for then all transitions from the tall vigorous twiner to low-growing feeble specimens exist.

In the localities where purple flowers fruit abundantly, germinating seeds of this type have not been found. Hundreds of seedlings have been uprooted, and terrestrial seeds only have been seen. If none of the preceding germinate, there would seem to be a tremendous waste of energy in the plant, for in some cases the amount of seed produced is not by any means to be despised. From study of the structure, and the experiments tried in the greenhouse, I think it is improbable that the germination of these aerial seeds occurs in their native haunts. Should they germinate the feeble specimens resulting, would soon be crowded out of existence, not only by their more vigorous relatives, but also by the surrounding vegetation.

Comparison of Amphicarpæa Flowers with those of other Plants.

An examination of the Leguminosæ shows that there are other members of the Order which share with *Amphicarpæa* the peculiarity of producing subterranean fruit. In Huth's paper [17], quite a number are enumerated; but with many of those mentioned, beyond the simple statement that the special plant produces two or more types of fruit, little definite information concerning the life history of the individual has been recorded. Among the most familiar, are *Trifolium subterraneum*, *Vicia amphicarpa*, and *Arachis hypogæa*.

Trifolium subterraneum produces practically but one kind of flower which may mature fruit above ground,[23] if the head is prevented from forcing its way under the surface. Usually after the flowering period is over, the peduncle bends, gradually lengthening, until the earth is reached.[11] Under the soil, the fruit ripens. According to Warming,[22] the inflorescence commonly contains but four or five normal flowers; the remaining ones he terms "metamorphosed." The calyx of this type is peculiarly developed, the function evidently being to assist in penetrating the soil. All other floral portions are absent in this type of flower. What structural differences, if any, exist between the aerial and subterranean legumes, I have not been able to ascertain; the subject probably awaits investigation. It is stated, however, by Belli [23] that the seeds contained in the former, germinate with difficulty unless the integument is broken.

Vicia amphicarpa bears two kinds of flower, each of which produces a distinct type of fruit. The aerial flower has a papilionaceous corolla, the subterranean is apetalous.[6] The aerial flower never matures a legume similar to that resulting from the subterranean flower; but there exists no record of experimental evidence regarding the behavior of either flower, if compelled to develop in a manner differing from that which is considered normal.

Arachis hypogæa has recently been studied by Mrs. Pettit.[25] *Arachis* bears practically but one kind of flower, which is usually found above ground, though occasionally specimens have been seen upon the subterranean portion of the stem. The flowers occur singly in the axils of the leaves, and are sessile. After fertilization, the floral parts fall, the gynophore lengthens and exhibits a decided geotropic tendency. Growth continues until the ovary is carried underground. This process is aided by the development of a brown hardened tip upon the ovary. If from any cause the ovary is prevented from entering the soil, no fruit results. This statement is verified by experiments conducted by M. Correa de Mello.[24] No differences in character have been observed in the fruit resulting from the subterranean flower. Mrs. Pettit observed the development of a zone of hairs upon the gynophore after its entrance into the soil; these hairs also developed where the gynophores were placed in moist chambers. After a series of experiments, she decided that their probable function is to assist in absorbing nourishment for the maturing fruit.

In marked contrast to all of these plants, stands *Amphicarpæa* with its three distinct types of flower and fruit occurring in a season. We have here a series of great value, as study of the structural pecularities shows a gradual transition from the aerial to the subterranean form. It is worthy of attention, too, that the aerial apetalous flower in the upper part of the plant may be forced to develop a fruit and seed of the subterranean type, provided the flower or a young legume is placed under the proper conditions. Possibly the above statement may apply even in the case of the purple flower; and experiments are now in progress to test the matter.

The abundance of axillary shoots, both primary and secondary, presents a feature quite different from the plants just discussed, as does also the habit of growth. The cotyledonary, axillary shoots normally produce many flowers and fruits. The runners above ground may do so likewise, and if a darkened moist place is reached, the ovate one-seeded legume results; otherwise a flat green legume resembling a diminutive aerial type is produced. These runners are not provided with any device to assist them in forcing their way into the soil. The runners from the simple leaves are not strongly geotropic; perhaps after a certain period of growth, they are best described as negatively heliotropic, yet the secondary branches frequently exhibit beautiful geotropic curves. The axillary runners from compound leaves are negatively geotropic, yet these may be so treated that subterranean flowers and fruits are borne. The cotyledonary axillary runners are feebly geotropic, extending from the cotyledons at an angle of 75 to 90 degrees.

In *Arachis* and *Trifolium* the geotropic characteristics of those portions bearing the flowers which are capable of maturing underground, are quite pronounced.

The purple flowers of *Amphicarpæa* evidently require for their development, as has already been stated, considerable light intensity, and possibly also demand the vigorous growth of the upper portion of the plant. When the special period for the production of these is past, the aerial apetalous form appears. The seeds in these legumes are numerous, yet they possess a very hard covering, and are difficult of germination. Filing these produced such a marked difference in percentage records of germination that the success obtained by similar treatment of *Trifolium* seeds matured above ground is recalled.

The subterranean fruit of *Amphicarpæa* is larger, and possesses a seed whose coat is delicate in structure, as is also that of the legume. No difficulty whatever is experienced in germinating these, whether the entire legume is used or the seed only. It is not yet known what function may be exercised by the hairs of gland-like base peculiar to this type of legume. These, as is surmised for the epidermal structures of *Arachis* may assist in the accumulation of nourishment.

Thus these seeds, though resulting from the most reduced type of flower, are those upon which the reproduction of the species may be said to depend. As it has been proved experimentally that these flowers do not give rise to this variety of seed, if they remain unexposed to dark surroundings or above ground, it seems almost useless to propose protection from destruction by animals as one reason for the subterranean seed development. It is true animals do seek them, but there would not exist these delicious morsels, if the seeds matured under other influences.

Darkness and moisture seem to exert some powerful influence upon these seeds, not only structurally, but also in the nourishment stored up, and which possibly contains certain substances valuable for the more successful growth of the future seedling. Whether or not materials are absorbed from the surrounding soil, cannot now be answered. Comparative chemical analyses of the aerial and subterranean seeds will perhaps afford an explanation.

The phenomenon of subterranean seed-production is one that has never been satisfactorily explained. It is generally conceded that there must be some signal advantage to the species. *Amphicarpæa monoica* is a plant whose flowers at present illustrate transitional reduction. One is inclined to consider that the statement might be also made for *Trifolium subterraneum* and *Vicia amphicarpa*. Was *Arachis hypogæa* ever in the same condition? *Amphicarpæa* in some instances produces only the subterranean type of legume. We have seen that the conversion of an aerial to a terrestrial legume may be accomplished experimentally within a short time—indeed, within the life of the individual. Doubtless, we may picture the frequent occurrence of just the proper combination of circumstances necessary to cause a similar transformation of the aerial legume. Consequent upon its production followed the more successful germination of the seed, and certain structural changes were initiated. The characteristics once acquired, were slowly, but persistently transmitted, until the habit of the plant as regards subterranean seed-production is now a permanent one.

It is puzzling to the biologist why in many instances *Amphicarpæa* still yields quantities of aerial seed from which, it appears, the species is so little benefited. Variation due to environmental conditions is in *Amphicarpæa* beautifully illustrated, and in the history of few plants is it possible to obtain a series equally valuable for demonstration of a transitional condition; for the presence of corolla, the number, size and degrees of perfection found in the stamens, the ovary, style and stigma—all afford material which is deserving of careful comparative investigation.

