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EFFECT OF SOME ENVIRONMENTAL FACTORS ON THE CAROTENE CONTENT OF CARROTS

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Introduction

The orange colour of our so-called red carrots is caused by carotenoids. In well coloured roots they are composed for 5—10 per cent of xanthophyll and for 90—95 per cent of carotenes. In hardly coloured very young roots there is of course very little pigment; in this very young stage there are proportionally less carotenes.

So far we have mostly only determined the total carotenoids (*t.c.*) as thus far this was sufficient for our physiological investigations. Nevertheless we often speak of carotene content when we mean total carotenoids.

Different varieties of orange carrots may differ in *t.c.*-content : 6—12 mg/10 g of dry matter is relatively common; 15 mg is rather high; but there are some so-called high-carotene selections with twice as much or more. The pigment is not evenly distributed over the root. In the cortex the concentration is higher than in the core, and in both the concentration decreases from the upper third part of the root downwards to the tip.

For a short review of literature and references till 1951 see Goodwin (8). I will restrict myself to the formulation of the following thesis and its argumentation, for the greater part based on our own experiments (1, 2, 3). *)

The ripening equilibrium of the root is the central mechanism through which the environmental factors influence its carotene content, carotene production in the root being a consequence of ripening.

Ripening equilibrium of a carrot root

The root of a carrot starts as a common tap root. This is its primary vegetative development. After having made a certain amount of growth it is more and more thickening and changing into a reserve food organ. It then enters a second stage of its vegetative development, the stage of ripening. The primary vegetative growth of the root as a whole then decreases, but locally, at the tip, it may proceed more or less intensely. So the tip of the root may be thin and unripe, while the other parts are riper the higher one comes till about 1/3 of the length from the top.

*) In these experiments Mr. J. W. de Bruyn, phytochemist, was responsible for the chemical side of the work, and Mr. L. Smeets, physiologist, for phytotron conditions.

With the exception of the very young stage both activities occur at the same time in every growing root, but not always in the same measure. They form an equilibrium that can be shifted more to the left or more to the right. The equilibrium may be written as follows:

(1) ... *primary vegetative growth* $\rightleftarrows$ *root thickening (ripening).*

Conditions which favour root thickening or suppress the primary vegetative growth will cause the equilibrium to shift to the right, turn an unripe root into a ripe one and increase the *t.c.* content.

Conditions which favour primary vegetative growth or suppress root thickening will cause the equilibrium to shift to the left, and create a situation in the root in which only little carotene is being produced. Under these conditions an unripe root will remain unripe. If a part of the root had ripened before, the ripened part will remain so, but the new growth will develop in an unripe condition.

Factor 1, the size of the root.

In a growing root its t.c. content increases in proportion to its size till a kind of maximal *t.c.*-content has been reached. After this a root may further increase in size without a further increase of *t.c.*-content. This phenomenon as such has been stated by several authors (4, 5, 7, 10, 11). And we have to consider now if it can be seen as a ripening-phenomenon.

If we take taste and appearance of the root as criteria there is nothing contradicting this. The oldest and thickest parts of the root are also the most coloured. As long as the tip grows it remains relatively thin and bleak; as soon as it starts swelling it also starts colouring.

The maximal *t.c.*-content that is reached by a carrot during its growing season is not the same every year. In a period of seven years Booth and Dark found it fluctuating between about 80 per cent and about 120 per cent of its average during these seven years. This fluctuation is not amazing, for the final ripening condition of carrots at their harvest time may also be quite different in different years.

According to the situation of the equilibrium mentioned above during the growth of the carrots, there are two possibilities:

a. A larger or a smaller part of the root can still be unripe.

b. The degree of ripeness of the most ripened tissue in the carrot might also vary.

Possibility *a* is real, as can be seen very often, but little can be said as yet of possibility *b*. Therefore, it is not yet quite clear what determines the height of the maximum. But, in relation to the study of the factors that will be discussed next, the proportion of *t.c.*-content to root size before the maximum has been reached is very important.

We have found that we have most reliable results if we calculate the *t.c.*-content as mg/10 g of dry matter, and if we take for the root size the root weight in grammes of dry matter (= dry root weight). This cuts out the fluctuations caused by differences in moisture content.

