FURTHER STUDIES ON THE INFLUENCE OF THE WATER TEMPERATURE ON THE WATER ABSORPTION AND THE STOMATAL APERTURE

By

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(With 8 Text-figures)

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In the previous paper (1937) the writer has reported the following facts: Within a temperature range between 0°C and 30°C, a rise of the water temperature caused a gradual increase of the rate of water absorption by the root of a seedling of *Phaseolus vulgaris* kept in water, while a decrease of the water temperature from 20°C to 0°C caused the stomata to open widely, in spite of the flaccid state of the plant leaf, owing to the decrease of the water absorption by the root. With a rise of the water temperature within a range between 0°C and 20°C, a gradual closure of stomata took place, but between 20°C and 30°C, their gradual opening, accompanied by an increase of water absorption happened, though the opening was not so remarkable as in the former case. This intimate relation between the water absorption by the root and the temperature of water suggests that importance should be attributed to the influence of temperature upon the resistance of the protoplast of root cells to the penetration of water. Regarding this problem many papers have been published[1].

It is generally accepted that when a plant is not well supplied with water and exists in a slightly wilted condition, the stomata would always be closed. This is, however, not always true, because stomata are still open or even a gradual widening of the aperture occurs when the plants have become badly wilted[2]. Though no explanation was attempted, such a remarkable opening of stomata, when the root was kept in water of varied temperature, was reported by the writer in his previous paper (1937). The aim of the

1) RYSSELBERGHE 1901, EWART 1905, DELF 1916, STILES, 1917, STILES and JØRGENSEN 1917, BODE 1923, HEYL 1933, DÖRING 1935, NITSCHE 1937.

2) STAHL 1894, DARWIN 1916, MOLISCH 1912, LAIDLAW and KNIGHT 1916, WEBER 1927.

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present work is to take further account of the problem, how the water absorption of cut plants and the stomatal opening are concerned with water temperature and to make clear the rôle of the root in the water absorption, comparing the results with those obtained in the previous work using intact plants.

Material (seedling of *Phaseolus vulgaris*), methods and standards of measurement are similar to those reported in previous papers (1934, 1936), so their full description is omitted here.

Experiment 1: As shown in a previous paper (1937), the writer has proven that under constant and continuous illumination the diurnal fluctuation of the stomatal movement stops, leaving the stomatal aperture and the rate of water absorption constant within five days after the transference from natural conditions, if the temperature and atmospheric humidity are kept constant.

In the present work, the plant was kept under constant conditions (air temperature 25°C, water temperature 20°C, atmospheric humidity 60% and illumination 200 watt Mazuda lamp), but the root was cut off from the base of the hypocotyl with a sharp razor on the previous evening and the cut surface was renewed the very day of the experiment, then the rate of water absorption and the stomatal aperture were measured during two days. The experiment was carried out on the 14th and 15th May, 1937. The results are shown in Tables 1 and 2 and Figure 1.

Results: In each experiment it is necessary to determine the amount of water absorbed by a plant kept in water of 20°C, which serves as the standard to the absorption at varied water temperatures. On the first day of the experiment, as seen from Figure 1, the rate of water absorption by the cut plant showed a certain fluctuation, namely, between 0.75 and 0.65 of calibration number on the potetometer tube and the mean value for the whole day was 0.69. The stomatal aperture on the first day showed a narrow fluctuation between 0.0215 and 0.0240 and its mean value during the midday hours was 0.0227. On the second day, however, a considerable depression of water absorption and less opening of stomata were ascertained, compared with those observed on the first day. The mean value of the water absorption was 0.058; accordingly the rate of water absorption on the second day may be expressed as 83.6%, taking the corresponding value on the first day as 100%. The mean value of the stomatal opening was 0.0206 and 90.8 expressed in percentage, if the corresponding value on the first day was taken as 100.

As the cause of such a depression of the rate of water absorption on the second day, the varied condition of the cut surface of the stem might be pointed out; for instance, the diminution of the absorbing area due to the development of microörganisms etc. In fact the examination of the cut surface at the end of the experiment revealed a colour change visible to the naked eye. Moreover, it may be very reasonable to consider that the rate of depression of water absorption varies according to the individual difference of the material used and also to the experimental temperature. It is also not impossible to consider that the decrease of the stomatal aperture on the second day may be attributed to the variation of the regulating ability of the guard cells owing to the depression of the water absorption as stated above.

In the previous work, conducted with intact plants having healthy roots, the rate of water absorption and the stomatal aperture on the second day were expressed in percentages, taking each corresponding value on the first day as 100. But in the present investigation it is impossible to use such an expression; accordingly in the following experiments the results on the first day and those on the second day were calculated separately. That is to say, on the first day the rate of water absorption and of the stomatal aperture at a water temperature of 20°C were measured and each of them was taken as 100, then the plant was transferred into water of varied temperatures. After a narrow fluctuation of the water absorption and of the stomatal aperture constant values were attained. The measured values of the water absorption as well as of the stomatal aperture observed under such a balanced condition, were averaged up separately and each of them was expressed in percentage, taking each corresponding value at a temperature of 20°C as 100.

On the second day the water absorption and the stomatal aperture under the same external condition as the previous day, were again measured, then the initial water temperature 20°C was restored. In this case also, the water absorption and the stomatal aperture became almost constant about one hour after the change of water temperature. The measured values of the water absorption and of the stomatal aperture observed under such a balanced condition at 20°C, were averaged and that average was taken in each case as the standard. Accordingly each corresponding value at varied water temperatures on the second day was expressed in percentages, taking the standard value at 20°C as 100.

Experiment 2: KOSAROFF (1897) reported that the plant root can absorb water even from frozen soil. In his previous paper (1937) the writer reported that the plant root can absorb a measurable volume of water from ice water. The present experiment was carried out in order to obtain further knowledge upon the problem of how much water can be absorbed by the plant from ice water when the root was cut away. The experiment was carried out on the 17th and 18th February, 1937. The results are shown in Tables 3 and 4 and Figure 2.

Results: As seen from Figure 2, the standard value of the water absorption at 20°C was 2.92, but after the plant was transferred into water of 0°C (this point is indicated by the mark "↓" in the figure), however, the rate of water absorption decreased suddenly. About one hour after the transference the water absorption attained the new constant value.

The water absorption by the intact plant, as reported in the previous paper (1937), decreased suddenly after the root was transferred from water of 20°C into ice water of 0°C and the leaves became distinctly flaccid due to the rapid decrease of the water absorption. Within certain hours after the transference the rate of water absorption exceeded that in water of 20°C for a time, owing to the increased suction force of the plant, which was caused by remarkable water deficit of the leaves. However this is not the case in the present work where a cut plant was used. The stomata gradually opened wider after the transference from 20°C into 0°C water and the aperture became 230.7%, if the stomatal aperture at 20°C on the first day of the experiment is taken as 100. But this value is not remarkable, when compared with the results with intact plant reported in the previous paper. When the plant was transferred into water of 0°C from that of 20°C, the leaves showed full turgescence in appearance, while the leaves, in the experiment with intact plant, showed a distinctly flaccid state after the transference.

