Geotropic Sensitiveness of the Root-tip [1].

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A RADICLE placed horizontally bends, as is well known, until its tip points vertically downwards, that is until it has attained its normal position of equilibrium. This geotropic movement is occasioned by gravitation, which however merely operates as a stimulus; that is, it affords the impulse in obedience to which the plant executes the necessary movement of curvature by means of the factors of growth at its command.

In principle then, the case is something like that of a man in darkness to whom a single lingering ray of light gives in the same way the impulse to so change his movements as to make his way towards the light. It is plain that the processes involved in the movement by which such an act is accomplished are to be distinguished from the perception of the stimulus. Furthermore, as is well known in the case of the higher organisms, and as also frequently occurs in plants the sensitive organ may be separated by some distance from the organs that perform the external action.

Such a relation exists in the root, in which the tip alone is geotropically sensitive. The root-tip therefore is the part

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that perceives the geotropic stimulus, and, as a result, enables the adjacent parts, that are themselves not sensitive, to carry out the geotropic curvature.

The geotropic reaction of the root was first conceived of in this way by Ch. Darwin [1] in the year 1880. Absolute proof of this view, to be sure, was not obtained by Darwin, nor has it been by the studies of other investigators [2]. As a matter of fact, however, Darwin's assumption is right, as is irrefutably proved by investigations that have recently been conducted under my direction by Dr. Czapek.

All previous investigations have been inconclusive because they were judged of by the results that followed cutting off the tip of the root. But by the infliction of such a wound the previous capacity for reaction may be suspended or destroyed. If then the root, after removal of the tip, no longer reacts geotropically, it is still wholly undetermined whether this result is occasioned by the want of the sensitive root-tip, or by the fact that through the infliction of the wound the geotropic sensitiveness has been suspended.

That such a suspension of the capacity for reaction may occur is shown very clearly by investigations on heliotropic sensitiveness which Professor Rothert [3] conducted in the Leipsic botanical institute. It was found, among other things, that the young cotyledon of *Avena sativa* is heliotropically sensitive throughout, but especially so at the tip. An heliotropic curvature of the uninjured leaf follows, therefore, as well when the tip alone, as when the middle of the leaf alone, is exposed to light. But if a small piece is cut off from the leaf-tip, the leaf becomes indifferent to illumination from one side, and only after one or two days, that is after the reaction due to wounding has ceased, does the sensitiveness return.

[1] The Power of Movement in Plants, 1880, p. 523.

[2] Among those who have studied the question are Detlefsen, Wiesner, Fr. Darwin, Kirchner, Krabbe, Brunchorst, Fritsch. The literature is given by Brunchorst, Berichte d. deutsch. botan. Gesellschaft, 1884, p. 79.

[3] Berichte d. deutsch. botan. Gesellschaft, 1893, p. 387.

But with this object it is possible to demonstrate with certainty that only the capacity to perceive the stimulus has been lost by wounding, but not the capacity to conduct a stimulus already perceived. For if we expose the tip of a leaf to light for only a short time, and cut it off before curvature is noticed, the heliotropic reaction takes place in the wounded leaf precisely as in an uninjured one, although through wounding the sensitiveness of the leaf has been suspended.

In an entirely analogous way, a reaction manifested in geotropic curvature takes place in roots when they are decapitated after geotropic induction. That, however, only proves that an actual geotropic induction is not necessarily connected with the continual existence of sensitiveness. The attempts made to prove from this fact the sensitiveness of the root-tip are in so far based on incorrect inferences.

As regards heliotropism the state of things is easily demonstrated, since the rays of light that act as a stimulus can easily be directed to a single point. On the other hand, it can hardly be thought of as practicable to expose the root-tip alone to the stimulus of gravitation, or in place of this to centrifugal force. We attained the end in another way, however, namely by compelling the tip of a root, whilst growing quite normally, to permanently take up a position at right angles to the rest of the root.

For this purpose we allowed roots of *Faba*, *Lupinus*, &c., to grow into short tubes of thin glass that were bent at a right angle. The advancing root easily follows the bend of the tube and pushes on as far as the other end which has been closed by heat. Corresponding to the shape of the glass, there is now a terminal portion of the root, 1, 5 or 2 mm. long, at right angles to the rest of the root, of which again 1, 5 or 2 mm. occupies the other arm of the tube. This condition of things is continuously maintained, since, with its growing region in the tube, the older parts of the root, like plastic wax, are pushed out of the glass cap.

To prevent geotropic stimulus, the roots were made to

revolve slowly about their own axis on a klinostat, while they were growing into the tubes. If now a specimen thus prepared is placed so that the terminal part points vertically downwards, whilst the rest of the root is horizontal, no geotropic curvature takes place. This, however, always took place, and with about the same promptness as in straight roots, when the terminal portion was directed horizontally, or in general at an acute angle with the normal position.

From these experiments it follows that the root thus treated is perfectly capable of reaction. A geotropic reaction, however, only follows when the tip of the root is not placed in the position of equilibrium, that is when it is inclined from the vertical. But if the tip is directed vertically downwards, the rest of the root may occupy the horizontal or any other position, without any geotropic reaction following.

By this means therefore it is proved with the most perfect certainty, that in an uninjured root only the root-tip is geotropically sensitive.