Memoirs of the College of Science, University of Kyoto, Series B,
Vol. XX, No. 3, Article 8, 1953.

Leaf Temperatures under Natural Environments (Microclimatic Study V*)

By

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(Received June 6, 1952)

1. Introduction

The mutual action exists between plant and the environmental climatic elements. That is, vegetation suffers from environmental elements especially from the climate in the lowest layer of atmosphere, and conversely the vegetation makes the climate change and forms the so-called plant climate. The environmental climatic elements in connection with the plant may be considered from various stand points. Many basic problems in the plant physiology such as assimilation or transpiration can not be explained without clarification of the enviromental factors surrounding the plants, and also it is no exaggeration to say that the plant ecology is in greater parts concerned with the relationship between plants and climate. But up to this time, the factors have been considered too often only from the general climatic or meteorological points, due to difficulties in the measurements and want of data. And now, at length, the development of microclimatic or micrometeorological methods brought the fields of plant physiology and plant ecology under reinvestigation. The present writer carried out, on the one hand, the microclimatic observations on the simple surface of various natures which could be considered as the foundation of microclimate, and on the other hand, attempted to reinvestigate the plant environment. First the relation between plant temperature, especially leaf-temperature, and the environmental elements is studied. Many reports have been published on the leaf-temperature, Huber[1] and Mäde,[2] for instance, studied the daily changes of leaf-temperature of various plants, employing the self-recording galvanometer of dotting system. And yet the continuous recording of leaf-temperature, especially with simultaneous records of air temperature, solar energy and wind velocity, has not be seen. The recording galvanometer of dotting-system may be convenient to study the changes throughout the whole day. But in order

* Microclimatic Study I-IV; Mem. Coll. Sci., Univ. Kyoto, Ser. A, Vol. XXV 1949 (I), Vol. XXVII 1952 (II-III). Vol. XXVIII 1953 (IV).

(1) Huber, Br.; Jahrb. f. wiss. Bot. 84, 1937.

(2) Mäde, A.: Bioklim. Beib. 6, 1939.

to record the instantaneous minute fluctuations precisely, and to study the correspondence between the leaf-temperature and the air temperature, wind velocity, solar energy, etc., the writer's recorder is advantageous, as it allows to make simultaneous records of several elements.

2. Method

For the convenience of manipulation in the field, the copper-constantan thermojunctions were directly connected to the galvanometer. The thermojunction was made flat at the joint so as to touch the leaf surface closely. And as indicated in Fig. 1, several centimeters of the leading wire was also made to touch the leaf surface to make the error owing to the heat conduction of the leading wire as small as possible. An end of the leaf being fixed, its surface was pressed by the thermojunction rather strongly so that the leaf itself assumed the form of the junction, and thus the touch being secured in winds. Though there have been many different shapes of thermojunctions[3] for leaf temperature measurement, the writer devised the special shapes, as indicated in Fig. 1 for the convenience of recording. The leaf temperature had usually been by touching the lower surface of leaf with the thermojunction, but now, applying the compensated thermojunction[4] previously mentioned, the actual leaf surface temperature could be measured at the upper surface of the leaf under direct sunshine, without being effected by radiation.

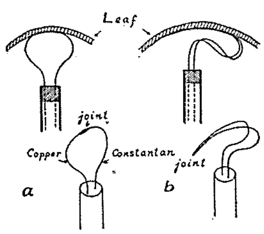


Fig. 1.

The environmental elements such as air temperature, soil temperature, (or water temperature), solar radiation (by Gorzinsky's solarimeter) and wind velocity (by hot-wire anemometer) were measured in the same manner as reported elsewhere[5]; the followings are the normal combinations, namely of the leaf temperature, air temperature near the leaf, surface temperature of soil, solar energy and wind velocity.