The rate of water absorption on the second day showed a narrow fluctuation, with a mean value of 2.15, while the stomatal aperture, showing no remarkable wilting in appearance, was 0.0781 in mean value. About one hour after the plant was put back into water of 20°C ("↑" in Figure 2), the water absorption increased gradually, until a constant value 2 74 was attained, which served as the standard value. The stomata showed gradual closure and reached a certain low constant value about one hour after the recovery of the water temperature. The value of the stomatal aperture was 0.0485 which served as the standard value on the second day. On the second day, accordingly, the water absorption was 78.3% and the stomatal aperture was 161.1%, taking each corresponding standard value on the second day as 100%.

Experiment 3: Similarly as in the previous experiments, the water absorption and the stomatal aperture were measured, keeping the plant in water of 5°C. The experiment was carried out on the 26th and 27th February, 1937. The results are shown in Tables 5 and 6 and Figure 3.

Results: As seen from Figure 3, the standard value of the water absorption at 20°C was 1.14 and that of the stomatal aperture at 20°C was 0.0284. After the plant was transferred from water of 20°C into that of 5°C (↓), the water absorption decreased suddenly. A few hours after the transference, however, a new constant value was recognized. The value of the water absorption under the balanced condition was 1.09, and 77.8 expressed in percentage, taking the corresponding standard value as 100. The leaves showed no sign of wilting even after the transference of the plant from 20°C water into that of 5°C (↓). The value of the stomatal aperture under such balanced condition was 0.0294 and it was 103.6 expressed in percentage of the standard value. From this result it will be clearly seen that the variation of the water temperature caused no remarkable change in the stomatal aperture on the first day.

On the second day of the experiment, the rate of water absorption much decreased compared with that of the previous day. The measured value was 0.66 on the average; the leaves were as turgid as on the previous day and the stomatal aperture was unchanged at 0.0300. When the plant was restored to water of the initial temperature 20°C (↑), the water absorption gradually attained a certain constant value about one hour after the transference. The value measured under such balanced condition may serve as the standard value. The stomata closed gradually after the recovery of the water temperature, and a new balanced value 0.0226 was reached which served as the standard value for the second day. On the second day, accordingly, the water absorption was 81.1 and the stomatal aperture was 132.9, both expressed in percentage, taking each corresponding standard value as 100. From these results, it will be clearly seen that the variation of the water temperature on the first day caused no remarkable change of the stomatal aperture on that very day, but on the second day a certain widening of the stomata resulted.

Experiment 4: The plant was transferred from water of 20°C into that of 10°C. The experiment was carried out on the 18th and 19th March,

1937. The results are shown in Tables 7 and 8 and Figure 4.

Results: As seen from Figure 4, the mean value of the water absorption at 20°C was 1.74 and that of the stomatal aperture was 0.0333 and each of them was taken as the standard value for the first day. But the rate of water absorption decreased suddenly to a certain constant value about one hour after the transference of the plant from water of 20°C into that of 10°C (↓). The value of the water absorption was 1.34 being 76.7 expressed in percentage of the standard value. The leaves were as turgid as before, in spite of the sudden decrease of the water temperature. The value of the stomatal aperture was 0.0329, or 98.9 expressed in percentage of the standard value.

On the second day the rate of water absorption much decreased compared with that of the previous day and the mean value was 0.98. The stomata opened wider than on the previous day and the mean value of the aperture became 0.0412. When the plant was replaced in water of the initial temperature 20°C (↑), the water absorption increased gradually, and about one hour after the transference a certain constant value 1.17 was reached. The stomatal opening attained also a certain constant value 0.0301 about one hour after the transference.

Accordingly, on the second day the water absorption was 83.6 and the stomatal aperture was 136.8 expressed in percentage, if each corresponding standard value was taken as 100. From these results, it will be clearly seen that the decrease of the water temperature from 20°C to 10°C on the first day caused no remarkable change in the stomatal aperture, but on the second day, a slight widening of the stomata resulted.

Experiment 5: The variations of the water absorption and of the stomatal aperture after the transference from 20°C water into 15°C water were examined. The experiment was carried out on the 15th and 16th April, 1937. The results are shown in Tables 9 and 10 and Figure 5.

Results: As seen from Tables 9 and 10 and Figure 5, the standard value of the water absorption on the first day at 20°C was 1.49 and that of the stomatal aperture was 0.0287. About one hour after the plant was transferred from 20°C into 15°C water (↓), the rate of water absorption decreased gradually and attained a new constant value 1.33, which is 81.9 expressed in percentage of the standard value. The leaves were as turgid as before the transference and no remarkable variation of the stomatal aperture was observed. The stomatal aperture was 0.0293 which is 102.0 expressed in percentage of the standard value. From these data, it may be assumed that the change of the water temperature worked no significant effect upon the stomatal opening on the first day.

On the second day the rate of water absorption much decreased compared with that on the previous day. The stomata were opened as wide as on the previous day showing a value of 0.0306. When the cut plant was again placed in water of the initial temperature, 20°C (↑), the water absorption increased suddenly until a certain constant value of 1.21 was attained about one hour after the transference. A slight closure of the stomata resulted; its value became 0.0283.

Experiment 6: In the above experiments, the variations of water absorption and of the stomatal aperture after the transference from 20°C into colder water were measured, but in the present experiment the plant was transferred from water of 20°C into warmer water, viz., of 25°C, and the variations were measured. The experiment was carried out on the 2nd and 3rd June, 1937. The results are shown in Tables 11 and 12 and Figure 6.

Results: As seen from Figure 6, the standard value of the water absorption on the first day at 20°C was 1.92 and that of the stomatal aperture was 0.0344. Upon the transference of the plant into water of 25°C (↑), the rate of water absorption increased gradually to the value 2.12, which corresponds to 110.2 expressed in percentage of the standard. After the transference, a certain widening of the stomata resulted. The value of the stomatal aperture became 0.0343 which is 99.8 expressed in percentage of the standard.

On the second day the rate of water absorption decreased a little compared with that on the previous day to a value, namely, of 0.0434. When the plant was restored to the water of 20°C (↓), a sudden depression of the water absorption occurred, and then it increased gradually until a new lower balanced rate (1.77) was attained. The stomata showed gradual closure and the aperture reached a certain balanced condition (0.0385) about one hour after the transference. On the second day of the experiment, accordingly, the water absorption was 101.9% and the stomatal aperture was 112.8%, taking each corresponding standard value on the same day as 100.

From this result it will clearly be seen that the rise of the water temperature by 5°C on the first day caused a certain increase of the rate of water absorption, but on the second day the initial value was restored. The stomata opened much wider as a result of the same treatment on the second day, while on the first day no change of the stomatal aperture took place.

Experiment 7: The variations of the stomatal aperture and of the water absorption after the plant was transferred from 20°C into 30°C water were measured. The experiment was carried out on the 23rd and 24th June, 1937. The results are shown in Tables 13 and 14 and Figure 7.

Results: As seen from Figure 7, the standard value of the water absorption on the first day at 20°C was 1.45 and that of the stomatal aperture was 0.0244. After the transference of the plant from 20°C water into 30°C (↑), the water absorption increased gradually showing a narrow fluctuation during about one hour after the transference. The mean value of the water absorption became 2.09, being 144.0 expressed in percentage of the standard value. No remarkable variation of the stomatal opening was measured after the transference in spite of the large increase in water absorption. The mean value of the stomatal aperture was 0.0223 or 99.8 expressed in percentage of the corresponding standard value.

