

POLAR ROOT FORMATION

by

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Preface.

In the year 1900 a circumstantial investigation was published by Noll on the formation of lateral roots on a curved tap root.

He drew attention to the fact that lateral roots on a curved tap root always arise from the tap root on the convex side of the curvature. The manner in which the curvation has originated is of no importance.

The phenomenon is to be seen both with geotropically, hydro-tropically and phototropically and with mechanically curved roots.

It is only the very young roots just in course of formation which undergo the influence of the curvation. The lateral roots which are a little older are not affected by the curvation of the tap root; they commonly go on growing on the concave side of the curvature as well as on the convex side.

By anatomical investigation of the curved root Noll ascertained

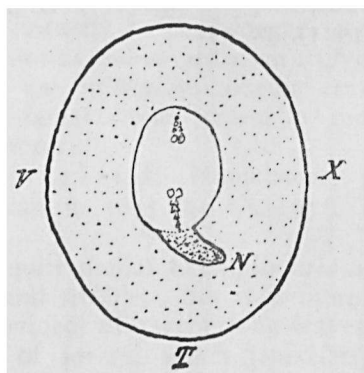


Fig. 1. Transverse section through a curved lupine root. V concave side, X convex side. A lateral root N originally formed on the transversal side T bends with a sharp curvature in the tissue of the tap root to the convex side. After Noll 1900.

that the appearance of the lateral roots on the convex side of the curvature only has two causes. In the first place no rudiments of lateral roots are formed on the concave side, and secondly the young lateral roots in the tissue of the tap root curve to the convex side of it.

The two following figures, adopted from Noll, demonstrate the phenomenon.

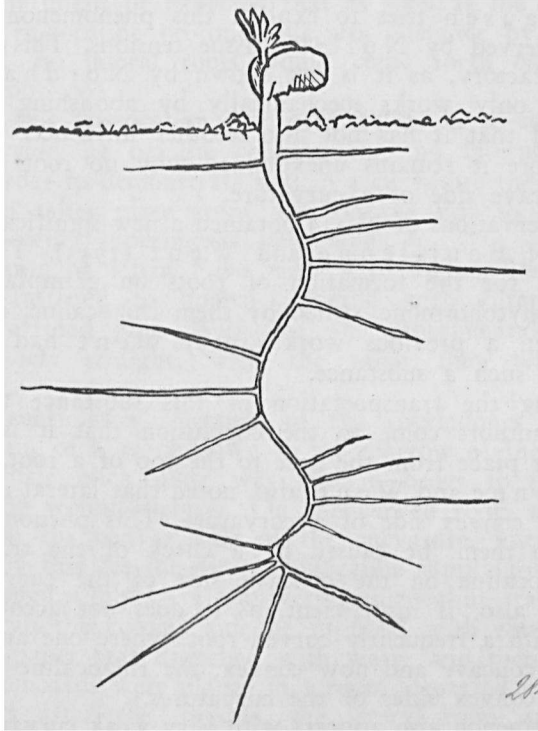


Fig. 2. Scheme of a curved tap root; lateral roots arising on the convex side. After Noll 1900.

Noll cannot give a good explanation of this phenomenon. He says that a plant has a specific perceptivity for the transformation of its own physique. He calls this „Morphästhesie” and compares this power with the phenomenon of the autotropy, the tendency to restraighen a curved organ.

The question of the direction of the growth of lateral roots observed by Noll, was again raised by Nordhausen in 1907. Nordhausen investigated the influence of wounds

of the tap root on the growth direction of the lateral roots. He made the wounds mostly by pricking a small hole in the tap root with a red-hot glass needle. He observed that the young lateral roots below the wound curved away from the wounded spot in the tissue of the tap root. This wound-influence asserted itself down to $\frac{1}{2}$ —1 cm below the wound, sometimes over a distance of several centimetres.

Nordhausen tries to explain this phenomenon as well as the one observed by Noll, by tissue tensions. This explanation is not satisfactory, as it is not shown by Nordhausen that the wound only works mechanically by abolishing the texture-tension, and that it has not also another influence.

Furthermore it remains unexplained why no roots are formed on the concave side of a curvature.