3. Some records showing leaf temperature and its microclimatic environmental factors

i) Leaf temperature of alpine plants

(a) Leaf temperature of *Veratrum stamineum Maxim.* (at the summit of Mt. Norikura)

(3) For instance; I. Tsuchiya (1935) and I. Hatakeyama (1939): Shokubutsu oyobi Dobutsu (in Japanese).
(4) Microclimatic Study II; Mem. Coll. Sci., Univ. Kyoto, Ser. A, Vol. XXVII, 1952.
(5) Cf. Microclimatic Study I: Preceding Memoirs.

Plate I-a is a record taken shortly after noon on July 18,1950 at the sumit of Mt. Norikura (ca. 2820m above sea level). Surface temperature of leaf of *Veratrum stamineum Maxim.* about 10 cm above the ground was measured by compensated thermojunctions as previously mentioned. As the environmental elements, solar radiation, air temperature around the leaf, surface temperature of the ground, and wind velocity (50 cm height) were recorded. The mean values from the record of 12h 11m–15m, when the solar radiation was almost constant, indicated that the leaf temperature was higher than the air temperature by about 4.1°C (Table 1.), and even at 52–56m, when shaded by cloud, still showed the difference of 2.7°C. (Table 2.)

Table 1.

		Air temp.	Leaf temp.	Soil temp.	Wind vel.	Sol. rad.
12h 11m –15m	Max.	22.9°C	25.5°C	43.2°C	2.3m/s	1.0gacl
	Min.	16.7	22.1	41.4	0.1	0.9
	Range	6.2	3.4			
	Mean	19.7	23.8	42.4	1.1	1.0

Table 2.

		Air temp.	Leaf temp.	Soil temp.	Wind vel.	Sol. rad.
12h 52m –56m	Max.	16.2°C	18.2°C	31.5°C	1.6m/s	0.2gcal
	Min.	13.4	16.7	27.4	0.3	0.1
	Range	2.9	1.4			
	Mean	14.8	17.5	28.6	0.9	0.1

(b) Leaf temperature of *Lagotis glauca Gaertn.* (at the summit of Mt. Shirouma)

Plate I-b is a record on 10h10m–11h10m, 16 July, 1943 at the summit ofMt. Shirouma (ca. 2720m above sea level). Leaf temperature measured by junction attached to the lower surface of *Lagotis glauca Gaertn.* (5 cm height), air temperature surrounding it, air temperature at 1m height, temperature of soil surface, solar radiation and wind velocity (10 cm height) were recorded simultaneously. There was a considerable fluctuation of solar radiation even though it was foggy, and the leaf temperature changed corresponding to it. In Table 3 are shown the maximum and the minimum temperatures in the whole record, the two values of 1 min. mean when the fluctuations were small, together with other environmental factors at those times.

Sudden increase of solar radiation brings about instantaneous rise of leaf temperature, but the latter falls gradually when the former decreases. For example, when the solar radiation rapidly increased from 1.26gcal. at 33.3min. to 2.3gcal. at 33.8min. and then dropped to 1.45gcal. at 34.1min., the corresponding leaf temperature rise began 0.4 min. later and the maximum temperature of 27°C appeared 0.2min. after the maximum of solar radiation, and then the leaf temperature gradually fell to 23.3°C in the course of 1.3min. whereas the solar radiation decreased rapidly. Surrounding air temperature measured under the leaf changed in parallel with the leaf temperature and temperature of the ground surface, but was quite independent of the air temperature at 1 m height. This is a remarkable feature at high mountains.

Table 3. Leaf temperature of *Lagotis glauca Gaertn.*

	Leaf temp.		Air temp.	1 m Air temp.	Soil temp.	Wind vel. (m/s)	Sol. rad. (gcal/cm²min)
10h 19m -20m	Max.	29.7°	26.4°	16.8°	34.0°	1.8	2.3 ⟶ 1.4
11h 06m -07m	Min.	17.8	17.9	12.0	28.0	3.0	0.5 ⟶ 0.6
10h 32m -33m	Max.	25.8°	24.4°	16.2°	32.2°	2.7	1.8
	Min.	25.2	22.3	12.0	31.9	0.4	1.5
	Range	0.6	2.1	4.2	0.3		
	Mean	25.5	23.4	14.1	32.1	1.4	1.7
10h 46m -47m	Max.	21.0°	21.5°	16.0°	30.0°	1.8	0.9
	Min.	20.3	19.4	11.7	29.8	(0.1)	0.7
	Range	0.7	2.1	4.3	0.2		
	Mean	20.7	20.5	13.9	29.9	0.9	0.8