On the second day the rate of water absorption much decreased compared with that on the previous day, and its mean value was 0.0232. When the initial water temperature 20°C (↓) was restored, the rate of water absorption decreased suddenly and a fluctuation followed it during about one hour after the transference. Between 16.30 and 18.15 o'clock the mean value was 1.58 which served as the standard value. The stomata tended to close to a slight degree after the transference. The mean value was 0.0220 between 16.30 and 18.00 o'clock. On the second day of the experiment, accordingly, the rate of water absorption was 106.5% and the stomatal aperture was 105.6%, if each of the corresponding standard values was taken as 100.

In order to facilitate the understanding of all the experimental results, they are summarized in the following Tables A and B and Figure A:

TABLE A

Water absorption by the cut plant kept in water of varied tempertures. Each value obtained in water at 20°C was taken as 100.

Temperature (C°)	0°	5°	10°	15°	20°	25°	30°
Water absorption on the first day (%)	70.2	77.8	76.8	89.1	100.0	110.2	144.0
Water absorption on the second day (%)	78.3	81.1	83.6	82.3	100.0	101.9	106.5

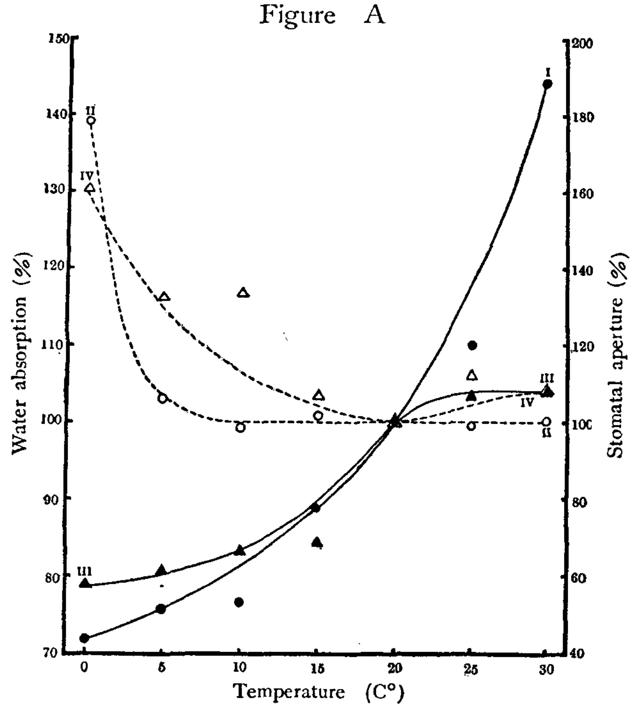
TABLE B

Variations of stomatal aperture of the cut plants kept in water of varied temperatures. Each value obtained in water of 20°C was taken as 100.

Temperature (C°)	0°	5°	10°	15°	20°	25°	30°
Stomatal aperture on the first day (%)	179.9	103.6	98.9	102.0	100.0	99.8	99.8
Stomatal aperture on the second day (%)	161.1	132.9	136.8	107.9	100 0	112.8	105.6

The results are quite comprehensible from Figure A.

Figure A



I———I (●—●—●): Water absorption on the first day
II———II (o----o----o): Stomatal aperture on the first day
III———III (▲—▲—▲): Water absorption on the second day
IV———IV (△---△---△): Stomatal aperture on the second day

Discussion

As reported in the previous paper (1937), the first contribution to the knowledge of the influence of low temperature upon the water absorption of the root was made by SACHS (1860). Following SACHS many authors paid much attention to this problem and a number of interesting observations were made. The water economy in a plant is intimately related to the balance between the transpiration and the water absorption. Accordingly, the remarkable increase of the former or the rapid depression of the latter, which is due to the increase of the resistance of plasma of root cell to penetration of water, causes a marked disturbance of the water economy of of the plant. According to RYSSELBEGHE (1901), EWART (1905), GATES (1914), DELF (1916), STILES (1917), STILES and JØRGENSEN (1917), BODE (1923), HEYL (1933), DÖRING (1935), in the investigation of the unfavourable influence of low temperature upon the water economy of the plant, mainly the disturbance of this balance must be taken into consideration.

As to what part of the tissue in the root may play the main rôle in water absorption, SCOTT and PRIESTLY (1928) expressed the following opinion:

(a) When water is present in excess in soil, and is in a state free to move to the plant, the soil solution permeates the cellulose walls of the cortex, and the cortical and endodermal cells take up water until they are turgid. In such a case the root cortex may be looked upon as a sponge-work of cellulose walls, but this sponge-work is interrupted at the endodermis by the Casparian strips. Accordingly the protoplasts of the endodermal cells act as a semipermeable membrane across which water is drawn from the outer tangential walls by the osmotic pull of the stelar solution in the inner tangential walls. Under these conditions the surface area of the root is not important.

(b) In drier soils water is less free to move in the soil, and under these conditions importance attaches to the increase in root surface due to growth and production of root hairs.

As the present investigations were carried out with plants kept in water, only case (a) is applicable, keeping case (b) out of consideration. The influence of the temperature on the penetration of water through such a sponge-work of the cellulose wall of the root cortex may be negligible, but importance must be attached rather to the influence of temperature upon the resistance of the protoplast of the endodermal cells to the penetration of water. In the previous paper (1937) it was reported, that the sudden decrease of the rate of water absorption after the transference of the plant into water below 20°C on the first day, was followed by its gradual increase up to a new constant value on the second. This may be probably explained by the assumption of a change of plasma resistance of the root cells mentioned above. Now what conditions are to be seen in the case of the cut plant? When a cut plant was transferred into water of lower temperature the rate of water absorption decreased gradually and then attained to a new lower constant value about one hour after the transference. From Figure A it will be seen that the variation of the water temperature was intimately correlated with the rate of water absorption without the root system. As the cause of the change of water absorption of the cut plant, which took place when the water temperature was suddenly lowered, the variation of the suction force of the plant top and the conducting tissue may be taken into consideration. (RENNER 1911, 1915, 1918, HOLLE 1915, JOST 1916, HUBER 1923, 1924, 1925, BODE 1923, CHU, 1936). On this point the writer will later discuss after the pursuance of further experiments.