One can get a good idea of differences in the *t.c.*-content of different groups of carrots if *t.c.*-content, percentage of dry matter and root weight are determined in a series of successive harvests. The average *t.c.*-content of each harvest is plotted against the average dry root weight. By connecting the points of the successive harvests of each treatment, one can compare the trend of the curves for the different treatments. In this way it is possible to take care of the dry root weight reached. Otherwise the t.c. values are not comparable. As this method has not been used in the earlier investigations on the influence of environmental factors on the *t.c.*-content, most earlier results are not very instructive and often contradictive.

Factor 2, the temperature.

It has often been stated that in cool conditions the roots are very often less coloured than when grown in warm conditions (4, 5, 9). Definite proof of the influence of temperature however was not furnished because the size of the roots was not taken into account. Moreover the observations were not always made in such conditions that one could be reasonably sure that there were no varying factors other than temperature.

We have made our experiments in a phytotron, so that temperature could be made the only varying factor. And by using the method described we could take into account the dry weights of the roots of the different treatments (2).

We have compared two temperatures: 8° C and 18° C.

For the results see figures 1 and 2.

It appears:

a. At both temperatures growth and carotene production have taken place.
b. After the roots have developed to a sufficient degree, the *t.c.*-content at 8° C is, at a certain dry root weight, considerably lower than that at 18° C. At the same time the root at 8° C is longer and more pointed than at 18° C; it has more the shape of an unripe root.

When growing at 8° C the equilibrium (1) lays more shifted to the left than when growing at 18° C. At 8° C the roots grew, but they remained in an unripe condition; consequently their *t.c.*-content remained lower. At 18° C ripening started earlier, thereby suppressing the primary vegetative growth to a certain degree; the roots remained shorter; their *t.c.*-content soon reached a high level.

Factor 3, the space available for growth.

If the individual plants have much space for growth, the primary vegetative development remains predominating for a longer time than if little space is available. In the latter case root thickening (ripening) takes the upperhand, as the primary vegetative growth is more or less blocked.

In the first place wider planting distances may provide more space for growth.

