Botany. — *"The influence of temperature on phototropism in seedlings of Avena sativa."* By Miss M. S. DE VRIES. (Communicated by Prof. F. A. F. C. WENT).

(Communicated in the meeting of Jan. 25, 1913).

In connection with RUTGERS'[1]) investigation on the influence of temperature on the geotropic presentation-time in *Avena sativa* seedlings, I have undertaken experiments to find out how far temperature influences phototropism.

I had originally no intention of making a preliminary statement at this stage because some of the experiments are not yet complete, but after the publication of TORSTEN NYBERGH'S[2]) work on the same subject in which results wholly opposed to mine are given, it became desirable to make a communication now.

TORSTEN NYBERGH comes to the conclusion that temperature has no influence on the process of phototropical stimulation. According to him therefore the influence of temperature on phototropism may be represented graphically by a straight line. The results I have obtained at various temperatures can however be represented by a definite optimum-curve. Before I consider the results, I should like to say a few words about the method.

Seedlings of Avena sativa having a length of about 2.5 cm. were used. The boxes of seedlings were warmed for at least an hour beforehand in the thermostat used by RUTGERS at the temperature to be investigated; they were then exposed to light in the thermostat and then taken out of the apparatus. The seedlings always executed their curvature at 20° C. While the seedlings were in the thermostat, fresh air was drawn through it, moreover the dark room in which all the experiments took place was ventilated as much as possible. The warming of the thermostat was done by electric lamps; gas was not burnt in the dark room, so that the atmosphere was as pure as possible. The source of illumination was incandescent gas light, placed outside the room; the light entered through a frosted glassplate, when the diaphragm was open.

1) A. A. L. RUTGERS: The influence of temperature in geotropism. Proceedings Royal Acad Amsterdam. Vol XIII, p. 476, 1910.

A. A. L. RUTGERS The influence of temperature on the geotropic presentation-time. Recueil des Trav. Botan. Néerlandais. Vol. IX, 1912.

2) TORSTEN NYBERGH. Studien über die Einwirkung der Temperatur auf die tropistische Reizbarkeit etiolierter Avena-Keimlinge. Berichte der deutschen Botan. Gesellschaft. Band 30. 1912.

The quantity of light-energy which at various temperatures was necessary to cause a definite degree of curvature was determined. As a standard a curvature of 2 mm. was always taken, that is to say, the apex of the coleoptile was bent 2 mm. out of the vertical.

To begin with, experiments were made at 20°C., since a quantity of light energy of 20 M. C. S. (metre-candle seconds) gave a curvature of 2 m.m. In order to find the quantity necessary for a curvature of 2 mm. a few boxes of seedlings were stimulated for a varying number of seconds, and it was ascertained after about $1^1/_2$ hours how many seedling had curved. Boxes in which $50^0/_0$ of the seedlings showed a curvature of 2 mm. served as a standard. The product of duration of stimulus and intensity of light then gave the required quantity of luminar energy in M. C. S.

The experiments were performed at temperatures ranging from 0° to 40° C. No experiments were made above 40° C.; after one hour's preliminary warming at 40°, so prolonged an illumination was necessary and the curvatures which finally occurred, were so indistinct, that there was no question of determination after more prolonged warming. At 43° the seedlings died.

From 0° to 25° the observations were made at intervals of 5°; above 25° more frequent determinations were found to be necessary.

At each of the temperatures to be investigated there was first a warming of one hour's duration, afterwards of 2 hours, 4 hours, 6 hours etc., in order to see whether increased duration of preliminary warming had any effect.

The results of the experiments are collected in the table given below, in which in successive columns is given in M. C. S. the luminar energy necessary for a curvature of 2 mm., after 1 hour, 2 hours', 4 hours' warming, etc., corresponding to the temperature given in the first column.

It is clear from the table that the phototropic stimulationprocess is dependent on temperature and that at higher temperatures the time-factor is of a great influence.

From 0° to 25° the length of preliminary warming has no influence on the quantity of luminar energy. At 27.5° and 30° longer preliminary warming has a favourable influence; that is to say after a longer exposure to a higher temperature a smaller quantity of luminar energy causes the same curvature as a greater quantity after a shorter preliminary warming. The harmful influence of longer preliminary warming is first observable at 32.5° and this is the case also at 35°, 37° and at higher temperatures, in always increasing amount.

Temp.	1 hour	2 hrs.	4 hrs.	6 hrs.	12 hrs.	18 hrs	24 hrs.	48 hrs.
— 2°	200	200						
0	160	160	160	160				
5	70	70	70	70				
10	52.5	52.5	52.5	52.5				
15	24.5	24.5	24.5	24.5		24.5		24.5
20	20	20	20	20		20		
25	9.5	9.5	9.5	9.5		9.5		
27.5	9.2	7.2	5.6	4.8	4	4	4	
30	8	6	4	3	2	2	2	2
31	8	8	8	8		8		
32.5	9.2	12	13.6	14.4		14.4		
35	10	15	20	22	25	26	26	26
37	40	64	80	88		92	92	
37.5	48	72	104	120		176	184	184
38	56	84	128	160		272	320	
39	120	176	240	280		400		
40	± 1600[1])							

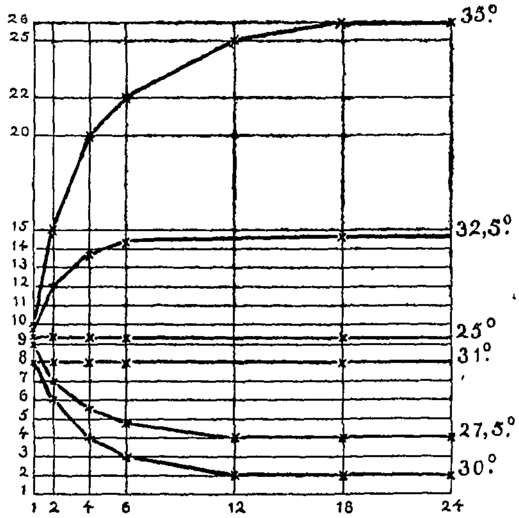

Fig. 1.