It is generally accepted that when a plant is not well suplied with water and exists in a slightly wilted condition, the stomata would always close. In recent years, however, DARWIN (1916), LAIDLAW and KNIGHT (1916), MOLISCH (1912) and WEBER (1927) have contradicted this statement after finding stomata still open when plants were in a badly wilted condition. WEBER (1927) ascertained that the stomata of many of the herbaceous plants remained open or rather widely open, for a few hours after the commencement of wilting in the natural growing place. BENECKE (1924) explained such a phenomenon as follows: The regulation of the osmotic value of the guard cell which is necesary for the closure of the stomata, can not run parallel to the rapid variation of the external conditions. STÅLFELT (1927) studied the mechanism of the stomatal movement in detail, using *Vicia Faba* as material, and distinguished the stomatal movement into two phases, that is,

1. Stretching phase (Die Spannungsphase)
2. Motive phase (Die motorische Phase)

He ascertained at first under the microscope the increase of the width of the guard cell at the commencement of the stomatal opening. The guard cell absorbed a certain amount of water from the auxiliary cells. Water absorption by the auxiliary cells from the surrounding epidermal cells urged that by the guard cells too. When the turgor pressure of the guard cell attained a certain value the opening of the central slit was observed, pushing aside the auxiliary and epidermal cells. According to him, the stretching phase means the time between the beginning of the increase of the width of the guard cell and the appearance of the opening of the central slit. The motive phase means the time between the very moment of the appearance of the central slit and the attainment of a certain aperture. The stomatal opening, accordingly, could be expected after the attainment of a certain turgor pressure of the guard cells by which the auxiliary and epidermal cells may be pushed aside. As a suitable example for this explanation, the results obtained by WEBER (1927) may be pointed out. He immersed the wilted leaf, of which the stomata were opened, in water or in an 8% sucrose solution, and observed a rapid closure of the stomata in the former, while in the latter all of the stomata remained open as wide as before. These phenomena may be explained as follows: In water, the auxiliary, epidermal and other mesophyll cells can absorb water enough to recover the initial turgescence and the stomatal closure is induced passively, owing to the side pressure of the cells. While in the sucrose solution the mesophyll cell of the wilted plant can not absorb enough water from the solution to recover the lost turgescence. Consequently the stomata remained open as before. Recently MONZI (1938) ascertained the facts, that the stomata of the fresh leaves of *Fatsia* closed suddenly when rain began and then gradually opened. But in the case of the wilted plant the stomata opened widely at first and a gradual closure followed. After the rain a rapid widening of the stomata of the fresh as well as wilted leaves was observed, but a new closing movement happened after a certain time in both cases. According to him such a peculiar opening and closing of stomata as observed in the rain is mainly to be attributed to the turgor difference between the guard cells on the one hand and the auxiliary and epidermal cells on the other hand, which was induced by the retardation of transpiration owing to the sudden increase of the atmospheric humidity by the rain.

In his previous paper (1937), the writer has reported that after the intact plant was transferred from water of 20°C into that of varied lower temperatures the stomata opened wider than at the initial temperature 20°C, in spite of the flaccid state of the plant leaves due to the decrease of the water absorption. In this case a close connection between such remarkable opening of the stomata and the water temperature may be accepted. In the present work, where the root was cut away, no remarkable change of the leaf turgescence was observed in spite of the gradual decrease of water absorption after the plant was transferred into water below 20°C. The stomata remained open as wide as before, except in the case at 0°C water on the first day. On the second day, however, a slight widening of the stomatal opening was observed accompanied by a slight decrease of the leaf turgescence due to the decrease of the water absorption. When the initial water temperature 20°C was restored, a rapid closure of the stomata was observed, owing to the increase of the water absorption and the recovery of the leaf turgescence. From this fact a close connection between the stomatal aperture and the water temperature may also be accepted. Such a remarkable difference of the stomatal opening observed between the intact and the cut plant seems not only to be due to the existence of the root system, but also to the influence of the water temperature upon the top of the plant, especially upon the conducting tissues. In the case of the intact plant the leaves wilted badly shortly after the transference, owing to the sudden depression of the water absorption. The remarkable opening of the stomata observed under such conditions may be attributed to the decrease of the side pressure of the epidermal cells upon the guard cells, as pointed out by WEBER (1927). In the case of the cut plant, however, the rate of water absorption decreased gradually and then attained a new low constant value about one hour after the transference. The leaves in appearance showed no sign of wilting and the stomata were also opened as wide as before. When the transpiration as well as the water absorption decreased, the turgor pressure of the guard cells and that of the surrounding epidermal cells just balanced. No remarkable variation of the stomatal aperture was caused and the water balance was so barely kept that no change of the leaf turgescence happened. The duration of such an unstable condition, however, will cause the decrease of the turgor pressure of the mesophyll cells and the widening of the stomatal opening might result passively. When the initial water temperature 20°C was restored a sudden closure of the stomata was observed. Such a rapid stomatal closure may be attributed to the sudden increase of the side pressure of the mesophyll cells upon the guard cell, which occurs when the turgescence of the epidermal cells is recovered, owing to the rapid increase of the water supply.

Summary

1. The present investigation was carried out in order to make clear the variation of the water absorption and that of the stomatal aperture, when the water temperature was changed, while air temperature, atmospheric humidity and light intensity were kept constant. A seedling of *Phaseolus vulgaris*, of which the root was cut away, was used as material.

2. Within a temperature range between 0°C and 30°C, a rise of the

water temperature caused an increase in the rate of water absorption, similarly as in the previous experiment using intact plant (1937). But the amount of water absorbed by the cut plant seems a little larger than that observed by the intact one. These results suggest that the retarding and accelerating influence of the water temperature upon the water absorption act not only on the absorbing function of the root itself, but also on the suction activity of the leaves and of the conducting tissue of the stem.

3. On the first day of the experiment, no remarkable change of the stomatal aperture was observed after the plant was transferred into water below 20°C, except in the case at 0°C. On the second day, however, a widening of the stomatal opening took place accompanied by a slight decrease of the leaf turgescence due to the decrease of the water absorption. When the initial water temperature of 20°C was restored, a rapid closure of the stomata was observed, owing to the increase of the water absorption and the recovery of the leaf turgescence. Under these conditions, it may be stated that the variation of the stomatal aperture is due not only to the change of the turgor pressure of the guard cells themselves, but also passively to the variation of the side pressure of the epidermal cells.

The writer wishes to express his sincere gratitude and hearty thanks to Prof. T. SAKAMURA for his suggestions and guidance in the present work.

TABLE I

Amount of water absorbed by a plant, of which root system was cut away, under continuous illumination, 5 and 6 days after transference from the natural condition. Each measurement was made at intervals of 15 minutes. Air temperature 25°C, water temperature 20°C and atmospheric humidity 60%.

5 days after transference (Time)	Amount of water absorbed	6 days after transference (Time)	Amount of water absorbed
10.00	0.70	9.30	0.60
10.15	0.70	9.45	0.60
10.30	0.75	10.00	0.50
10.45	0.70	10.15	0.60
11.00	0.75	10.30	0.60
11.15	0.65	10.45	0.55
11.30	0.70	11.00	0.55
11.45	0.65	11.15	0.60
12.00	0.70	11.30	0.60
12.15	0.70	11.45	0.55
12.30	0.70	12.00	0.55
12.45	0.65	12.15	0.60
13.00	0.70	12.30	0.60
13.15	6.65	12.45	0.55
13.30	0.65	13.00	0.55
13.45	0.70	13.15	0.60
14.00	0.70	13.30	0.55
14.15	0.65	13.45	0.55
14.30	0.70	14.00	0.55
14.45	0.65	14.15	0.60
15.00	6.70	14.30	0.60
15.15	0.65	14.45	0.55
15.30	0.70	15.00	0.55
15.45	0.70	15.15	0.55
16.00	0.70	15.30	0.55
16.15	0.70	15.45	0.60
16.30	0.70	16.00	0.60
16.45	0.70	16.15	0.60
17.00	0.70	16.30	0.60
17.15	0.70	16.45	0.60
17.30	0.70	17.00	0.60
17.45	0.70	17.15	0.60
18.00	0.70	17.30	0.60
Mean value	0.69	17.45	0.55
		18.00	0.60
		Mean value	0.58

TABLE 2

Variation of the stomatal aperture under constant and continuous illumination, 5 and 6 days after transference from natural condition. The root system of the plant was cut away. Air temperature 25°C, water temperature 20°C and atmospheric humidity 60 %.