In conclusion, the facility exhibited by certain of the axillary runners, in acquiring new habits of growth, which are continued through life, deserves emphasis. It has already been stated that in case of injury to the main stem, the cotyledonary axillary shoots and also those from the axils of the simple leaves—themselves non-twiners—will assume the duties of the main shoot. While the latter remains uninjured, or should injury occur after the runners have become five or six inches long (perhaps shorter) no amount of artificial assistance and training is sufficient to induce the twining habit. Since the experiments recorded in the early part of this paper were performed, axillary shoots from the simple leaves have been fastened so that they were made to grow upward. Many of these have now reached the height of five feet, and are nearly on a level with the main stem, yet their free ends do not twine. Their actions indicate negatively heliotropic and feebly geotropic tendencies. The question may well be asked, from the evolutionary standpoint, Would these peculiarities be modified or ultimately disappear if continued cultivation under these artificial conditions were persistently carried out?

With the readiness to change the habits transmitted by inheritance to the various plant parts and to acquire new ones from the pressure of external conditions, with great possibilities in subterranean seed production, and the unfailing germination of these seeds, it is not strange that a luxuriant growth of *Amphicarpæa* greets the visitor to the woods.

A Review of the Species of Amphicarpæa.

Recalling the dimorphism in plants resulting from the germination of the terrestrial and aerial seeds in the greenhouse, the variation in size, strength, and habit of the individuals growing in the open, and also the variation in the flower production, a consideration of the probable number of species or varieties with which we are dealing, is worthy of our attention. A brief discussion of some of the causes operating to produce such results will now be undertaken.

One reason why purple flowers do not appear upon plants growing in shaded localities may be due to the non-development of the upper stem-region and its axillary shoots where these flowers are normally borne. Repeated injuries to the growing main stem, and even to its successors may be an explanation. Insects, birds and small rodents are fond of the foliage, and the struggles for existence in a wooded spot have doubtless something to do with the low-growing condition described.

Those found upon the outskirts of the woods are taller possibly because receiving more sunlight, but there may be fewer enemies of the classes mentioned.

Amphicarpæa is rarely found as an isolated specimen; it seems incapable of developing except among other plants. If no suitable support be available, several adjacent individuals will form a coil by the union of their stems.

These statements were proved by attempting to grow out of doors, for more careful observation, single plants in pots or in soil, so arranged that they were separated by quite a distance. Even a slight breeze interfered with the attempts of the stem to continue its normal habit of growth; stronger winds uncoiled it for some distance, frequently snapping it in two, and so injuring the plant that it lay upon the ground.

The number of types of flower produced, depends largely upon the character of the natural conditions to which the plants may be subjected.

As it is possible to raise from seed such different specimens of *Amphicarpæa*, the question arises, How many distinct species of the genus should be recognized for the Eastern United States?

The Manuals mention *A. monoica*, *sarmentosa* and *Pitcheri*. The first two certainly seem to be but varieties, resulting from environmental conditions. This appears to the writer to be proved by the study of plants in the greenhouse, Botanic Garden, and several natural localities.

Twining plants of *A. monoica* from Wissahickon differ in no apparent respect from herbarium specimens of *A. Pitcheri;* for large, healthy leaves, a dense growth of ferruginous hairs, and heavily-flowered racemes described for the latter are likewise borne upon the individuals of the former found in the above locality. Gray states that it is not known whether *A. Pitcheri* produces underground legumes or not. I have also received from F. Reppert, of Muscatine, Iowa, plants of these species. While sufficient examination of them has not yet been made, the statement by Gray, that has just been referred to, may be said to be incorrect, for the cotyledonary shoots have been seen in fresh material, and also underground pods in the herbarium specimens. Nothing definite can be yet reported concerning aerial flowers.

I consider, from observations that have been made, that *A. Pitcheri* is an extremely vigorous *A. monoica;* while *A. sarmentosa* represents the poorly nourished type.

A. Edgeworthii is a Himalayan species, differing little in appearance from *A. monoica*. Concerning those found in Mexico, nothing explicit could be learned.

Summary.

1. *A. monoica* is strictly annual under ordinary conditions.

2. There are two types of seed, aerial and subterranean. The aerial may be divided into (*a*) those resulting from purple flowers, (*b*) and (*d*) from cleistogamic ones.

3. Four distinct types of legume are developed (*a*) aerial, green lanceolate acuminate pods, containing three to four seeds; (*b*) aerial green oblong acuminate pods, containing two to three seeds; (*d*) aerial green, oblong pods, containing two seeds; (*c*) subterranean purplish one-seeded ovate pods.

4. In weight the subterranean pods exceed the aerial in the ratio of 40 to 1.

5. During winter a sharp dimorphism is noticeable in the plants resulting from germination of subterranean and aerial seeds. The form produced from the latter is a low-growing non-twining plant, that from the former is a tall vigorous twiner. During the summer, a dimorphism still exists, but not in so marked a degree. The aerial seed-plant is usually feebler in appearance, although it twines.

6. The normally hypogean cotyledons of all seeds, if placed so that they are exposed to light, develop chlorophyll.

7. Injury to the main stem below the simple leaves when a plant is young, causes cotyledonary shoots to develop. These normally negatively heliotropic and non-twining shoots become apogeotropic and twining.

8. Cotyledonary axillary runners if allowed to develop naturally, and then brought above ground, do not twine. If the main stem is destroyed after these shoots have reached a length of several inches, twining does not take place.

9. Axillary runners from the simple leaves (*i. e.*, first pair of green leaves) in their natural condition are geotropic and refuse to twine. When, however, the main stem is destroyed, these runners become apogeotropic and twine well.

10. Axillary shoots from compound leaves soon exhibit apogeotropic tendencies, and twine. If the main stem of the plant is destroyed, axillary shoots from any compound leaf will readily continue the twining habit of growth.

11. Circumnutation experiments show for *Amphicarpæa* the most rapid rate of movement known for a twining plant. A complete revolution may be made in 51 minutes. The optimum temperature is from 26° C. to 32° C.; the behavior is greatly modified by environmental conditions.

12. In early development numerous crystals appear in the cells forming the inner row of the cortex of the stem. These ultimately constitute a distinct crystal sheath. The crystals are somewhat prismatic in form, possessing an apparent partition across the middle. These twin structures occur also round the vascular areas of the leaves, and also in the cortex of the pulvini.

13. All green leaves are capable of assuming normal, paraheliotropic and nyctitropic positions. These positions are absolutely dissimilar.

14. When young, the simple leaves assume peculiar paraheliotropic and nyctitropic positions.

15. All leaflets manifest great activity during the night hours.

16. *Amphicarpæa* produces four types of flower: (*a*) purple aerial, (*b*) green aerial, (*c*) subterranean, (*d*) winter aerial. A comparison of these leads to the conclusion that the purple aerial is the original type, and that by a series of transitions through (*b*) and (*d*) the most reduced type (*c*) is reached. These variations are doubtless due to the environmental conditions under which they are produced.

17. Purple flowers are not produced during the winter, even though the greenhouse is kept at a high temperature. It is believed that the non-production of these flowers and

also the sharp dimorphism previously noted as existing in the winter between plants developing from aerial and subterranean seeds, is due to a want of sufficient light intensity.

18. The purple aerial flowers (*a*) are produced on the upper part of the plant from the latter part of July on to September. The green aerial (*b*) do not appear until the latter part of August, and they may be found in all stages—flower to fruit—as late as October. They are not so definitely located upon the plant as the purple flowers are. The production of the subterranean type begins in June and continues throughout the entire season.

19. The purple flowers (*a*) possess 10 diadelphous stamens, the filaments of the 9 being united almost the entire length; their anthers are similar and perfect. The green aerial (*b*) flowers have 10 stamens, distinct or with the filaments united into a short tube; these anthers exhibit varying degrees of imperfection. The winter flowers (*d*) have 10 stamens, which are distinct; four of these usually bear perfect anthers, the remaining stamens being quite rudimentary. The terrestrial flowers (*c*) have indications of 10 stamens (many of them exceedingly rudimentary), those which develop anthers vary from 6 to 4, and usually but 2 possess perfect anthers.

20. The thickened hypodermal layer (endothecium) present in the anthers of (*a*), is absent in anthers of the remaining types.

21. The microspores and macrospores of the three types of flower exhibit a gradual reduction in size.

22. A very complete series illustrating transitional reduction in styles and stigma may readily be obtained from a study of types *a*, *b*, *c*.