These observations of Noll obtained a new significance through the work of Bouillenne and Went (1933). They demonstrated that for the formation of roots on germplants and on cuttings a phytohormone, called by them rhizocaline, is necessary.

Already in a previous work (1929) Went had shown the existence of such a substance.

Concerning the transportation of this substance through the plant, the authors come to the conclusion that it is polar, i.e. that it takes place from the base to the top of a root.

Bouillenne and Went, also, noted that lateral roots always arise on the convex side of a curvature. This phenomenon must, according to them, be caused by a check of the transportation of the rhizocaline on the concave side of the curvature. This explanation, also, is insufficient, as it does not account for the fact that, with a frequently curved root, where one and the same side is now concave and now convex, the rhizocaline accumulates just on the convex sides of the curvatures.

The phenomenon also appears with very weak curvatures, where the supposed check can certainly be deemed impossible.

They also give no explanation for the curvation of the young lateral root in the tissue of the tap root, which curvation contributes in such a high degree to the fact that the lateral roots, which originate in a curvature, come out on the convex side of it.

An explanation of the phenomenon observed by Noll must give an answer to the question why the rhizocaline accumulates on the convex side of a curvature, in consequence of which the young lateral roots develop there. Secondly, also the curvation of the lateral roots, which arise between the convex and the concave side, must be explained.

Experimental Part.

1. *Experiments on the transportation of the rhizocaline.*

According to Bouillenne and Went (1933) the rhizocaline is formed in the leaves and leaf-buds, and is transported towards the apex in the root.

Therefore it might be expected that as soon as the transportation of the rhizocaline on one side, for instance by a wound, was checked, no lateral roots would come forth on that side of the tap root.

Evidently this rhizocaline transport bends in a curvature to the convex side, as on the concave side no lateral roots are formed. In order to demonstrate that in a curvature the rhizocaline transportation takes place from the concave side to the convex side, the following experiments were made.

Young plants of *Vicia Faba* with 8 to 10 cm long, straight roots were fastened to boards, covered with filter-paper, by help of paraffined pins. With the one experimental series the roots were left straight, with the other they were curved mechanically.

At some centimetres' distance of the cotyledones a cut was made by means of a razor down to the marrow of the root. Into this cut a little mica plate was laid in order to prevent the contact of the wound-surfaces. On the curved roots this incision was made on the convex side of the curvature, just above the bend. Thus by this cut the direct rhizocaline supply to the convex side was stopped. Only by a transversal rhizocaline transport over the wound can the convex side be supplied with rhizocaline.

The filter-paper was drenched with water and then the young plants on the boards were placed in a room saturated with vapour.

Some days after the incision, the lateral roots appeared on the tap root. The number of lateral roots that came forth within a fixed distance below the wound was counted as well on the wounded side as on the intact one.

The result of these experiments is put down in table I and in table II.

In table I we see the influence of the wound on straight roots, and in table II the influence of the wound on curved roots.

In table I it will be seen that on the straight root fewer lateral roots have come up on the wounded side than on the unhurt side; this amounts to 15 on the wounded side in comparison with 57 on the unhurt side.

Table I.

The influence of a one-sided wounding on the number and on the place of origin of the lateral roots on a straight root of *Vicia Faba*.

Root No.	Distance from the wound to the cotyledones	Number of lateral roots on the wounded side	Number of lateral roots on the unhurt side	Distance from the wound to first lateral root on the wounded side	Distance from the wound to first lateral root on the unhurt side	Distance in which the roots are counted
1	20 m.m.	3	9	3 m.m.	1 m.m.	25 m.m.
2	20 "	0	9	25 "	1 "	25 "
3	18 "	8	11	5 "	1 "	25 "
4	15 "	0	10	25 "	3 "	25 "
5	15 "	3	7	14 "	0 "	25 "
6	35 "	0	3	20 "	1 "	20 "
7	20 "	0	2	15 "	2 "	15 "
8	20 "	1	5	33 "	6 "	35 "
		Sum total 15	Sum total 57	Average: 17,5 m.m.	Average: 1,8 m.m.	

Table II.

The influence of a one-sided wounding, made on the convex side of a curved root of *Vicia Faba*, on the number and on the place of origin of the lateral roots.