5 days after transference (Time)	Stomatal aperture	6 days after transference (Time)	Stomatal aperture
10.00	0.0232	9.30	0.0200
10.30	0.0232	10.00	0.0217
11.00	0.0238	10.30	0.0213
11.30	0.0217	11.00	0.0208
12.00	0.0238	11.30	0.0222
12.30	0.0227	12.00	0.0227
13.00	0.0227	12.30	0.0227
13.30	0.0240	13.00	0.0213
14.00	0.0240	13.30	0.0182
14.30	0.0213	14.00	0.0200
15.00	0.0238	14.30	0.0182
15.30	0.0232	15.00	0.0213
16.00	0.0227	15.30	0.0182
16.30	0.0227	16.00	0.0222
17.00	0.0213	16.30	0.0217
17.30	0.0213	17.00	0.0200
18.00	0.0213	17.30	0.0196
Mean value	0.0227	18.00	0.0189
		Mean value	0.0206

TABLE 3

Variation of the water absorption of a plant of which the root system was cut away, after transference from water of 20°C into that of 0°C.

5 days after transference (Time)	Amount of water absorbed
12.00	3.30
12.15	3.15
12.30	3.15
12.45	2.85
13.00	2.85
13.15	2.75
13.30	2.75
13.45	2.75
14.00	2.75
Mean value	2.92
In water at 0°C	
14.45	1.90
15.00	1.10
15.15	1.60
15.30	1.80
15.45	1.60
16.00	1.60
16.15	2.00
16.30	2.00
16.45	1.95
17.00	1.95
17.15	2.00
17.30	2.00
17.45	2.10
18.00	2.10
18.15	2.50
18.30	2.50
18.45	2.00
19.00	2.00
Mean value	2.05

6 days after transference (Time)	Amount of water absorbed
10.00	2.00
10.15	1.70
10.30	1.70
10.45	1.90
11.00	2.40
11.15	2.40
11.30	2.45
11.45	2.35
12.00	2.30
12.15	2.45
12.30	2.45
12.45	2.20
13.00	2.20
13.15	2.20
13.30	2.10
13.45	2.05
14.00	2.05
14.15	2.05
14.30	2.05
14.45	2.05
15.00	2.00
Mean value	2.15
In water at 20°C	
15.45	2.25
16.00	2.45
16.15	2.90
16.30	2.90
16.45	2.65
17.00	2.65
17.15	2.80
17.30	2.75
17.45	2.75
18.00	2.75
18.15	2.75
18.30	2.75
18.45	2.75
19.00	2.75
Mean value	2.74

TABLE 4

Variation of the stomatal aperture of a plant of which the root system was cut away, after transference of the plant from water of 20°C into that of 0°C.

5 days after transference (Time)	Stomatal aperture
12.00	0.0400
12.30	0.0385
13.00	0.0385
13.30	0.0400
14.00	0.0400
Mean value	0.0394
In water at 0°C	
14.30	0.0500
15.00	0.0529
15.30	0.0556
16.00	0.0588
16.30	0.0625
17.00	0.0625
17.30	0.0667
18.00	0.0714
18.30	0.0833
19.00	0.0909
Mean value	0.0709

6 days after transference (Time)	Stomatal aperture
10.00	0.0833
10.30	0.0769
11.00	0.0769
11.30	0.0769
12.00	0.0833
12.30	0.0769
13.00	0.0833
13.30	0.0769
14.00	0.0769
14.30	0.0769
15.00	0·0714
Mean value	0.0781
In water at 20°C	
16.00	0.0556
16.30	0.0500
17.00	0.0500
17.30	0.0500
18.00	0.0476
18.30	0.0455
19.00	0.0476
Mean value	0.0485

TABLE 5

Variation of the water absorption of a plant of which the root system was cut away, after transference of the plant from water of 20°C into that of 5°C.

5 days after transference (Time)	Amount of water absorbed
11.00	1.45
11.15	1.45
11.30	1.50
11.45	1.50
12.00	1.45
12.15	1.50
12.30	1.45
12.45	1.30
13.00	1.30
13.15	1.35
13.30	1.30
13.45	1.40
14.00	1.40
Mean value	1.41
In water at 5°C.	
14.30	0.90
14 45	0.80
15.00	0.75
15.15	0.80
15.30	0.90
15.45	0.80
16.00	0.95
16.15	1.00
16.30	1.00
16.45	1.10
17.00	1.05
17.15	1.10
17.30	1.10
17.45	1.10
18.00	1.15
18.15	1.15
18.30	1.15
18.45	1.15
19.00	1.15
19.15	1.15
19.30	1.15
Mean value	1.09

6 days after transference (Time)	Amount of water absorbed
10.00	0.60
10.15	0.60
10.30	0.60
10.45	0.60
11.00	0.60
11.15	0.60
11.30	0.60
11.45	0.65
12.00	0.65
12.15	0.65
12.30	0.65
12.45	0.70
13.00	0.70
13.15	0.70
13.30	0.70
13.45	0.70
14.00	0.70
14.15	0.70
14.30	0.70
14.45	0.70
15.00	0.70
Mean value	0.657
In water at 20°C.	
15.30	1.05
15.45	1.00
16.00	0.95
16.15	0.85
16.30	0.85
16.45	0.85
17.00	0.80
17.15	0.80
17.30	0.80
17.45	0.80
18.00	0.80
Mean value	0.81

TABLE 6

Variation of the stomatal aperture of a plant of which the root system was cut away, after transference of the plant from water of 20°C into that of 5°C.

5 days after transference (Time)	Stomatal aperture
11.00	0.0286
11.30	0.0286
12.00	0.0286
12.30	0.0289
13.00	0.0286
13.30	0.0278
14.00	0.0278
Mean value	0.0284
In water at 5°C.	
14.30	0.0294
15.00	0.0263
15.30	0.0294
16.00	0.0294
16.30	0.0294
17.00	0.0263
17.30	0.0278
18.00	0.0286
18.30	0.0303
19.00	0.0313
19.30	0.0323
Mean value	0.0294

6 days after transference (Time)	Stomatal aperture
10.00	0.0333
10.30	0.0313
11.00	0.0303
11.30	0.0294
12.00	0.0303
12.30	0.0294
13.00	0.0294
13.30	0.0286
14.00	0.0286
14.30	0.0286
15.00	0.0313
Mean value	0.0300
In water at 20°C.	
15.30	0.0250
16.00	0.0250
16.30	0.0238
17.00	0.0222
17.30	0.0222
18.00	0.0222
	0.0222
Mean value	0.0226

TABLE 7

Variation of the water absorption of a plant of which the root system was cut away, after transference from water of 20°C into that of 10°C.