ii) Leaf temperature of sand-dune plants

(a) Leaf temperature of *Phellopterus littoralis Fr. Schm.*

Plate II-a is a record on the sand-dune at Karo, Tottori Pref., in the afternoon Aug. 2, 1947. The measured elements were air temperature (4 cm height), temperature of sand surface, wind velocity (10 cm height), solar radiation and the temperature of petiole of about 2 cm underground. It was rather cloudy (8/10 Ci, Cu), and sea-breeze of about 3 m/s was blowing. The mean values derived from the record of 14h 20m–24m indicates that the temperatures of leaf (4.5 cm height) and air were 34.9° and 38.8°C respectively, the difference being 3.9°C. The leaf temperature appeared always lower by about 4°C than the air, the maximum difference in the record being 5.8°C. As this lowering is considered to be due to transpiration from the leaf surface, an attempt was made to prove this by cutting the leaf at the base of petiole to stop the water supply from the root, at 14h 25.5 m. There was no change for 1 min. after the cutting, then leaf temperature began to rise (as the record indicated) linearly for about 4 min., to be roughly equal to the air temperature. As no change could be seen in both records of solar energy and wind velocity during this experiment, this temperature rise must be due to impeded transpiration. Actually the leaf was found wilted with colour faded at the end of the measurement.

Table 4. Leaf temperature of *Phellopterus littoralis Fr. Schm.*

14h	Leaf temp (°C) Max	Min	Air temp (°C) Max	Min	Petiol temp. (°C)	Surf. temp. of sand (°C) Max	Min	Sol. rad. (gcal)	Wind vel. (m/s)
20m	35.3	34.4	41.1	36.5	39.5	55.5	55.0	1.17	2.5
21	35.7	34.5	40.9	36.5	39.5	55.6	55.5	1.20	3.0
22	35.8	34.5	41.3	36.3	39.7	55.8	55.6	1.20	2.9
23	35.7	33.8	41.7	36.3	39.7	55.9	55 5	1.17	3.0
24	34.8	34.0	41.2	36.0	39.7	55.6	55.4	1.15	2.8
Mean	35.46	34.24	41.24	36.32	39.62	55.68	55.40	1.18	2.8
	34.85		38.78			55.51			
* 25m	35.0	34.3	40.5	36.5	** –	55.7	55.4	1.12	3.0
26	35.7	34.5	40.6	36.7	–	55.7	55.4	1.12	2.8
27	37.2	35.3	41.5	36.6	39.7	55.6	55.4	1.12	3.1
28	38.1	36.7	41.2	37.7	39.7	55.7	55.4	1.13	3.0
29	38.5	37.7	41.8	37.8	39.8	55.7	55.7	1.13	3.5
30	38.8	38.0	40.2	36.7	39.8	56.1	55.7	1.14	2.7
31	39.4	38.2	41.7	36.5	39.9	56.3	55.8	1.15	2.3
32	40.0	38.8	42.5	36.7	40.0	56.6	56.3	1.15	2.7
33	39.3	38.3	40.8	36.2	40.1	56.8	56.6	1.15	2.5
34	39.4	38.7	41.2	37.0	40.2	56.9	56.4	1.13	3.1

* 25.5m : Cutting off the petiole.

** Petiole is exposed in the air owing to digging up sand for cutting it at the base.

From these experiments we easily recognise that the considerable temperature lowering is seen in the sand-dune plant. Reading values are shown in Table 4.