Root No.	Distance from the wound to the cotyledones	Number of lateral roots on the wounded side	Number of lateral roots on the unhurt side	Distance from the wound to first lateral root on the wounded side	Distance from the wound to first lateral root on the unhurt side	Distance in which the roots are counted
1	30 m.m.	8	6	1,0 m.m.	1,0 m.m.	25 m.m.
2	10 "	13	6	1,5 "	0,5 "	25 "
3	18 "	6	13	4,0 "	1,0 "	20 "
4	23 "	6	1	5,5 "	11,0 "	28 "
5	12 "	8	3	3,0 "	10,0 "	25 "
6	15 "	6	6	4,0 "	5,0 "	30 "
7	25 "	4	2	6,0 "	7,0 "	15 "
		Sum total 51	Sum total 37	Average: 3,5 m.m.	Average: 5,0 m.m.	

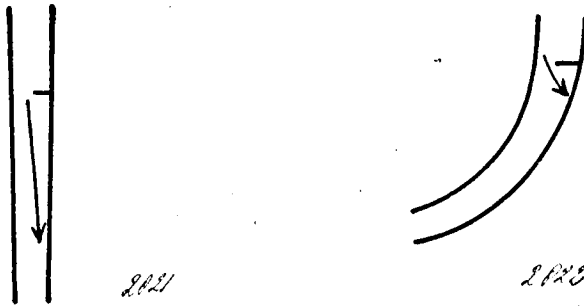
On the straight root the first lateral root on the wounded side stands at a rather great distance below the wound; this distance is 17,5 mm on an average.

Table II shows that the influence of the wound upon a curved root is quite different.

The number of lateral roots on the wounded side, i.e. the convex one, amounts here to 51 in comparison with 37 on the unhurt side. The distance from the first lateral root on the wounded side up to the wound amounts to 3,5 mm on an average.

Experiments were also made with the roots of *Phaseolus multiflorus*, which gave exactly the same result. It follows thus from these data that after wounding on a straight root the rhizocaline transportation is checked. On the curved root however a rhizocaline transport took place round about the wound from the concave to the convex side.

In diagram this rhizocaline transport is marked by the hands in Fig. 3 and Fig. 4.



From these experiments I therefore conclude that in the tissue of a curved root a transversal polarity exists, which causes the rhizocaline transportation to take place on the convex side of the curvature.

2. *The demonstration of the transversal polarity.*

Thus the curvature of a root causes a transversal polarity in the curvature, in consequence of which a transversal transportation of rhizocaline to the convex side takes place.

It is conceivable that the curvature of the young lateral roots in the tissue of the tap root is also caused by the same transversal polarity. Here we think of a displacing of the growth-substance, which may cause the difference in the growth-celerity on both sides of the lateral root.

Though this transversal polarity in consequence of the displacing of the rhizocaline transport has already been demonstrated, I have tried to define it still further. Several authors

are of the opinion that a polar substance-transport is caused by a potential difference existing in the plant; Keller (1931, 1932) Wertheimer (1924) and Wowski (1931).

Went (1928), and van der Wey (1932) demonstrated that the transport of the growth-substance is polar.

After it was shown through the investigations of Kögl and Haagen Smit (1931), that growth-substance is a one-basic aliphatic acid, it was probable, that the transport of the growth-substance would also take place under the influence of an electric potential difference. The hypothesis that with the photo- or geotropical reaction a transversal transport of the growth-substance takes place, in consequence of the photo-geotropically induced electric polarization of the tissue, was advanced by Cholodny in 1927 and by Dolk in 1930. The same idea was elaborated by Went (1932) to his „Botanisch-Polaritätstheorie“.

His experimental support of this theory however is not very cogent.

A better foundation is provided for this theory by the work of Brauner (1927), Brauner and Bünning (1930), Am-long (1933) and Koch (1934).

Especially after Thimann and Went (1934) had shown that rhizocaline, also, is an organic acid according to the nature of the growth-substance, it was permissible to suppose here a polar transport of the rhizocaline, in consequence of a potential difference in the tissue. Went (1934) also ascertained experimentally that rhizocaline moves towards the positive pole. Schechter (1934) obtained a similar result for the rhizoid formation in the red algae.