5 days after transference (Time)	Amount of water absorbed	6 days after transference (Time)	Amount of water absorbed
11.00	1.80	10.00	1.00
11.15	1.80	10.15	1.00
11.30	1.90	10.30	1.00
11.45	1.75	10.45	1.00
12.00	1.70	11.00	1.00
12.15	1.80	11.15	1.00
12.30	1.80	11.30	1.00
12.45	1.60	11.45	1.00
13.00	1.60	12.00	1.00
13.15	1.60	12.15	1.00
13.30	1.70	12.30	1.00
13.45	1.90	12.45	1.00
14.00	1.70	13.00	1.00
14.15	1.70	13.15	1.00
14.30	1.70	13.30	0.95
Mean value	1.74	13.45	0.95
		14.00	0.95
In water at 10°C.		14.15	0.90
		14.30	1.00
15.00	1.70	14.45	0.95
15.15	1.45	15.00	0.95
15.30	1.35	15.15	0.95
15.45	1.40	15.30	0.95
16.00	1.35	15.45	0.95
16.15	1.35	16.00	0.95
16.30	1.40	Mean value	0.978
16.45	1.40		
17.00	1.40	In water at 20°C.	
17.15	1.35		
17.30	1.35	16.30	1.00
17.45	1.30	16.45	1.00
18.00	1.30	17.00	1.15
18.15	1.30	17.15	1.15
18.30	1.30	17.30	1.20
18.45	1.30	17.45	1.15
19.00	1.30	18.00	1.15
Mean value	1.34	18.15	1.15
		18.30	1.20
		Mean value	1.17

TABLE 8

Variation of the stomatal aperture of a plant of which the root system was cut away, after transference from water of 20°C into that of 10°C.

5 days after transference (Time)	Stomatal aperture
11.00	0.0322
11.30	0.0322
12.00	0.0333
12.30	0.0333
13.00	0.0333
13.30	0.0333
14.00	0.0345
14.30	0.0345
Mean value	0.0333
In water at 10°C.	
15.00	0.0345
15.00	0.0333
16.00	0.3222
16.30	0.0333
17.00	0.0313
17.30	0.0333
18.00	0.0333
18.30	0.0333
19.00	0.0333
Mean value	0.0329

6 days after transference (Time)	Stomatal aperture
10.00	0.0417
10.30	0.0435
11.00	0.0435
11.30	0.0417
12.00	0.0400
12.30	0.0400
13.00	0.0400
13.30	0.0400
14.00	0.0417
14.30	0.0417
15.00	0.0417
15.30	0.0400
16.00	0.0400
Mean value	0.0412
In water at 20°C.	
16.30	0.0345
17.00	0.0312
17.30	0.0303
18.00	0.0303
18.30	0.0286
Mean value	0.0301

TABLE 9

Variation of the water absorption of a plant of which the root system was cut away, after transference from water of 20°C into that of 15°C.

5 days after transference (Time)	Amount of water	6 days after transference (Time)	Amount of water absorbed
10.00	1.40	9.30	1.10
10.15	1.55	9.45	1.00
10.30	1.55	10.00	1.00
10.45	1.50	10.15	1.00
11.00	1.45	10.30	0.90
11.15	1.60	10.45	1.00
11.30	1.55	11.00	1.00
11 45	1.50	11.15	1.00
12.00	1.45	11.30	1.00
12.15	1.50	11.45	1.00
12.30	1.45	12.00	1.05
12.45	1.45	12.15	1.00
13.00	1.45	12.30	1.00
13.15	1.50	12.45	0.90
13.30	1.55	13.00	1.00
13.45	1.45	13.15	0.90
14.00	1.45	13.30	1.00
Mean value	1.49	13.45	1.00
In water at 15°C.		14.15	1.00
14.30	1.35	14.30	1.00
14.45	1.30	14.45	1.00
15.00	1.40	15.00	1.00
15.15	1.40	15.15	1.05
15.30	1.35	15.30	1.05
15 45	1.25	15.45	1.00
16.00	1.25	16.00	1.00
16.15	1.30	Mean value	0.99
16.30	1.30	In water at 20°C.	
16.45	1.30	16.30	1.00
17.00	1.35	16.45	1.10
17.15	1.40	17.00	1.20
17.30	1.40	17.15	1.20
17.45	1.35	17.30	1.25
18.00	1.35	17.45	1.25
18.15	1.35	18.00	1.25
18.30	1.30	18.15	1.25
18.45	1.30	18.30	1.10
19.00	1.30	18.45	1.10
Mean value	1.33	19.00	1.25
		Mean value	1.21

TABLE 10

Variation of the stomatal aperture of a plant of which the root system was cut away on the previous evening, after transference from water of 20°C into that of 15°C.

5 days after transference (Time)	Stomatal aperture
10.00	0.0282
10.30	0.0286
11.00	0.0282
11.30	0.0282
12.00	0.0294
12.30	0.0303
13.00	0.0294
13.30	0.0270
14.00	0.0294
Mean value	0.0287
In water at 15°C.	
14.30	0.0294
15.00	0.0294
15.30	0.0303
16.00	0.0313
16.30	0.0286
17.00	0.0270
17.30	0.0303
18.00	0.0294
18.30	0.0290
19.00	0.0294
Mean value	0.0293

6 days after transference (Time)	Stomatal aperture
9.30	0.0313
10.00	0.0313
10.30	0.0317
11.00	0.0313
11.30	0.0294
12.00	0.0286
12.30	0.0323
13.00	0.0303
13.30	0.0294
14.00	0.0308
14.30	0.0294
15.00	0.0303
15.30	0.0313
16.00	0.0303
Mean value	0.0306
In water at 20C°	
16.30	0.0313
17.00	0.0299
17.30	0.0289
18.00	0.0286
18.30	0.0278
19.00	0.0279
Mean value	0.0283

TABLE II

Variation of the water absorption of plant of which the root system was cut away on the previous evening, after transference from water of 20°C into that of 25°C.

5 days after transference (Time)	Amount of water absorbed
11.45	1.95
12.00	1.95
12.15	1.95
12.30	1.95
12.45	1.95
13.00	1.95
13.15	1.95
13.30	1.95
13.45	1.85
14.00	1.85
14.15	1.85
14.30	1.90
Mean value	1.92
In water at 25°C.	
15.00	1.90
15.15	2.00
15.30	2.00
15.45	2.00
16.00	2.00
16.15	2.00
16.30	2.00
16.45	2.20
17.00	2.20
17.15	2.20
17.30	2.20
17.45	2.05
18.00	2.05
18.15	2.15
18.30	2.15
18.45	2.15
19.00	2.15
Mean value	2.12

6 days after transference (Time)	Amount of water absorbed
9.30	2.10
9.45	1.90
10.00	1.90
10.15	1.75
10.30	1.75
10.45	1.75
11.00	1.75
11.15	1.85
11.30	1.85
11.45	1.85
12.00	1.85
12.15	1.70
12.30	1.70
12.45	1.70
13.00	1.75
13.15	1.80
13.30	1.80
13.45	1.75
14.00	1.80
14.15	1.80
14.30	1.80
14.45	1.80
15.00	1.80
15.15	1.80
15.30	1.80
Mean value	1.80
In water at 20°C.	
16.00	1.70
16.15	1.65
16.30	1.65
16.45	1.80
17.00	1.85
17.15	1.80
17.30	1.75
Mean value	1.77

Table 12

Variation of the stomatal aperture of a plant of which the root system was cut away on the previous evening, after transference from water of 20°C into that of 25°C.