23. Flowers of type (*a*) are probably close fertilized, although there are present several devices associated with insect fertilization. The remainder are cleistogamic flowers; the pollen not being discharged from the anthers, but sending forth tubes toward the stigma.

24. Flowers of type (*a*) do quite frequently produce

legumes. Those of the remaining types rarely fail to produce fruit.

25. Legumes of types *a*, *b*, *d*, possess firm resisting walls, being provided with sclerenchymatous fibres. These fibres are absent in (*c*). But two types of hair are found upon legumes of types (*a*, *b*, *d*); they are more numerous upon (*d*) than upon the others. Three distinct types of hair are seen upon the surface of legumes of type (*c*). The stomata of the aerial and subterranean legumes also differ.

26. Aerial cleistogamic flowers or young legumes may be converted into the subterranean form of legume (c), if buried in the soil.

27. A plant raised from terrestrial seed is capable of bearing in summer, flowers of all three types—*a*, *b*, *c*.

28. The low-growing forms of *Amphicarpæa* found in the woods, which may be feeble twiners or non-twiners; and the taller, more vigorous specimens found upon the outskirts of the woods, are believed to be varieties due to environment and not distinct species as some have supposed.

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EXPLANATION OF PLATES.

PLATE XIX.

Roots of three plants, showing legumes and tubercles; from photograph.

PLATE XX.

Fig. 1. Terrestrial legume; one-seeded type, natural size.
Fig. 2. Terrestrial legume; two-seeded type, natural size.
Fig. 3. Transverse section through seed-coat of terrestrial seed.
Fig. 4. Legume of purple flower; immature condition; slightly reduced.
Fig. 5. Legume of purple flower; mature condition; slightly reduced.
Fig. 6. Legume of green aerial flower; slightly reduced.
Figs. 7 and 8. Legumes of winter type of aerial flower; slightly reduced.
Fig. 9. Transverse section through seed-coat of seed of aerial type.

PLATE XXI.

Plants of the same age; one raised from terrestrial seed, the other from aerial seed; from photograph.

PLATE XXII.

Lower portion of a plant, showing axillary shoots, which were raised from their normal position, and supported by means of thread; from photograph.

PLATE XXIII.

Fig. 1. Plant a few days after truncation had taken place.
Fig. 2. Plant in twining condition; from photographs.

PLATE XXIV.

Fig. 1. Transverse section of very young stem.

Fig. 2. Transverse section of older stem.

Fig. 3. Transverse section of still older stem.

Fig. 4. Transverse section of stem about the age of that shown in Fig. 2—much magnified.

Fig. 5. Portion of leaf, showing vascular bundle, containing crystals. All figures from photo-micrographs.

PLATE XXV.

Fig. 1. A fair-sized plant showing leaves in paraheliotropic position.

Fig. 2. Young plant showing leaves in paraheliotropic position.

Fig. 3. Young plant showing leaves in nyctitropic position: from photographs.

PLATE XXVI.

Plant showing position of leaves at 11 P.M; from photograph.

PLATE XXVII.

Fig. 1. Racemes of purple flowers, showing manner of growth.

Fig. 2. Compound raceme of purple flowers.

Fig. 3. Transverse section of a purple flower-bud. Figs. 1 and 2 from photographs; Fig. 3 from photo-micrograph.

PLATE XXVIII.

Fig. 1. Transverse section of purple flower-bud showing nectary.

Fig. 2. Transverse section of ovary of green aerial flower.

Figs. 3 and 4. Transverse section; longitudinal section of terrestrial flower-bud; from photo-micrographs.

PLATE XXIX.

Fig. 1. Stamens and pistil from green aerial flower. × 35°.

Fig. 2. An enlarged anther from green aerial flower. × 75°.

Fig. 3. Stamens and pistil from terrestrial flower. × 35°.

Fig. 4. Stages of staminal reduction from terrestrial flower; 1 consists of filament only, 2 and 3 possess imperfect anthers, 4 is perfect. × 75°.

Fig. 5. Microspores from terrestrial flower. × 350°.

PLATES XXX AND XXXI.

Series of styles and stigmas showing transitional reduction, taken from three types of flower. Drawn to same scale.

Figs. 1 and 2. From terrestrial flower.

Figs. 3–7. From green aerial flower.

Fig. 8. Immature form, purple flower.

Fig. 9. Mature form, purple flower; drawings from photo-micrographs.

PLATE XXXII.

Fig. 1. Thickened roots of plant; slightly reduced.

Fig. 2. Pistil of purple flower. × 18°.

Fig. 3. Pistil of green aerial flower. × 18°.

Fig. 4. Pistil of terrestrial flower. × 18°.

PLATE XXXIII.

Axillary shoot showing arrangement of the winter legumes; from photograph.

PLATE XXXIV.

Fig. 1. Stoma from aerial legume. × 350°.

Fig. 2. Epidermal hairs from terrestrial legume. × 250°.

Fig. 3. Hair with glandular base from terrestrial legume. × 250°.

Fig. 4. Stoma from terrestrial legume. × 350°.

PLATE XXXV.

Fig. 1. Low-growing plants raised from terrestrial seeds; from photograph.

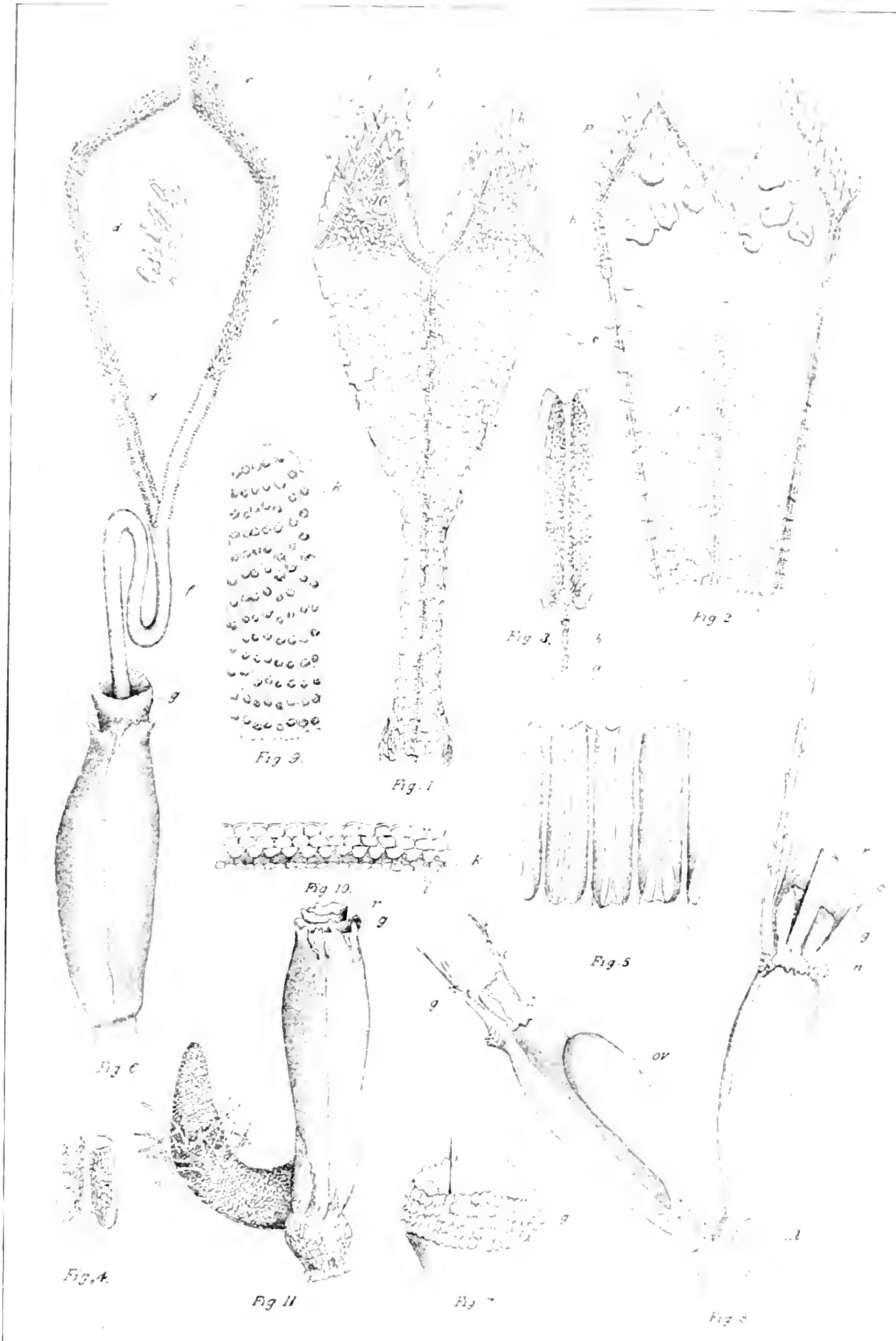
Fig. 2. Plant raised from aerial seed, bearing terrestrial seeds; from photograph.