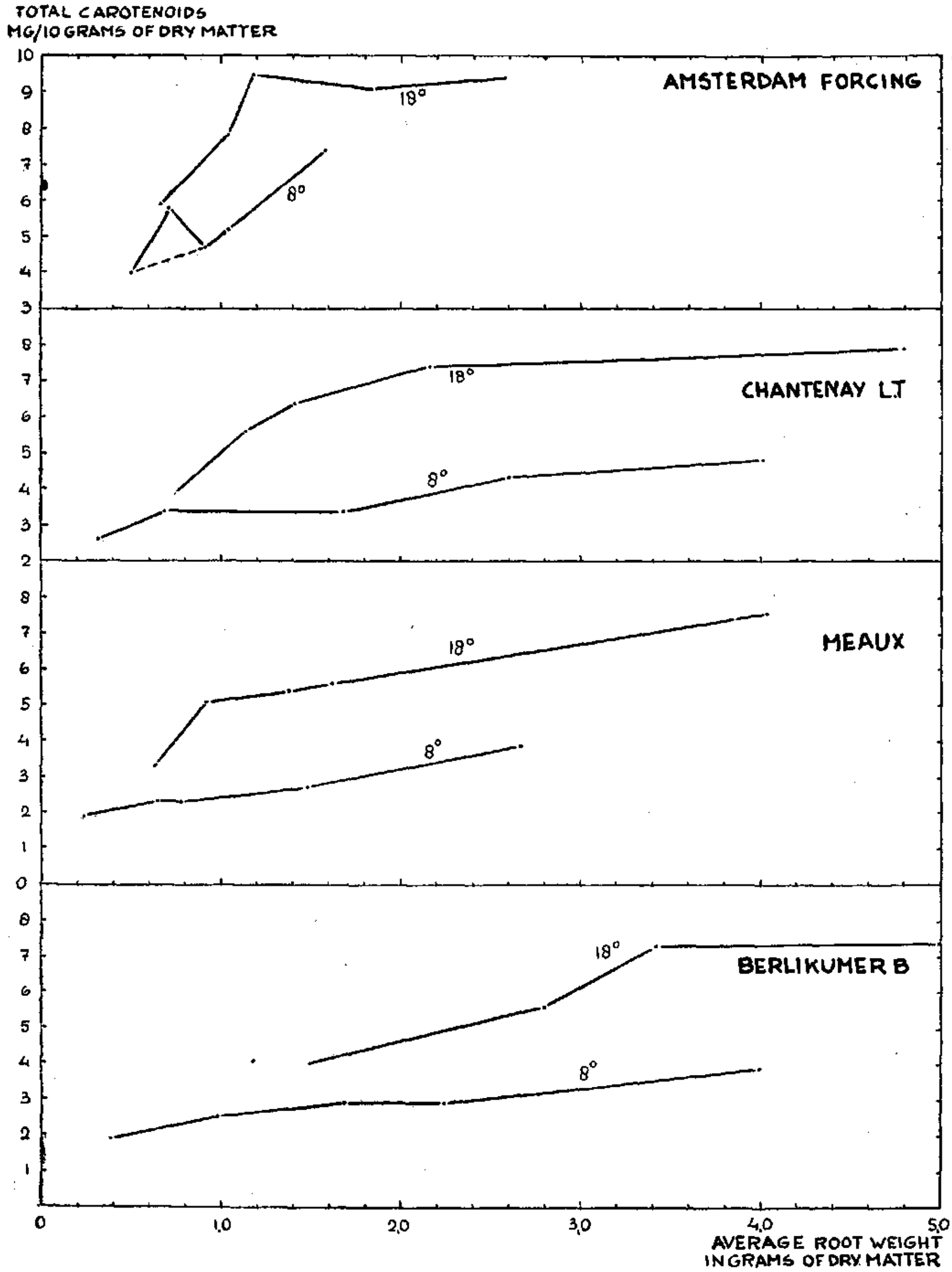
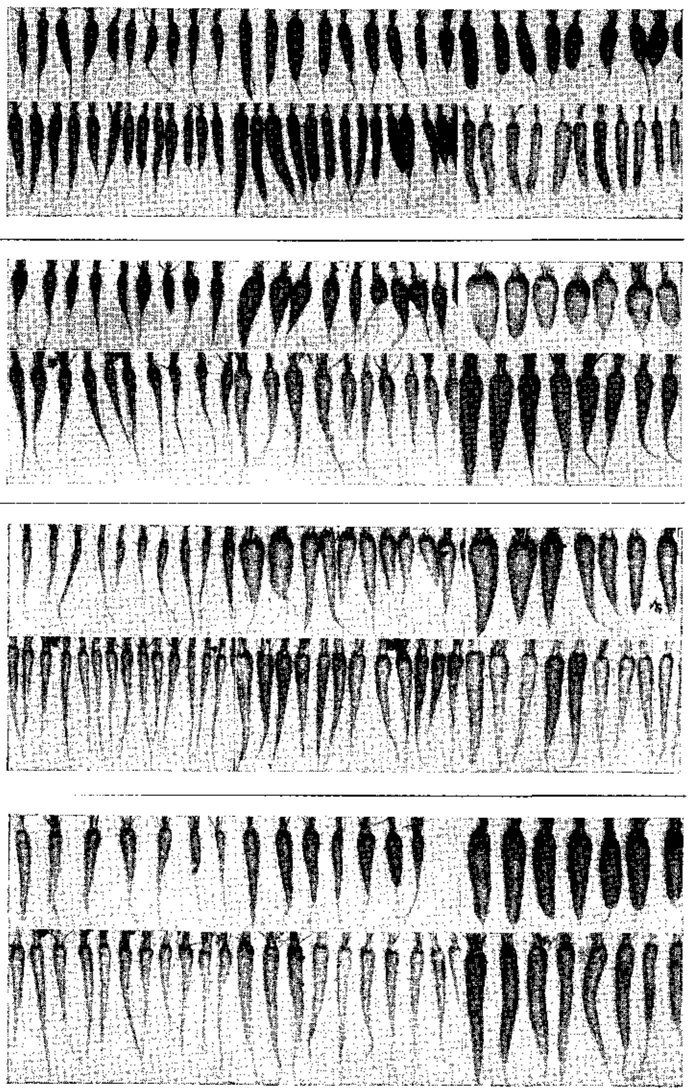


Fig. 1

Course of the total carotenoid content of four carrot varieties at 18° C and 8° C.