5 days after transference (Time)	Stomatal aperture
11.30	0.0357
12.00	0.0357
12.30	0.0345
13.00	0.0357
13.30	0.0345
14.00	0.0323
14.30	0.0323
Mean value	0.0344
In water at 25°C.	
15.00	0.0333
15.30	0.0333
16.00	0.0357
16.30	0.0333
17.00	0.0333
17.30	0.0333
18.00	0.0357
18.30	0.0333
19.00	0.0357
Mean value	0.0343

6 days after transference (Time)	Stomatal aperture
9.30	0.0400
10.00	0.0417
10.30	0.0435
11.00	0.0455
11.30	0.0455
12.00	0.0444
12.30	0.0435
13.00	0.0455
13.30	0.0435
14.00	0.0417
14.30	0.0444
15.00	0.0435
15.30	0.0417
Mean value	0.0434
In water at 20°C.	
16.00	0.0400
16.30	0.0385
17.00	0.0385
17.30	0.0385
Mean value	0.0385

TABLE 13

Variation of the water absorption of a plant of which the root system was cut away on the previous evening, after transference from water of 20°C into that of 30C°.

5 days after transference (Time)	Amount of water absorbed
10.15	1.45
10.30	1.40
10.45	1.60
11.00	1.65
11.15	1.40
11.30	1.40
11.45	1.35
12.00	1.25
12.15	1.40
12.30	1.40
12.45	1.45
13.00	1.45
13.15	1.50
13.30	1.50
13.45	1.50
14.00	1.50
14.15	1.40
Mean value	1.45
In water at 30°C.	
15.00	1.90
15.15	2.00
15.30	2.20
15.45	2.20
16.00	2.00
16.15	2.00
16.30	2.10
16.45	2.15
17.00	2.15
17.15	2.20
17.30	2.20
17.45	2.15
18.00	2.15
18.15	2.10
18.30	2.10
18.45	2.05
19.00	2.05
19.15	2.05
19.30	2.05
19.45	2.00
20.00	2.00
Mean value	2.09

6 days after transference (Time)	Amount of water absorbed
9.45	1.65
10.00	1.40
10.15	1.40
10.30	1.40
10.45	1.30
11.00	1.30
11.15	1.50
11.30	1.50
11.45	1.40
12.00	1.40
12.15	1.60
12.30	1.60
12.45	1.70
13.00	1.70
13.15	1.70
13.30	1.70
13.45	1.80
14.00	1.80
14.15	2.00
14.30	2.00
14.45	2.00
15.00	2.00
Mean value	1.63
In water at 20°C.	
15.45	1.40
16.00	1.40
16.15	1.50
16.30	1.50
16.45	1.45
17.00	1.45
17.15	1.50
17.30	1.50
17.45	1.65
18.00	1.65
18.15	1.50
Mean value	1.53

TABLE 14

Variation of the stomatal aperture of a plant of which the root system was cut away on the previous evening, after transference from water of 20°C into that of 30°C.

5 days after transference (Time)	Stomatal aperture
10.00	0.0217
10.30	0.0222
11.00	0 0222
11.30	0.0222
12.00	0.0222
12.30	0.0227
13.00	0.0233
13.30	0.0233
14.00	0.0222
Mean value	0.0224
In water at 30°C.	
15.00	0.0222
15.30	0.0222
16.00	0.0222
16.30	0.0222
17.00	0.0222
17.30	0.0227
18.00	0.0222
18.30	0.0227
19.00	0.0222
19.30	0.0227
20.00	0.0222
Mean value	0.0223

6 days after transference (Time)	Stomatal aperture
9.30	0.0233
10.00	0.0233
10.30	0.0233
11.00	0.0238
11.30	0.0233
12.00	0.0233
12.30	0.0233
13.00	0.0233
13.30	0.0227
14.00	0.0227
14.30	0.0233
15.00	0.0227
Mean value	0.0233
In water at 20°C.	
15.30	0.0227
16.00	0.0220
16.30	0.0217
17.00	0.0222
17.30	1.0219
18.00	0.0222
Mean value	0.0220