Fig. 3. Cotyledonary region of plant, showing the arrangement of terrestrial legumes; from photograph.

PLATE XXXVI.

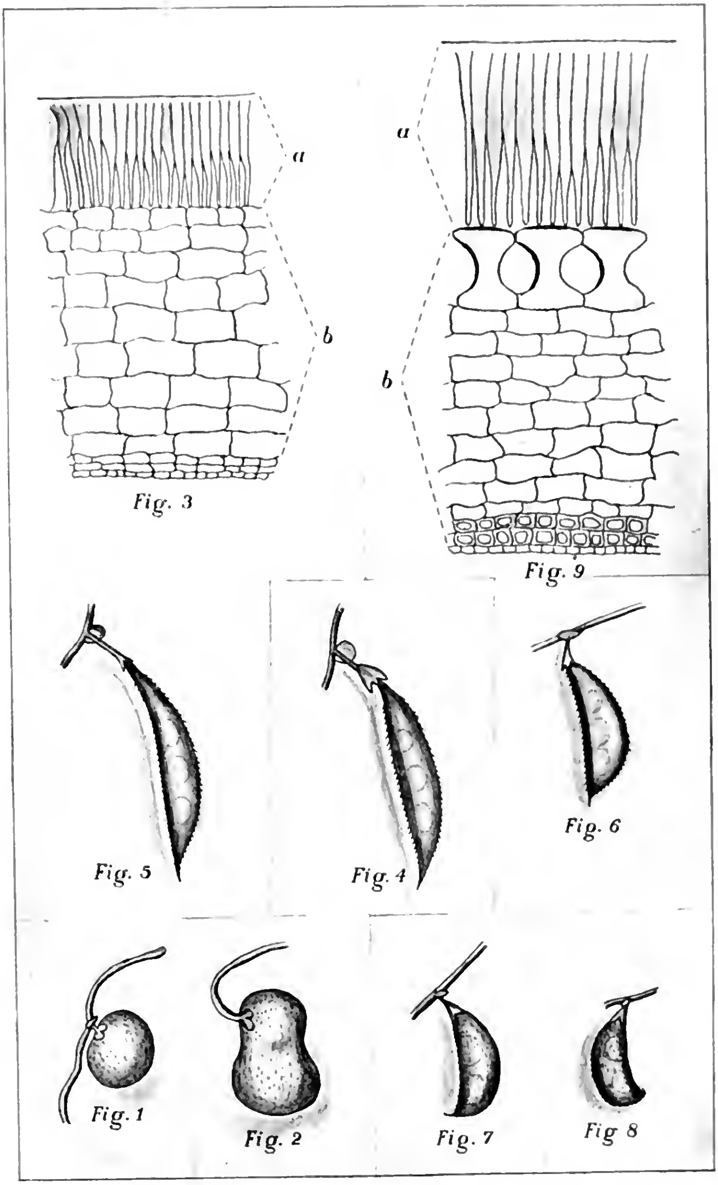
Fig. 1. Cotyledonary region of plant showing all stages of flowers and legume formation; from photograph.

Fig. 2 Cotyledonary region of plant showing cotyledons spread open and axillary shoots arising; from photograph.



CROSS ON EUPATORIUM.

SCHIVELY ON AMPHICARPÆA.



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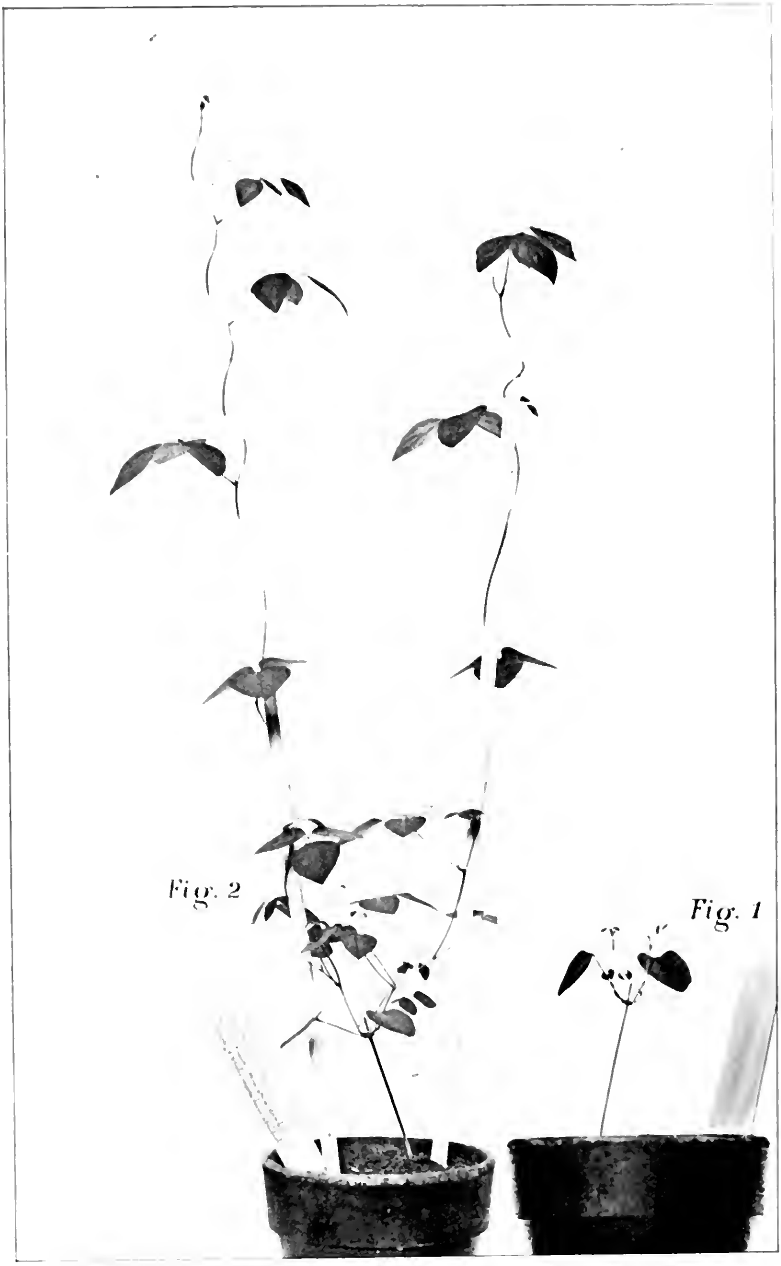

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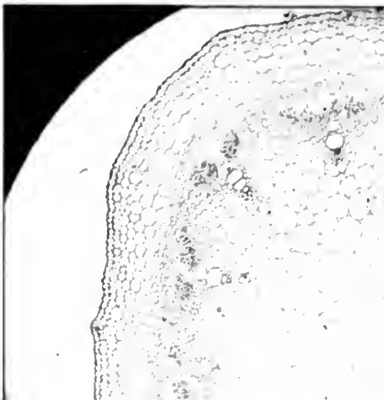

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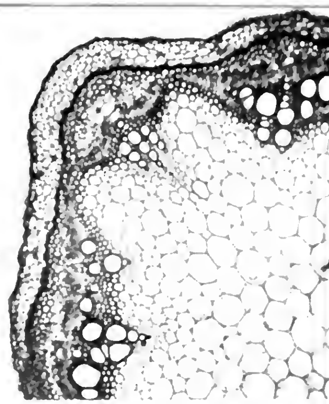

Fig. 2.