I had not the electric measuring-instruments and electrodes necessary to demonstrate such a contingent potential difference at my disposal. I therefore resorted to the simpler colouring-method according to the school of Keller, see Keller 1932 and Keller 1929. „Elektrostatistik in der Biochemie“. Kolloid. Chem. Beih. Bd. 28, Gicklhorn and Keller 1932 and Umrath 1928. The purpose of this investigation was thus to demonstrate a contingent potential difference in transversal direction between the convex and the concave side in the curvature of a curved root.

If this potential difference existed, then it was to be expected that the colouring substance would be absorbed more on the convex than on the concave side or vice-versa, according to its electric nature.

I used young germ-plants of *Vicia Faba* with geotropically curved roots.

The young plants were fastened to boards by means of parafined pins and then dipped entirely into the coloured liquid.

After 15-24 hours the colouring-result was examined. During this time the plants in the eosine-solutions were standing in the dark, those in the other solutions in the light.

In most cases a qualitative difference in the colouring between the convex and the concave side could be distinctly perceived.

In order to be able to judge of this difference in the colouring as objectively as possible, the number of the coloured cell-series of the rind-tissue was counted from within to without. In the tables at foot the colouring substances used and their concentration, as well as the number of the coloured cell-series on the convex and on the concave side of the curvature, are set forth.

The classification of the colouring substances is adopted from the tables of Keller (1932) and from Keller and Gicklhorn (1932). In table III the cathode colouring substances are inserted. It will be seen that these colouring substances accumulate most on the concave side of the curvature.

Most of these experiments were made with eosine.

The concave side is not always more coloured than the convex one. I think that this must be ascribed to an unequal penetration of the colouring substance, which has in some cases entered in higher

Table III.
Cathode colouring substances.

eosine 0,1 ‰		eosine 0,1 ‰		vesuvine 0,1 ‰		benzo-azurine
convex	concave	convex	concave	convex	concave	
3	8	1	5	3	4	One observation. The concave side coloured most, no cell-series to be counted.
8	5	1	5	2	4	
4	8	1	5	3	4	
3	6	3	8	3	5	
4	6	4	8	3	7	
3	2	3	10	4	2	
2	4	2	4	3	2	
3	7	1	4	1	3	
4	2	3	15	3	6	
3	5	8	5			
5	2	9	5			
6	3	2	4			
1	3	7	11			
		Average	Average	Average	Average	
		3.7	5.8	2.7	4.1	

Table IV.
Anode colouring substances.

Safranine 0,01%		Fuchsine S 0.1 %		Methyl- orange 0.1%		Methylene- blue 0,1 %		Light green 0.1%		Methylviolet 0.1%		Neutralred 0.1%	
conv.	conc.	conv.	conc.	conv.	conc.	conv.	conc.	conv.	conc.	conv.	conc.	conv.	conc.
4	6	1	2	4	2	8	2	2 observations 2 times convex no cell series to be counted.		5	7	10	16
12	7	17	10	5	2	4	2			5	10	5	8
10	5	14	12	4	2					4	6		
8	4	18	13	1	3					3	4		
	6	5	2	5	2								
				6	3								
				5	2								
				10	2								
				3	1								
				12	2								
Average													
9	6	11	8	5.5	2	6	2			4	7	7.5	12

degree on one side, through holes invisible for the eye for instance through a wound.

The shade of the colouring should not always be relied on quite, as factors may be present which may give rise to errors. The general conclusion however is that the cathode colouring substances examined are absorbed most on the concave side.

The anode colouring substances which are put down in table IV show a less conformable image. According to the list of Keller in the „Handbuch der Methodik d. wiss. Biol. I“ page 490 (Editor Peterfi 1928), Fuchsin S. is an anode colouring substance, but in the table of Keller and Gicklhorn (1932) in „Abderhaldens Handb.“ Abt. V.T. 2 p. 1279 it is classed with the cathode colouring substances.

According to these tables safranine, neutralred and lightgreen are anode colouring substances; methylviolet, a toxicant anode colouring substance, methyleneblue and methylorange are charged otherwise.

By help of the „testobject“ *Hedera Helix*, see Keller (1928) „Meth. d. Wiss. Biol. I.“, I obtained with these colouring substances an anode colouring. I have therefore considered them as anode colouring substances.