(b) Leaf temperature of *Vitex rotundifolia L. fil.*

Plate II-b is a record on the same sand-dune as (a), on 9h27m–10h12m, 2 Aug. The temperature of a leaf (2cm from the sand surface) on the creeping stalk, stalk temperature, air temperature around the leaf, sand surface temperature, solar radiation and wind velocity (10cm height) are recorded simultaneously. The normal state under the constant solar energy and the variations caused by cloud shadows are seen in the record. The maximum and the minimum of leaf temperature under almost constant solar radiation are shown in Table 5 together with other environmental factors.

Table 5.

	Leaf temp.	Air temp.	Stem temp.	Soil temp.	Wind vel.	Sol. rad.
10h11m (Max.)	36.4°	39.7°	38.7°	50.3°	2.2m/s	1.2gcal/cm²m
9h38m (Min.)	33.4	33.0	39.2	46.6	3.5	1.15
10h44m-49m (5min. mean)	34.7	35.7	39.8	48.5	2.2	1.25

(3/10 Cc. Wind dir. S)

The variations due to shadows are examined, for instance, as follows : Solar radiation drops from 1.3 gcal. at 49 min. to 0.3 gcal. at 51 min. and again goes up to 1.3gcal. at 54.4 min. Corresponding to these changes, first sand temperature (0.5min.), next stalk temperature (0.8min.), followed by the leaf and air temperatures (ca. 1.0min.), become lower. The minima of these temperatures in this case are as follows, the time lag being shown in brackets :

Leaf temp.	Air temp.	Stalk temp.	Sand temp.
31.4° (0.3m)	32.7° (1.6m)	36.2° (2.3m)	42.9° (1.3m)

iii) Leaf temperature of tea-plant at the time of frost formation on it (at Tahara, near Uji, Kyoto Prefecture.)

Plate III is a record in the early morning,May 1, 1941, when the frost was just developing at tea-plantation in Tahara, near Uji, Kyoto Pref., taken during the microclimatic surveys on damages of tea leaf by May frost. The record shows the air temperature and the temperature difference between leaf and air. The leaf temperature is generally about 0.5°C lower than the air temperature near the leaf. But at 3h52m, there happened a sudden rise of 1.5°C. Since corresponding change did not appear in the air temperature, the change should be regarded to be due to the latent heat generated by freezing of the water on or in the leaf. A minute observation shows that the change had taken place in two steps; the first sudden rise of ca. 1.5°C, and a slower rise of 0.7°C 2.5min. later. The first rise is supposed to be brought about by freezing of dew upon leaf surface and the second due to freezing of intercellular water. Experiments in the laboratory, using refrigerator, proved that only a single sudden temperature rise is usually observed, no gradual rise following it being noticeable. When the leaf was wet, however, the two-stepped change as mentioned above was often observed. It is to be noticed that the freezing of tea-leaves took place when the air temperature was ca. −1.0°C and the leaf temperature was ca. −1.5°C.

iv) Leaf temperatures under direct sunshine and in the shelter (at an orange orchard in Wakayama Prefecture.)

The "Komokake" (covering orange trees by rush-matt) is the general practice for purpose of protecting trees against the cold-damages in the orange orchards. Plate IV–a is a record obtained in the survey of the effect of this covering at the orange orchard in Miyabara, Wakayama Pref., on 11h–11h50m, 9Feb., 1942, under the calm weather (5/10 Cu). The temperature of leaves in (80 cm height) and out (65 cm height) of the "Komokake" (the shelter), the air temperature surrounding them, and solar radiation and wind velocity (50 cm height) outside the shelter are recorded simultaneously. Changes of temperatures corresponding to sudden changes of solar radiation may be examined in the record. Under the shelter, there seems no great difference between leaf temperature and air temperature even when solar radiation suddenly changes, though the leaf temperature under direct sunshine rises considerably rapidly. Table 6 indicates the reading values of these changes.

Plate IV-b is a record when the sky was overcast (10/10 Ci). Owing to the weak solar radiation, there appeared no remarkable changes as in the preceeding case, and the similarity between the curves of solar radiation and of leaf temperature outside the shelter is better in present case. Generally, there was no great difference between the air temperatures in and out of the shelter, except that the fluctuation was considerably smaller inside than outside. Inside the shelter, the leaf temperature fluctuated little and was almost equal to the air temperature.