Fig. 3.

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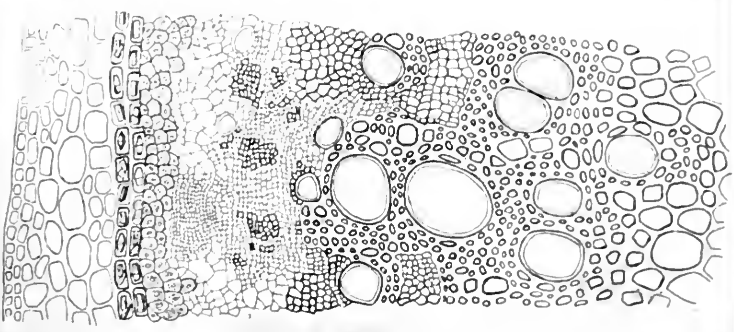

Fig. 4.

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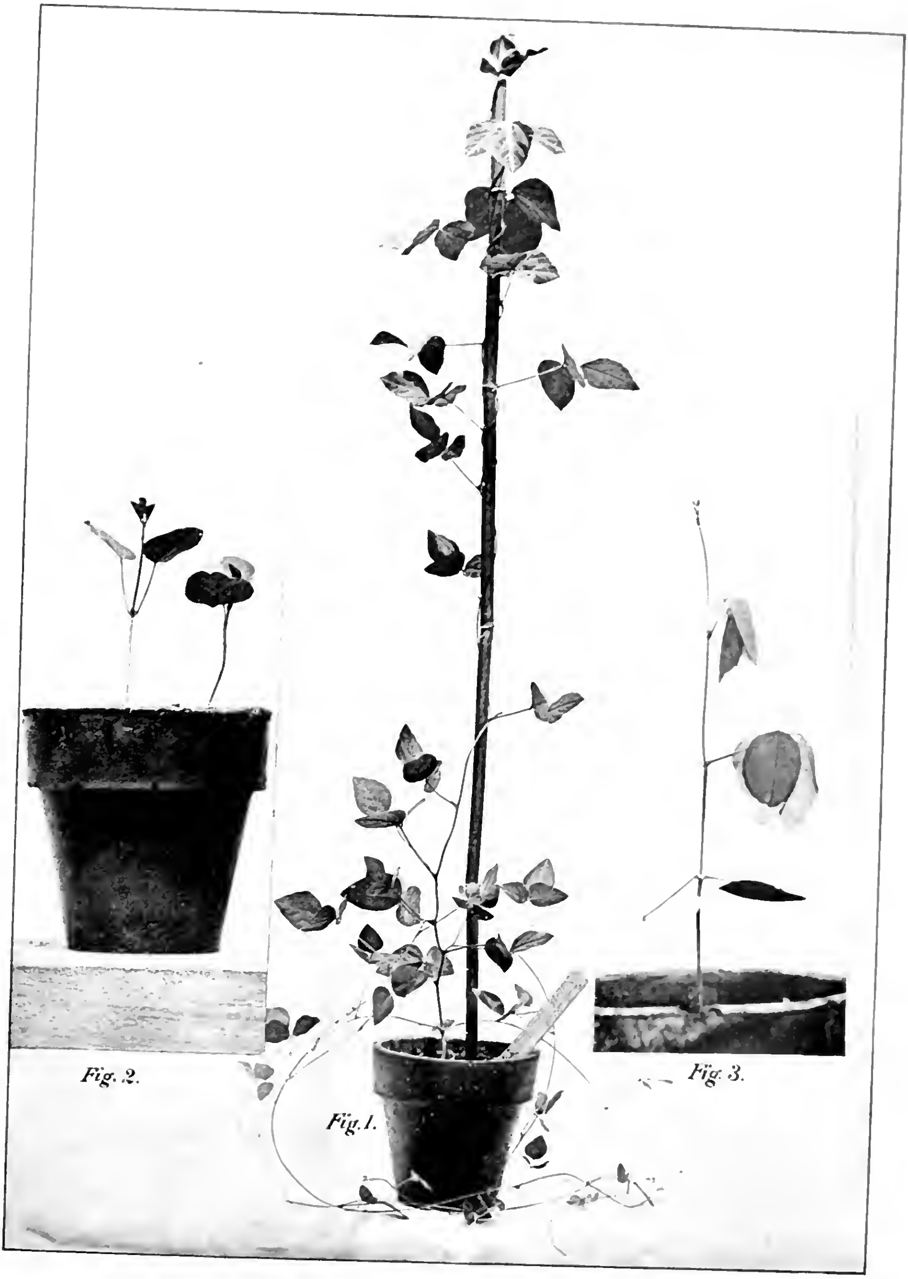


SCHIVELY ON AMPHICARPÆA.

SCHIVELY ON AMPHICARPÆA.

Fig. 1

Fig. 2

Fig. 3

SCHIVELY ON AMPHICARPAEA

Fig. 1

Fig. 2

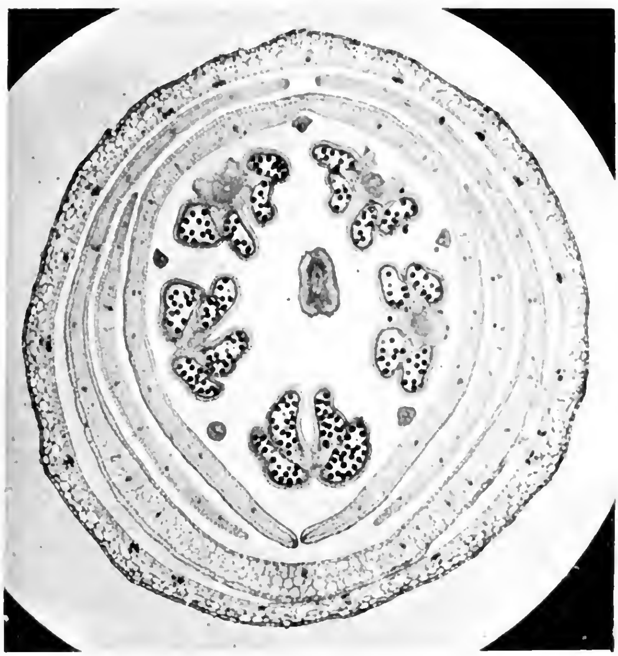


Fig. 3

SCHIVELY ON AMPHICARPÆA.