As shown in table IV I found safranine, methylorange, fuchsin S., methyleneblue and lightgreen absorbed most on the convex side; methylviolet and neutralred most on the concave side.

As Keller has several times said in his work, the colouring-difference of some colouring substances in itself cannot be considered

as a proof for the lading-nature of a tissue. In our case the 3 cathode colouring substances examined stain the concave side of the curvature most. This indicates that this tissue is negative with regard to the convex side.

Safranine, methylorange, methyleneblue and lightgreen stain most the convex side. This indicates that this tissue is positive with regard to the concave side.

Neutralred and methylviolet, which, as anode colouring substances, stained the concave side most, form an exception.

Altogether I am nevertheless of opinion that this colouring difference is a strong indication that the tissue on the convex side is positive with regard to that on the concave side of the curvature.

Thus, as did Went (1932), I have tried to demonstrate by means of a colouring method a potential difference in a plant tissue.

I must however draw attention to the fact that I have interpreted the difference in the colouring differently.

I divided the colouring substances according to Keller (1932) and Keller and Gicklhorn (1932) into cathode and anode colouring substances, because it is not always the acid or basic nature which decides the colouring; see Süllmann (1931). A so-called „acid” colouring substance has negative laden particles. Thus according to Keller we should find them in a positive tissue. In the table of the „acid” colouring substances of Went we therefore also find the anodic substance lightgreen. That this colouring substance is most absorbed apically is in my opinion in accordance with the measurement of Ramshorn (1934), who found the apical cut-surface of the hypocotyl of *Impatiens balsamina* positive with regard to the base.

In Went's table of the „basic” colouring substances, however anodic substances are also to be found, and these were found at the base.

The colouring difference of the convex side and the concave one, found by me, indicate that the convex side is positive with regard to the concave side.

This result is in accordance with the investigation of Ramshorn (1934), who demonstrated that also in the case of roots the points of strongest growth were positive with regard to the points with a less strong growth. From this it follows that, with a curvature which has originated owing to the one side (the convex side) growing more than the other (the concave side), this convex side is positive with regard to the concave side.

The fact that the convex side is positive accounts for the turning

aside of the rhizocaline transport to the convex side. (Compare Thimann and Went 1934, Went 1934).

To the fact that growth-substance moves to positively charged tissues was already pointed on page 299.

The occurrence of lateral roots on the convex side of a curvature can therefore be explained through the transversal polarity, which prevails in the curvature and which is of such a nature that the tissue on the convex side is positive with regard to the tissue on the concave side. In consequence of this the rhizocaline transport as well as the growth-substance transport undergoes a turning aside. Accumulation of the rhizocaline on the convex side causes the development of rudiments of roots on that side, whereas the stronger supply with growth-substance entails a retarded growth of the young lateral root on that side, which results in a curvation directed to the convex side of the tap root.

Discussion.

We have seen that in the curvature of a curved root a transversal rhizocaline transport takes place, which is always directed to the convex side of the curvature. It was further found that the convex side of the curvature is positive with regard to the concave side.

Attention was drawn, on page 298, to the investigations of Brauner (1927), Brauner and Bünning (1930), Amlong (1933) and Koch (1934), which showed that a transversal growth-substance transport can take place through an electrical potential difference.

Thimann and Went (1934) demonstrated that rhizocaline is an organic acid of the same chemical nature as auxin A, whereas Went (1934) found that rhizocaline accumulates on a positive pole.

The fact that the convex side is positive may account for the transversal transport of rhizocaline as well as of the growth-substance. Here however a closer consideration is wanted. Amlong has imitated the geo-electrical effect by producing a potential difference on either side of the plant (root of *Vicia Faba*, hypocotyl of *Helianthus annuus*). These curvatures, induced electro-tropically by imitation of the geo-electrical effect, show a clear conformity with the geotropical reactions.

The tip plays in all cases the same decisive part. The course of the curves, which show the electrotropical reaction and the geotropical reaction are in accordance with each other, with regard to their time circumstances also.

It is true with regard to quantity that there is no absolute conformity. According to Amlong this is to be ascribed to the counteraction of gravitation in the electrotropical curvation.