In each of three experiments (October-sowing, January-sowing, and July-sowing) a selection of the variety "Amsterdam Forcing" was grown at three planting distances (very narrow: 5 cm x very close; normal: 13 x 1,5 cm; and very wide: 20 x 10 cm). The temperature conditions of the three experiments were different. The plants from the October-sowing developed during January-May. The first three of these months were cold, the last two cool. The



18° C
harv. I, II, IV
Amsterdam Forcing
8° C
harv. II, IV, V

18° C
harv. I, III, V
Chantenay Long Type
8° C
harv. II, III, V

18° C
harv. I, IV, V
Meaux
8° C
harv. II, IV, V

18° C
harv. I, II, IV
Berlikumer Bierma
8° C
harv. II, III, V

Fig. 2

Root shape of four carrot varieties in successive harvests at 18° and 8° C. Out of five successive harvests at each temperature three with about comparable root weights at the two temperatures were selected for representation above.

plants from the January-sowing had cool weather during April and May, and favourable conditions during June and July.

The plants from the July-sowing had a favourable temperature for growth during their whole growing period.

For the results see figures 3 and 4.

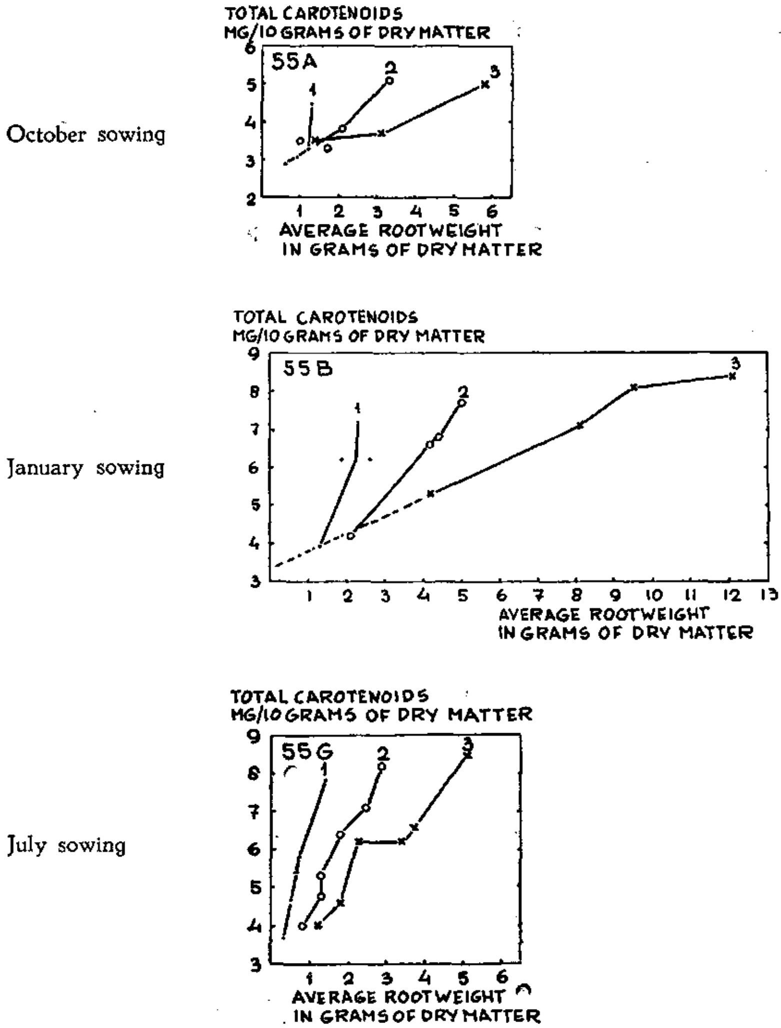


Fig. 3

Course of the total carotenoid content of Amsterdam forcing at three different planting distances.

1 = very narrow,
2 = normal,
3 = very wide

It appears:

a. At all treatments growth and carotene production have taken place.