Fig. 1

Fig. 3

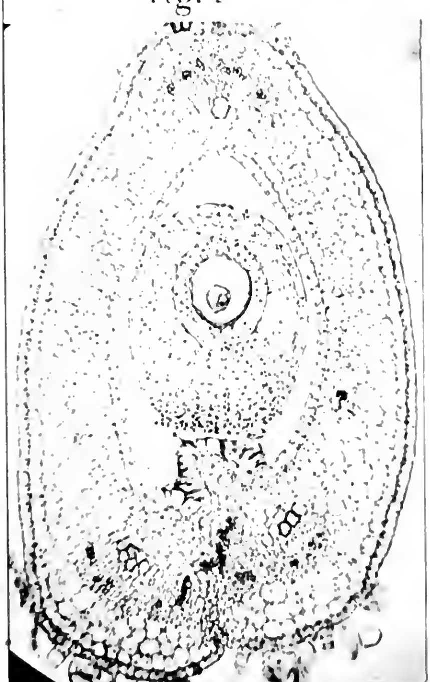
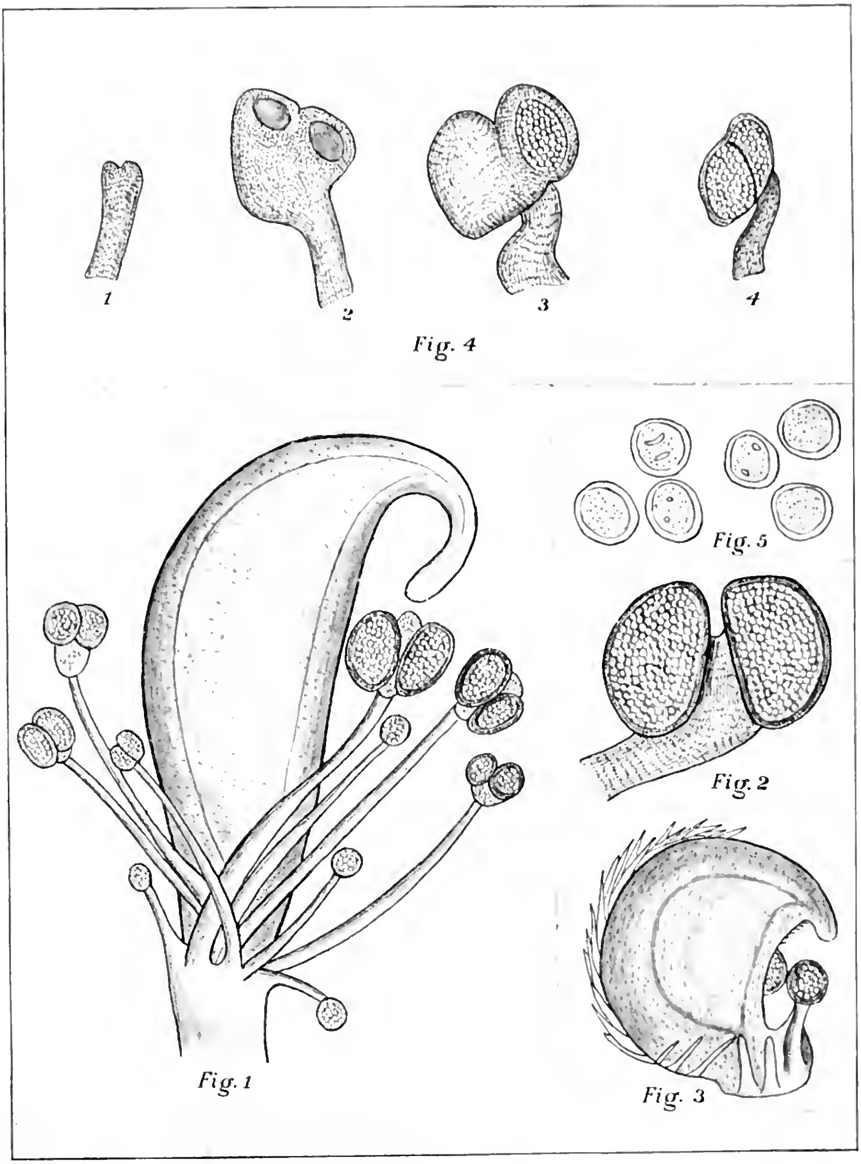


Fig 2

Fig. 4

SCHIVELY ON AMPHICARPÆA.



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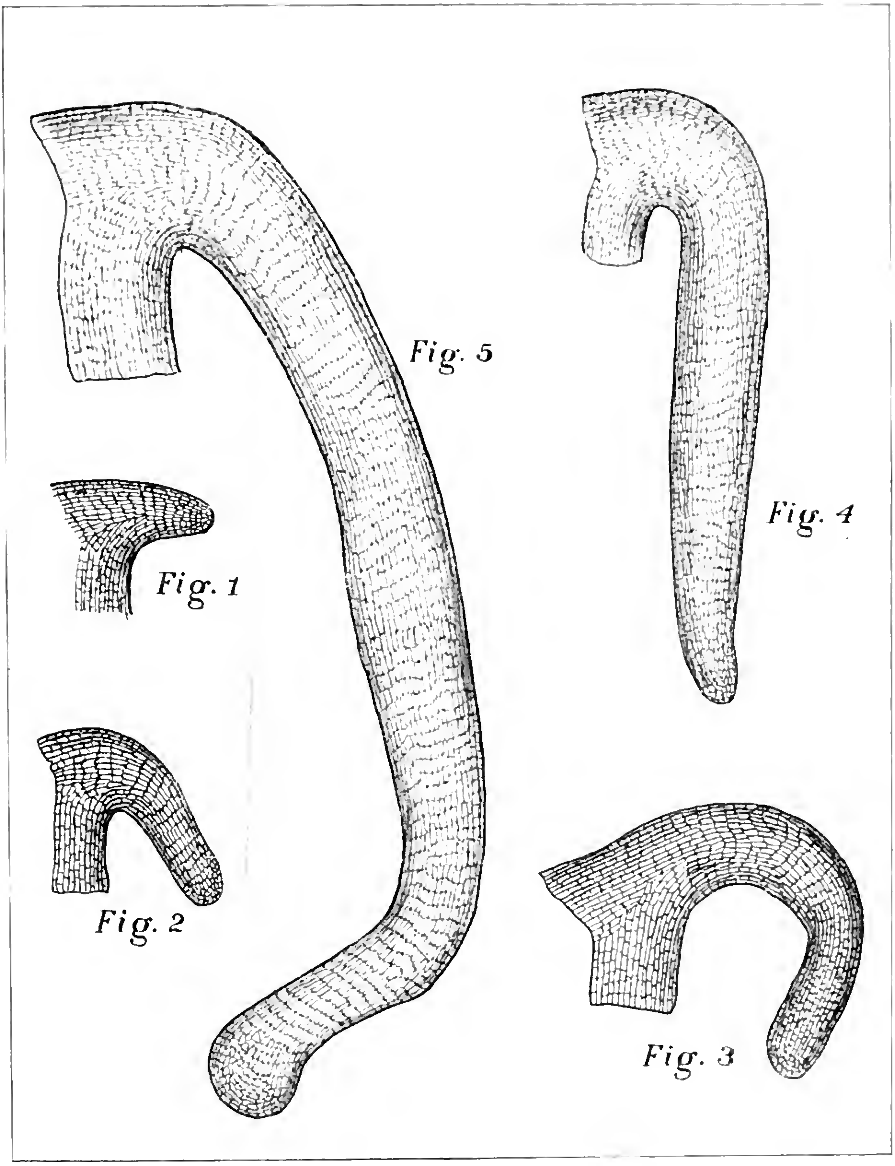