[1]) For the absolute correctness of this figure I cannot vouch on account of the difficulty mentioned on a previous page.

The favourable influence of longer preliminary warming at 27.5° and 30°, also the unfavourable influence of a longer exposure at 32.5° and 35° is represented graphically in figure 1 in which the abscissae show the duration of preliminary warming, and the ordinates the energy in M. C. S.

It is further clear from the figure that there is a transition point between the favourable and unfavourable influence; the amount of M. C. S. is here constant.

Figure 2 represents graphically the energy in M. C. S. which causes a curvature of 2 m.m., as a function of temperature. The abscissae represent temperature, and the ordinates luminar energy in M. C. S. As the drawing is much reduced the lines representing longer preliminary warming are omitted for the sake of clearness; only the line for one hour's warming has been drawn.

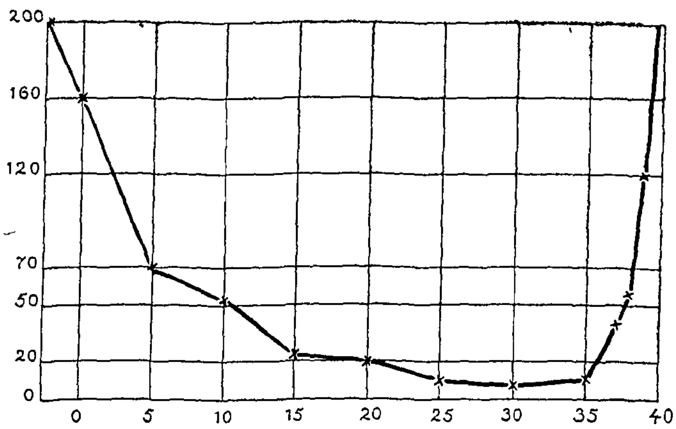

Fig. 2.

Evidently we are here concerned with an optimum-curve. The optimum is at 30°.

Finally there is the question whether VAN 'T HOFF's rule applies to phototropism. The energy in M. C. S. decreases to the optimum because perception takes place more rapidly. To determine the temperature-coefficients, the ratios of the quantities of luminar energy must not be taken, but the ratios of their reciprocal values, as was done by RUTGERS[1]) for geotropism. For this reason $\frac{K_{10}}{K_{20}}$ etc. is taken, and not $\frac{K_{20}}{K_{10}}$ etc.

The following temperature-coefficients are then found:

[1]) A. A. L. RUTGERS. Proceedings Royal Acad. Amsterdam, Vol. XIII.

$$\frac{K_0}{K_{10}} = 3. \qquad \frac{K_{15}}{K_{25}} = 2.6.$$

$$\frac{K_5}{K_{15}} = 2.8. \qquad \frac{K_{20}}{K_{30}} = 2.5.$$

$$\frac{K_{10}}{K_{20}} = 2.6. \qquad \frac{K_{25}}{K_{35}} = 0.95.$$

The quotients appear to remain constant up to 30° and after that decrease markedly, in agreement with what is observed in other vital processes. I refer to the paper of COHEN STUART [1]) for this point.

Does the observed influence of temperature only affect perception or is the time of curvature (reaction-time) also influenced by temperature? The reaction took place at 20° C in all the experiments. Of course it is conceivable that there is an after-effect of the preliminary warming at the temperature investigated. The times of curvature (reaction-times) amounted to:

At 0° C.	120	minutes	
,, 5° ,,	90	,,	
,, 10° ,,	90	,,	
,, 15° ,,	90	,,	
,, 20° ,,	90	,,	
,, 25° ,,	85	,,	
,, 30° ,,	85	,,	
,, 35° ,,	90	,,	afrer 1 to 12 hours' previous warming after longer warming 120′
,, 37° ,,	90	,,	after long warming 120′
,, 38° ,,	± 100	,,	after long warming 120′
,, 39° ,,	120	,,	
,, 40° ,,	2½ to 3 hours.		

By time of curvature (reaction-time) there is here meant the time which elapses till 50% of the plants are curved. The reaction-time is therefore fairly constant except at 0° and at the high temperatures. It seems clear from the tables, that, if there is any influence of the temperature at which the plant was warmed beforehand, on the reaction, this is found exclusively at 0°, 39° and 40° and, when the previous warming is of very great duration also at 35°, 37° and 38°. If may therefore be considered probable that the influence of temperature specially acted on perception.

I hope later to give further theoretical considerations and a review of the literature in a fuller communication.

Utrecht, January 1913. *University Botanical Laboratory.*

1) C. P. COHEN STUART. "A study of temperature-coefficients and VAN 'T HOFF's rule". Proceedings Royal Acad. Amsterdam; Vol. XIV, p. 1159, 1912.