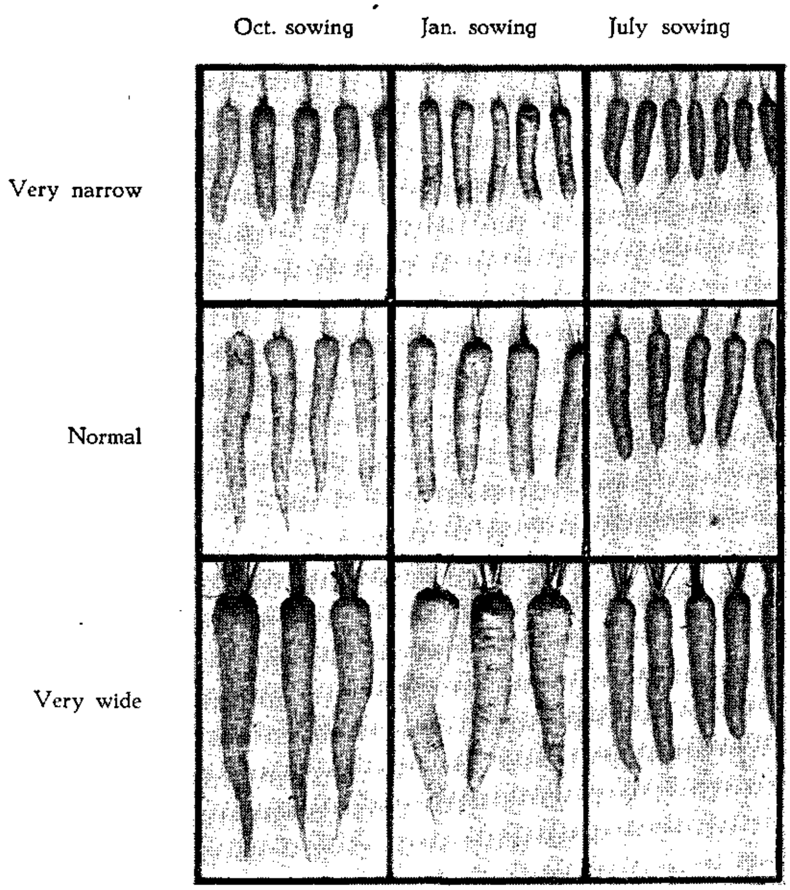


Fig. 4

Shape of Amsterdam Forcing as influenced by planting distances and temperature (different times of sowing).

b. At a certain dry root weight the *t.c.*-content was lower and the root shape was more unripe at a wider planting distance than at a narrower one.

c. The differences were largest in the experiments where the temperature during growth was lowest.

In the second place a deeper soil water table may provide more space for growth.

The same selection of „Amsterdam Forcing" was grown at 17° C in a series of pots with water tables at 17 cm or at 50 cm.

For the results see figure 5.

It appears that at a certain dry root weight the *t.c.*-content at a water table of 17 cm was higher than that at a water table of 50 cm.

Factor 4, the soil moisture content.

We ourselves did not study this factor. W. C. Barness (4) has grown Chantenay carrots in pots with soil moisture contents of

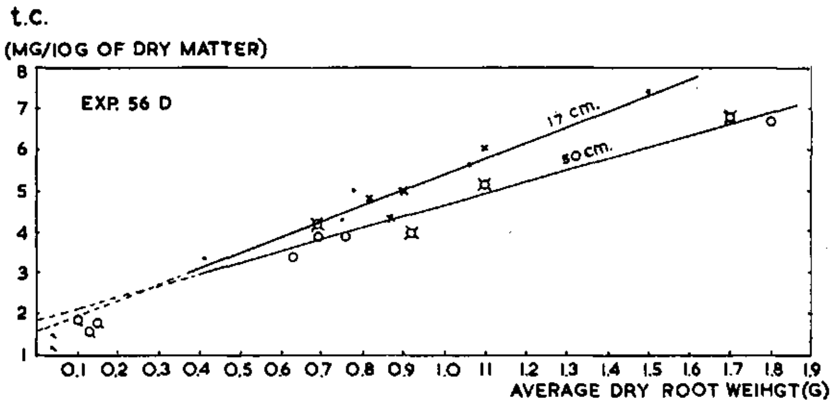


Fig. 5

Course of the total carotenoid content in roots of Amsterdam Forcing at 17° C at two soil water tables. (17 and 50 cm).