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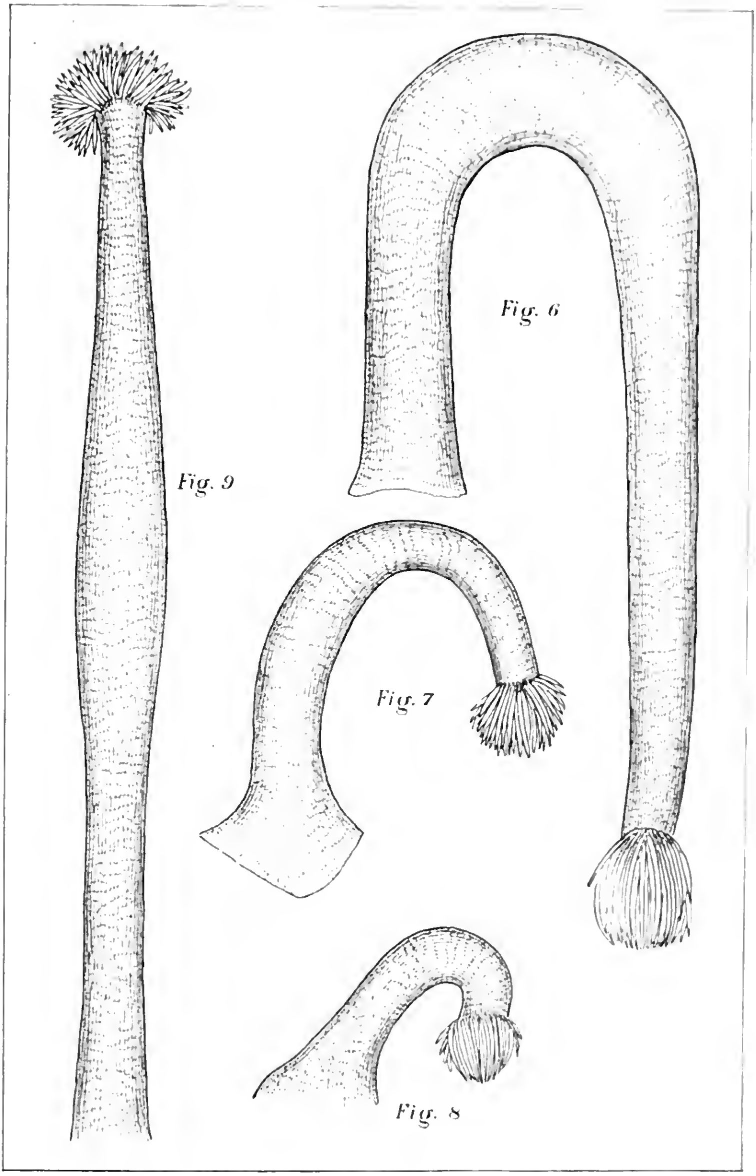

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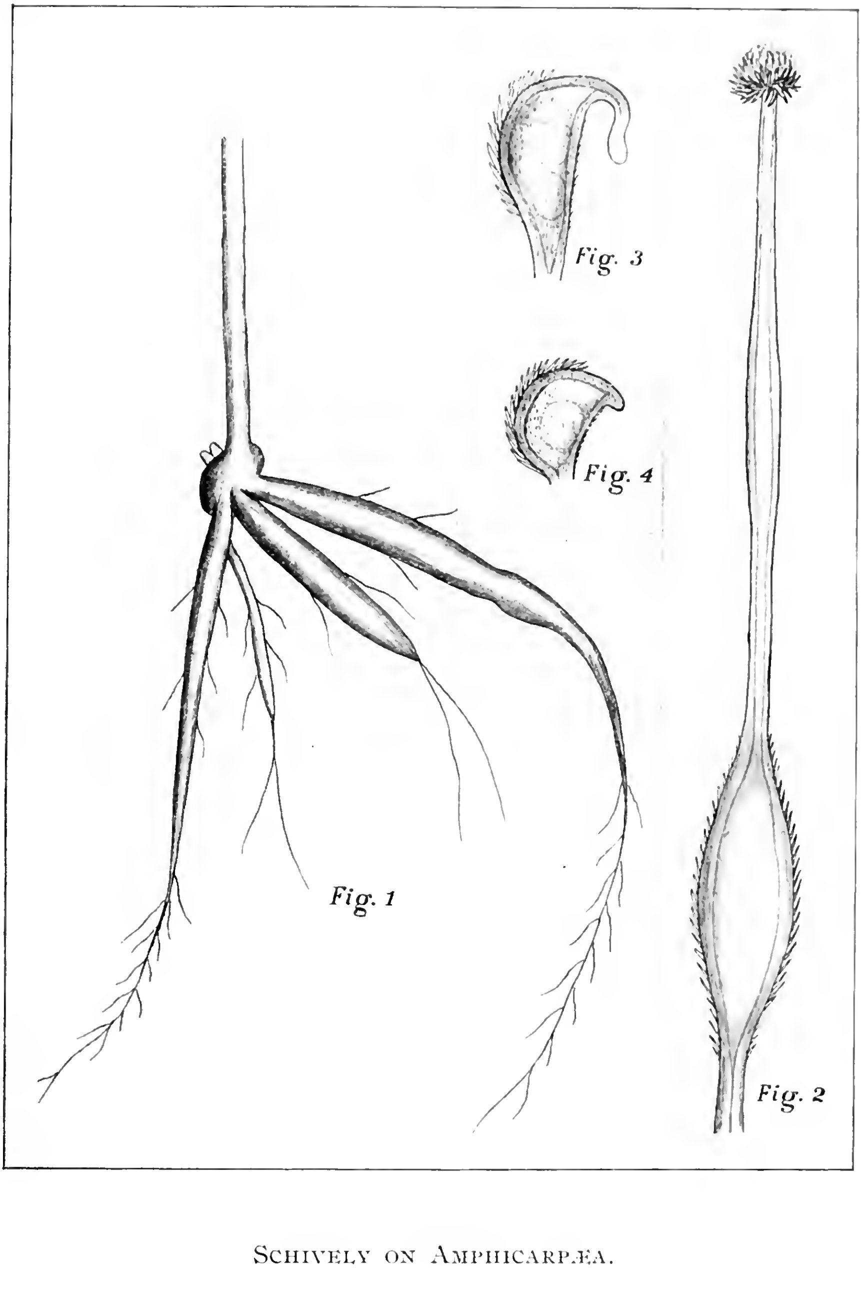

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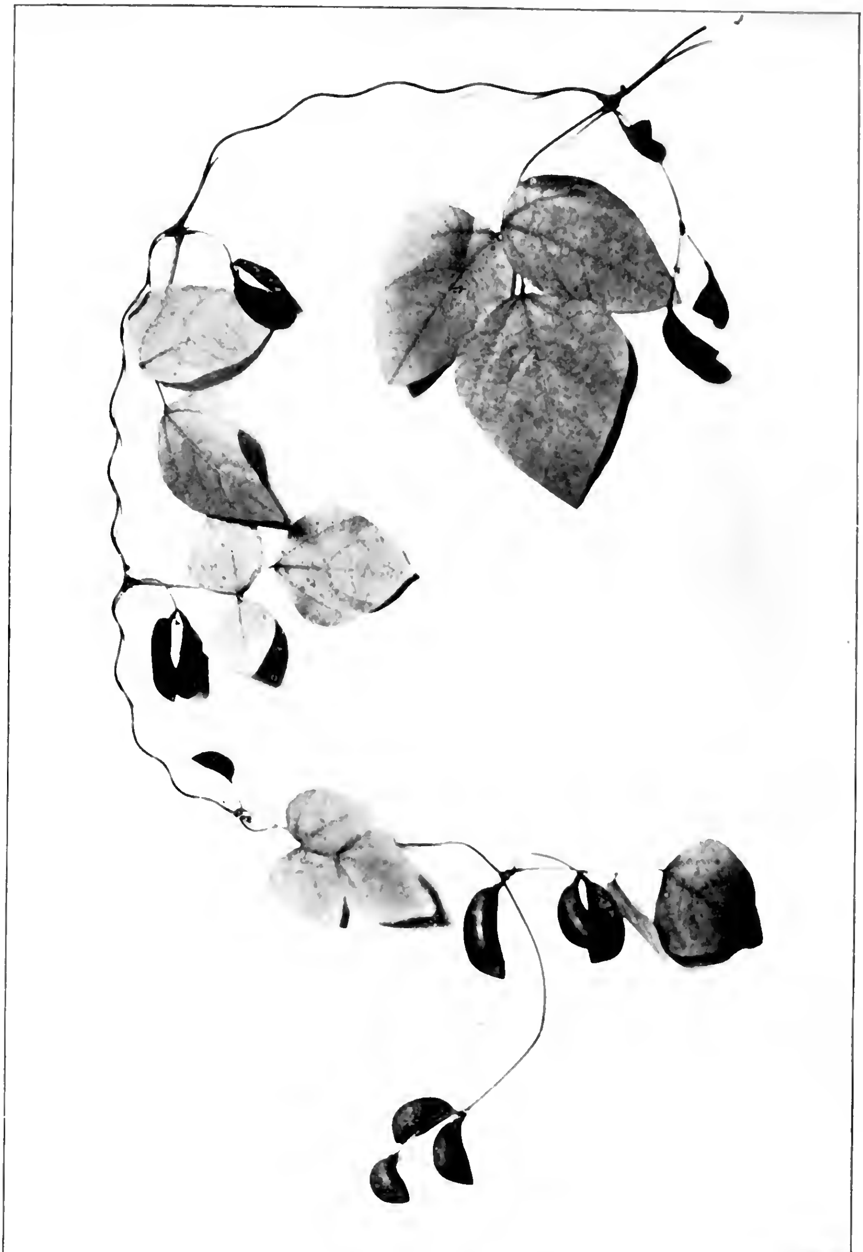