Amlong thinks it very probable that with the geotropical reaction the transversal growth-substance transport takes place in consequence of the geo-electrically induced potential difference.

The investigations of Koch (1934) also show distinctly that an explanation of geotropism and phototropism, caused by a transversal growth-substance transport, is possible by means of a potential difference, brought about geo- or photo-electrically.

The phenomena with which we have to deal here, are very complicated, as appears from the work of Ramshorn (1934).

Ramshorn found that parts of plants (stalk as well as root), in which young tissue is to be found, are always positive with regard to older, full-grown parts.

This gives the potential-difference curve the same course as the growth-difference curve.

Ramshorn further found that if a small cube of growth-substance-agar were placed on one side of a decapitated coleoptile, so that this side was caused to grow more than the one not supplied with growth-substance, the growing side became at the same time positive with regard to the other side. If one side of the hypocotyl of *Helianthus* be made more positive with regard to the other, a stronger growth of the more positive side is also induced.

Thus Ramshorn found:

1. Growth-substance supply \Rightarrow growth \Rightarrow turning positive.
2. Making positive \Rightarrow growth.

These experiments demonstrate thus in my opinion, that a complicated connection exists between growth-substance supply — growth — and the electrical potential difference; and that there is still an unknown factor (or factors) in it, which regulate the harmonical co-operation of these processes.

On the strength of the literature referring thereto, we may, in my opinion, safely assume that the making positive causes supply of growth-substance to that side.

The experiments of Ramshorn have not shown, that the growth-substance, with the disturbance of the electrical balance (geo- and photo-electrical phenomenon) of through the production of a potential difference, do not move to the positive pole.

That the growth-substance does move to a positive pole is indicated especially by the experiments of Brauner and Büning, Amlong and Koch.

In this connection I wish to point further to their experiments with roots, where the making positive of the one side causes a growth-check of that side, which accords very well with an accumulation of growth-substance on that side. (Compare Nielsen (1930), Boysen Jensen (1933), Cholodny (1933, 1934). I am therefore of opinion that Czaja (1935 a, b) inverts the matter, when he says that the growth-substance transport does not take place in consequence of the electrically determined polarity of the organ, but that on the contrary a growth-substance current electrically polarizes the organ.

He bases this opinion in the first place on his experiments with the *Helianthus hypocotyl*, on which he places lateral or annular growth-substance paste of very high concentration (Czaja 1935 a).

The hypocotyl responds with a local thickening and check of the growth longitudinally. It is seen, that the cells of the thickened place have grown very much in radial direction. This thickening does not appear when the growth-substance paste is put on the cut-off stump.

Czaja is of opinion that the "cross-current" (Querstrom) of the growth-substance, (the growth-substance was placed transversally with regard to the axis of the organ) has altered the polarisation of the cells morphologically and physiologically.

This reaction (thickening and growth-check) however only appears with very strong growth-substance concentrations.

On this subject I should like to remark that we cannot speak of a "Querstrom", because nothing is known for certain as to how under these circumstances the growth-substance is transported in the plant.

Furthermore we are quite ignorant as to how such strong growth-substance concentrations encroach on the life of the cell. Czaja says that this "Querstrom" checks (or abolishes) the physiologically existing normal, thus apical basal directed polarity. It is then, however, quite incomprehensible how the strong curvations with the material of Laibach (1933) and Laibach and Kornmann (1933, 1934) have come about. On their material it is to be seen that besides a strong growth of the side coated with growth-substance paste, a basal directed transport also took place in this side.

I mention these experiments of Czaja only because he has based his conclusions to a large extent on these experiments. On the strength of the experiments of Brauner and Bünnig (1930), Amfong (1933), Koch (1934) and Went (1934) I think that

we may suppose that growth-substance and rhizocaline are transported in consequence of a potential difference.

I must now return to the transport of growth-substance and rhizocaline in the curved root.

When the curvation of the root is caused in consequence of a geotropical stimulation, then the under-side is first charged positively with regard to the upper-side (geo-electrical effect); afterwards this upper-side, which has then become the convex side, becomes, in consequence of the stronger growth, positive with regard to under-side, which has then become the concave side. These two potential differences are of a different nature, the former is a physical-chemical phenomenon, the latter originates in consequence of vital functions.