Figure 1

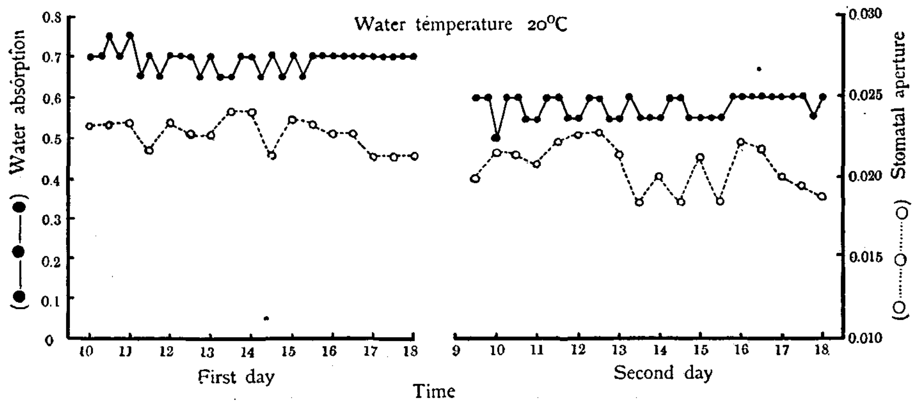


Figure 2

Water temperature 0°C

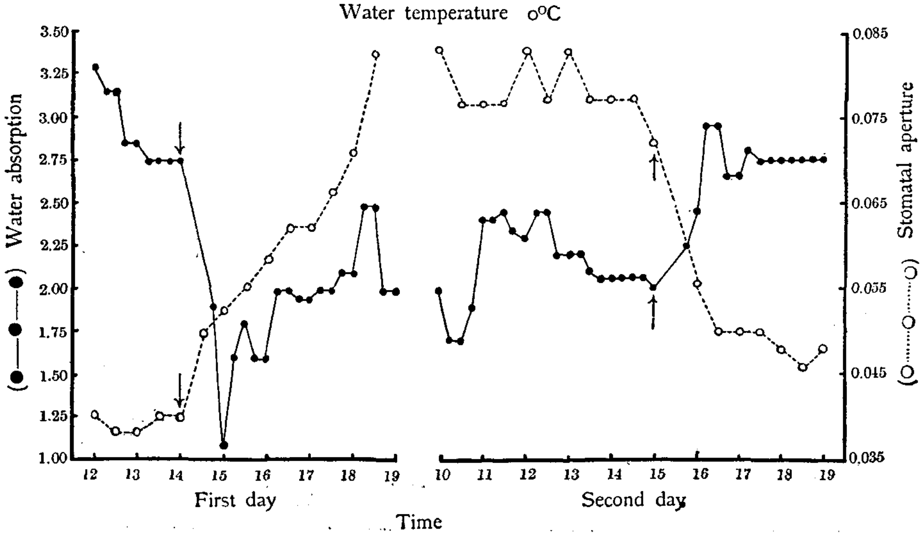


Figure 3

Water temperature 5°C

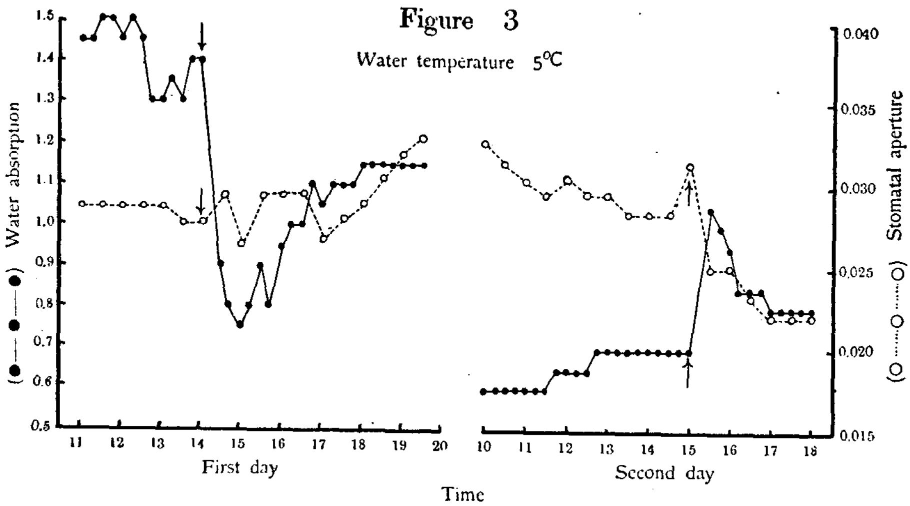


Figure 4

Water temperature 10°C

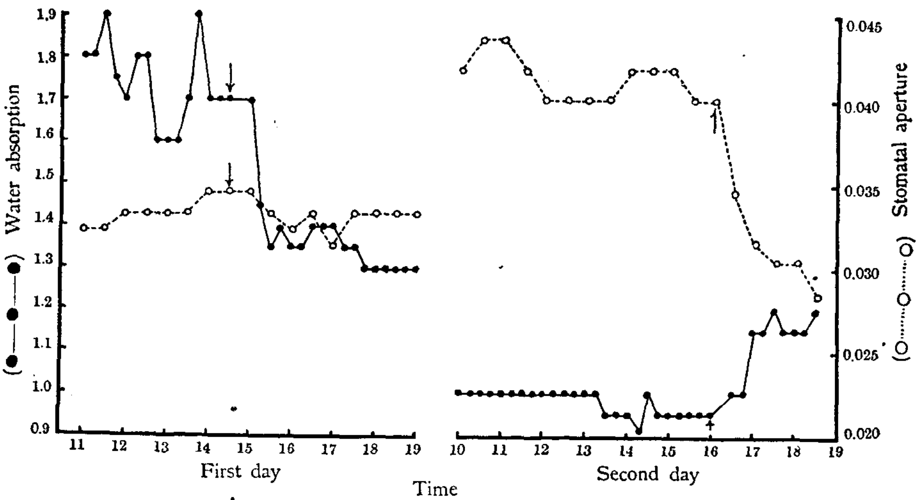


Figure 5

Water temperature 15°C

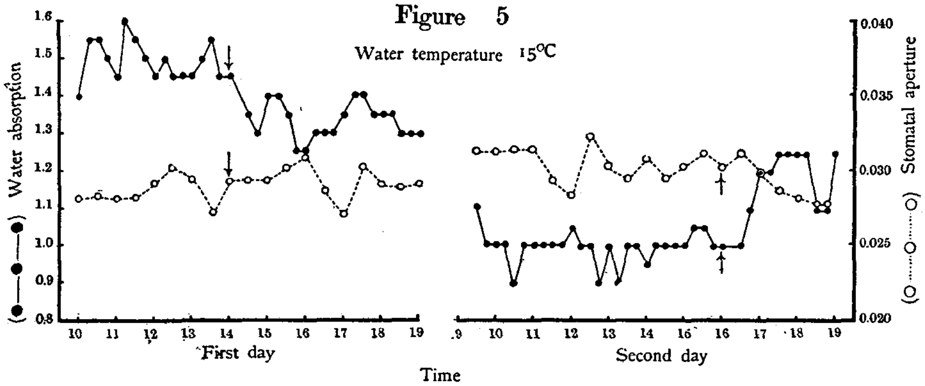


Figure 6

Water temperature 25°C

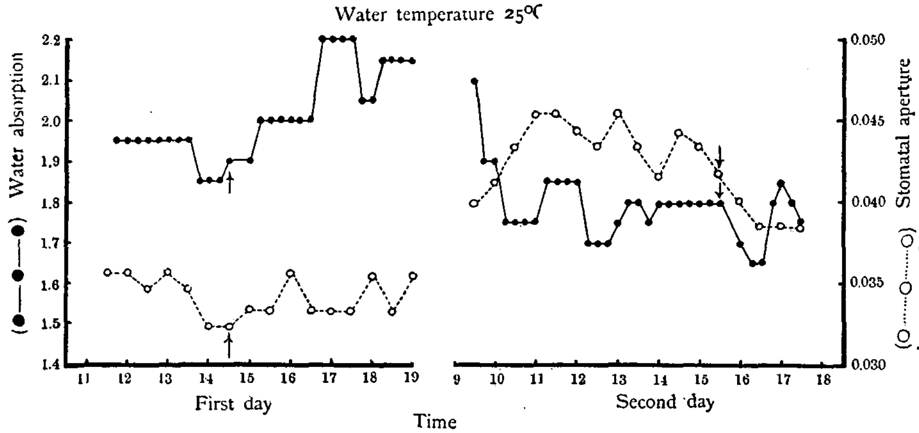
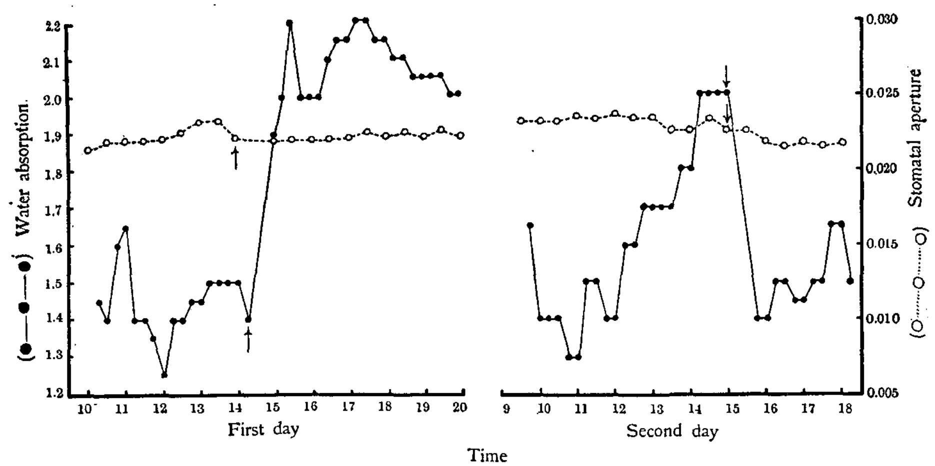


Figure 7

Water temperature 30°C



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