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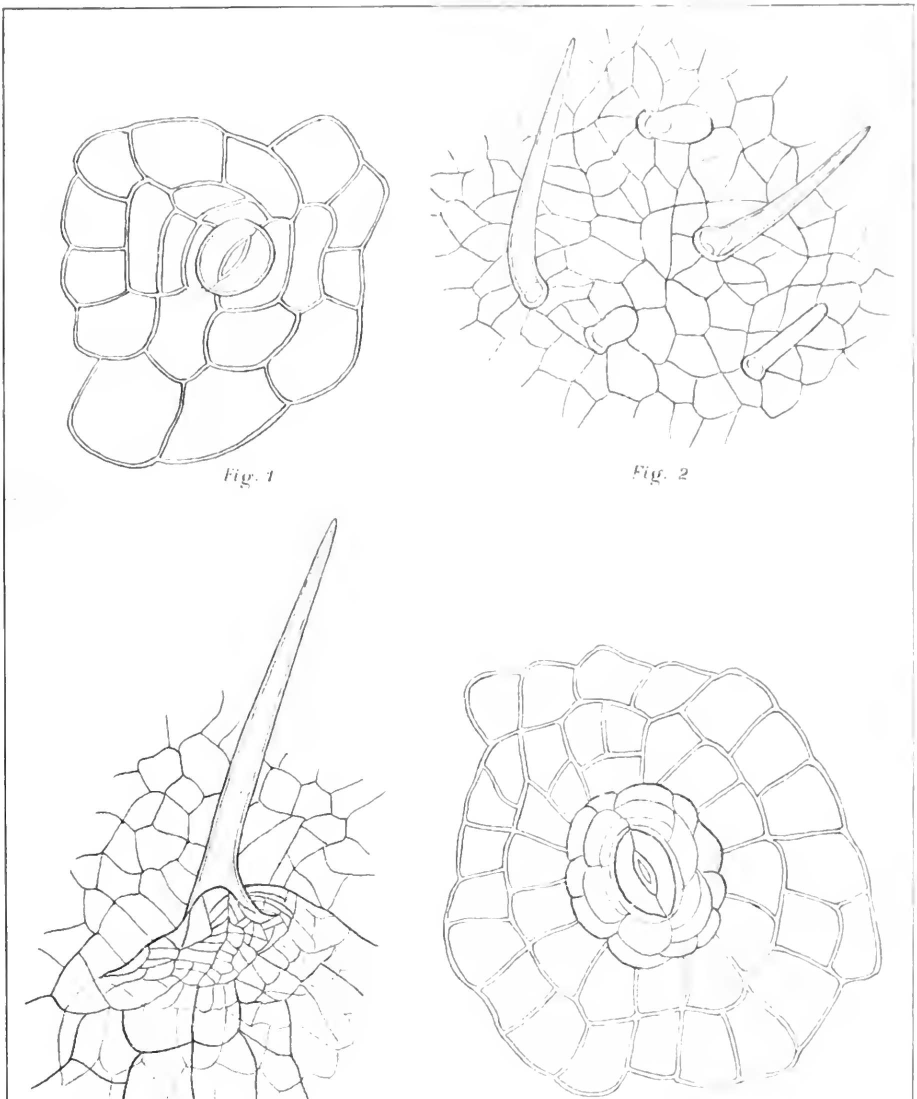
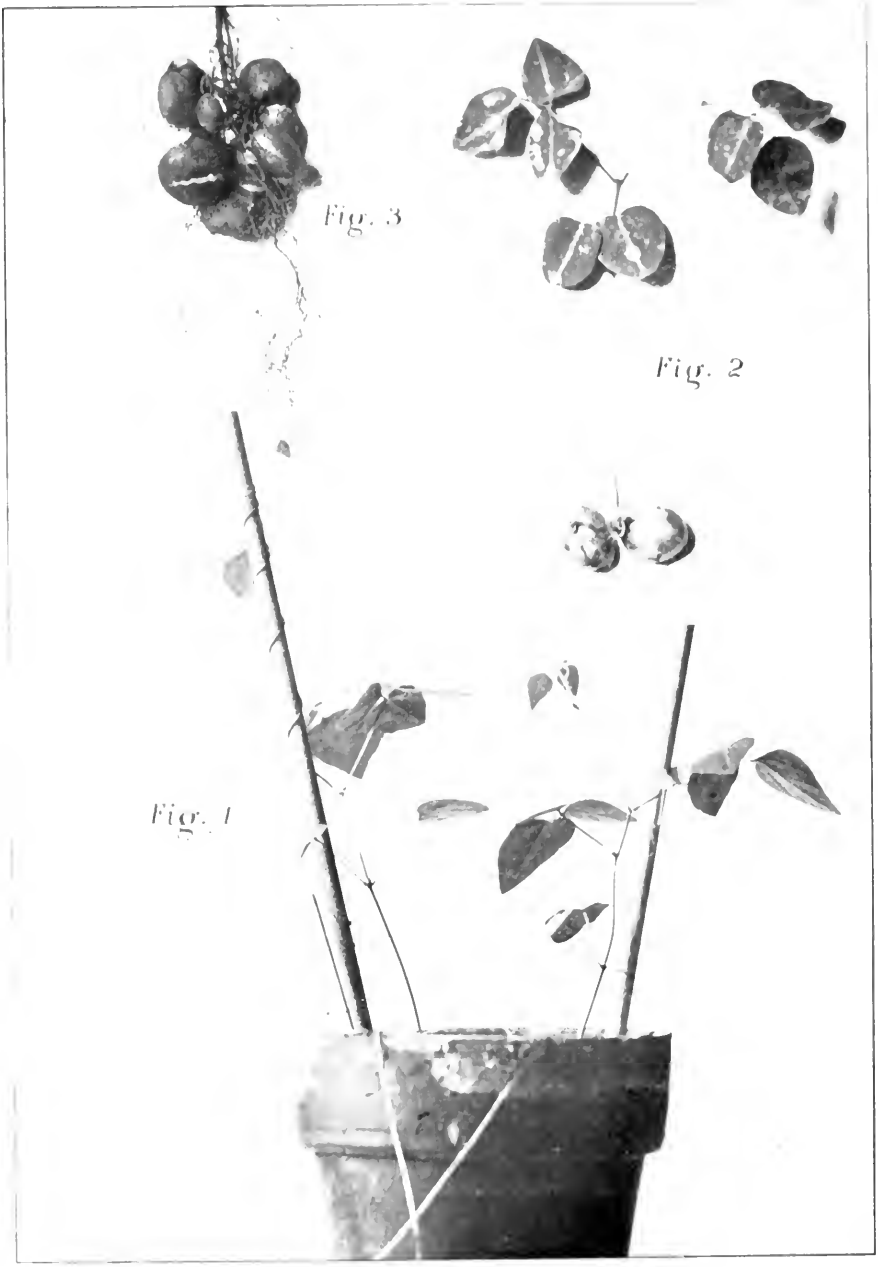


Fig. 1 Fig. 2 Fig. 3 Fig. 4

SCHIVELY ON AMPHICARPÆA.



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