The growth-substance accumulates first on the positive under-side and then moves to the upper-side, when this has become positive. This must therefore result in the curvation receding, in so far as it is not yet fixed.

Here we find an explanation of the autotropism of the root.

The autotropism of the root was examined well by Simon (1912) in connection with Czapek (1895).

The following facts found by them, are of interest here. Czapek found, that the root-tip is not necessary for the autotropical reaction, and further, that an all-sided growth is not sufficient to effect the receding of the curvation.

Simon ascertained that the autotropical straightening (Ausgleichbewegung) takes place both after a geotropical curvation and after bending mechanically.

He further states that with the autotropical straightening the concave side grows for more strongly than the convex side. With the autotropical reaction no growth takes place on the convex side, and even a slight compression may appear here in consequence of the strong growth on the concave side.

These facts can be explained very well by means of the transversal growth-substance transport. The growth-substance flows from the concave side away to the convex side, causes a check of the growth there, and in the same measure an increased growth on the concave side is brought about. We can easily imagine that if the curvation is not yet fixed, this may induce an over-curved. Through this fact can also easily be explained the moving to and fro of the organ, before it is evenly balanced.

Dolk (1930) tried to explain the autotropism of the *Avena coleoptile* by means of a longitudinally running growth-substance current.

He observed that the autotropical curving straight with decapitated germ-plants only began after the regeneration of a new physiological tip had taken place.

Dolk imagines that with the coming about of the curvature on the convex side „Zellstreckungsmaterial” (compare Went 1928) is used up.

Now, when, after the cessation of the stimulation, the growth-substance flows, equally again on both sides, then, as he says, the concave side will grow more, because on the convex side there will be a deficiency of „Zellstreckungsmaterial”.

With roots the explanation of Dolk leaves us in the lurch. Czapek (1895) found that for the autotropy of roots the tip does not play any part, and even if with roots we suppose an all-sided growth-substance supply from basal regions, we cannot comprehend why the concave side should grow more than the convex side.

A deficit of „Zellstreckungsmaterial” of the convex side cannot help us, for why does not this deficit assert itself with the formation of a strong curvature? Then it also remains unexplained how the surplus of growth-substance on the concave side is taken away.

The explanation of the autotropy of the root, given above, is not applicable without further ceremony to stalks or to the *Avena coleoptile*.

When we charge one side of a *Avena coleoptile* or of a hypocotyl of *Helianthus* positively with regard to the other side, then this side grows more. This fact we can explain by means of an accumulation of growth-substance on that side. When thereupon this side grows more, according to Ramshorn this must cause it to get still more positive, whereby still more growth-substance would flow to the growing side. After a maximal supply with growth-substance the growth no longer increases in proportion with the extant quantity of growth-substance. Even the experiments of Czaja (1935a) and of Thimann and Skoog (1934) point to a check of the growth when a surplus of growth-substance is present.

In this may be found an explanation of the autotropism of the stalks.

In this connection I would further point out that according to Amlong (1933) both with roots and with the hypocotyl of *Helianthus* after an electric stimulation, the efficiency curve goes through an optimum. With the rise of the potential difference between the two sides the curvature does not increase.

From this it is seen that the problems we have touched upon but slightly above, are very complicated, and that many more experiments must be made to solve the problem of the connection between growth-substance, growth and electricity.

Summary.

In the curvature of a curved root lateral roots are formed chiefly on the convex side, whereas the lateral roots which originate between the concave and the convex side, curve in the tissue of the tap root to the convex side. This is the reason that the lateral roots come out exclusively on the convex side (Noll 1900).

It was demonstrated that this phenomenon is based on a transversal transport of rhizocaline and of growth-substance in the curvature.

The transversal transportation of rhizocaline and of growth-substance can be explained through the electrical polarization of the root-tissue in the curvature.

By means of this transversal growth-substance transport also the autotropism of the root can be explained.

Here I wish to express my sincere thanks to Mr. L. Petrick Lic. Nat. Wet. at Gent for his co-operation and assistance in the experimental part.
Gent, June 1935.

Botanical Institute.

LITERATURE.

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