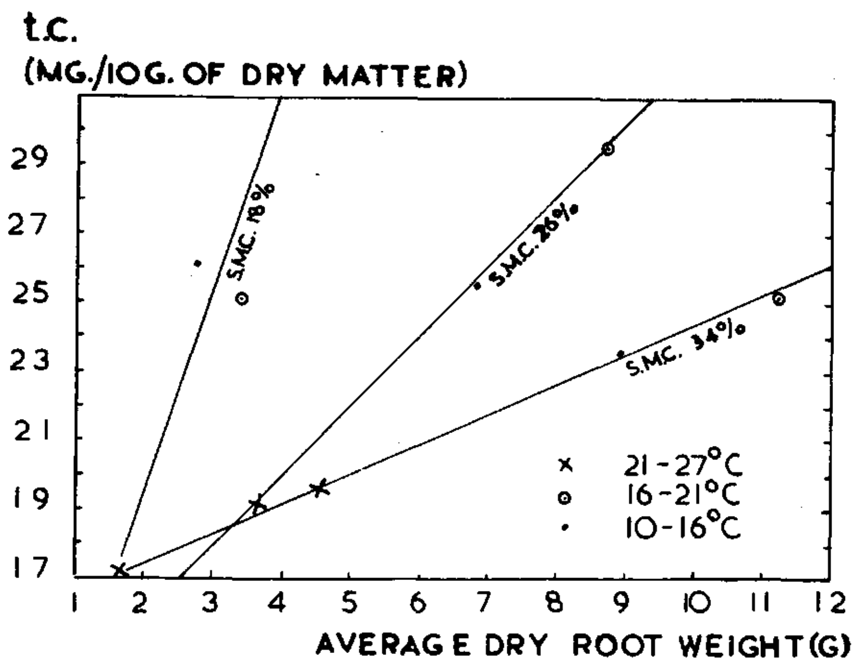


Fig. 6

Total carotenoids in roots of the variety Chantenay after having grown for a same period at three temperatures and at each temperature at three soil moisture contents (s.m.c.).

Calculated from data produced by Barness (4).

18 per cent, 26 percent and 34 per cent, at temperatures of 10-16° C, 16-21° C and 21-27° C. So there were 9 treatments; for each treatment 10 pots were used. All pots were sown on November 13, 1932, and harvested on April 11-13, 1933. From the data collected and published by Barnless I could take the *t.c.*-contents as mg/10 g of dry matter and calculate the dry root weights on April 11-13. They are shown in fig. 6.

All points together do not show any regular connection. But taking the three soil moisture groups separately, it appears that the three temperature points in each of the groups of 26 and 34 per cent soil moisture are situated on a straight line. Within the group of 18 per cent soil moisture the points of 10-16° C and 16-21° C are quite near to each other. In this case the line has been drawn through an imaginary point between these two points.

It can be seen that:

a. At all treatments growth and carotene production have taken place.
b. The lower the soil moisture content, the smaller the roots have grown.
c. At a certain dry root weight the *t.c.*-content was higher the lower the soil moisture content was.

Evidently the soil moisture content has influenced the primary vegetative growth of the roots.

Taking the 26 per cent moisture line as the normal one, less water in the soil (18 per cent) reduced the primary vegetative growth. This caused the equilibrium (1) to shift to the right, with the consequence of an early colouring. More water in the soil (34 per cent) favoured the predomination of the primary vegetative growth for a longer time. This caused the ripening equilibrium to shift to the left, with the consequence of a later colouring.

As for the influence of the temperature, it seems that we must conclude from fig. 6 that in the range from 10—16° C till 21—27° C (or expressed in average temperatures from 14° till 24° C) no shifting of the ripening equilibrium has occurred. Otherwise the three temperature points would not have been situated on a straight line.

Summary

1. The following thesis has been forwarded: The ripening equilibrium of the root is the central mechanism through which the environmental factors influence its carotene content, carotene production in the root being a consequence of ripening.

2. The ripening equilibrium of the root can be written as follows: *primary vegetative growth* $\rightleftarrows$ *root thickening (ripening).*
In a growing root both activities as a rule occur at the same time, but not always equally. The influence of environmental factors consists in stimulating or suppressing one of the components of the equilibrium, thus causing the equilibrium to shift to the left or to the right.

3. The influence of the factors root size, temperature, space available for growth, and soil moisture content has been shown. The way they act seems to be in accordance with the thesis mentioned above.

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