Table 6.

	10h57.2m	→ 57.4	→ 57.8	→ 58	→ 59	→ 11h00m
Sol. rad.	0.3gcal	→ 1.23	→ 1.27		→ 0.4	→ 0.3gcal
Air temp.						
outside	6.2°C	→ 8.5				→ 6.5°C
inside	6.2	→ 7.2	→ 8.0			→ 6.5
Leaf temp.						
outside	7.0		→ 13.3			→ 8.5
inside	5.7			→ 6.8	→ 6.8	→ 6.3

Temp. rise	A	B	C	D*
Leaf temp,				
outside	8.3° (0.4m)	5.0° (0.8m)	7.0° (0.8m)	11.5° (6.4m)
inside	1.1 (0.6)	1.0 (0.8)	2.0 (1.2)	3.6 (7.8)
Air temp.				
outside	2.0 (0.0m)	2.0 (0.2m)	3.0 (0.7m)	6.0 (5.0m)
inside	2.0 (0.2)	1.8 (0.8)	2.5 (1.2)	4.5 (7.6)
Leaf temp. -Air temp.				
outside	6.3°C	3.0°C	4.0°C	5.5°C
inside	-0.9	-0.8	-0.5	-0.9

Time lag is shown in brackets. D*: the maximum values.

Plate IV-c shows a record at night, about 2h 30m, 9 Feb. Both leaf temperature and air temperature rise when wind blows. This rise of temperature may be considered to be caused by perturbation of cooled and stratified air layer, formed by night radiation, through mixing with comparatively warm upper air. First rises the air temperature, which in turn, makes the leaf temperature rise. The air temperature inside the shelter is almost the same as that outside, though the fluctuation of the former is smaller. But there exists a distinct difference between the temperatures of leaves in and out the shelter. For instance at 2h42m-43m, when air temperature outside the shelter was minimum, being 0.7°C, that in the shelter was 0.8°C, and leaf temperatures outside and inside were 0.2°C and 0.8°C respectively. That is to say, the leaf temperature inside was 0.6°C higher than that outside. The difference, though smaller than 1°C, may not be overlooked, since it is large enough to prevent inside leaves from freezing when outside temperature becomes just below zero, cold enough to freeze outside leaves. Changes of temperature corresponding to changes of wind added in Table 7.

Table 7.

Time		46m		46.5m
Wind vel.		0.3m/s	⟶	0.8m/s
Air temp.	outside	1.2°C	⟶	1.8°C
	inside	1.0	⟶	1.5
Leaf temp.	outside	0.7°C	⟶	1.4°C
	inside	1.0	⟶	1.4 *

* The change is gradual and is 0.5 min. behind.

v) **Leaf temperature at the rice-field under the special environment** (at Tairadate, Aomori Prefecture.)

Plate V is a record obtained in the survey of the rice-field watered with cold mountain stream inside of the shelter belt at Tairadate, Aomori Pref. Leaf temperature of rice plant, surrounding air temperature, air temperature, air temperatures of different height, water temperature, solar radiation and wind velocity were simultaneously recorded. The rice field used was the first section of the series of the fields where the fresh and coldest water comes in directly from mountain stream. It is called a sacrificial field, because the temperature is too low to expect crop yield. Water in the paddy field was 3.5 cm deep at the time of observation. The rice-plants were about 35 cm high, and each hill was 20 cm apart from one another. The record indicates that the water temperature barely rised up to 28°C in the daytime even when the solar radiation was the strongest. The leaf temperature was higher than air temperatures at any height. And as the air temperature should be influence by leaf, the former was the highest at the height of 25 cm, where leaves thrived most. The most active heat-surface in this paddy-field is not water, as in warmer districts where the water temperature is the highest of the elements in sunny daytime. The maximum and minimum temperatures and the temperature changes due to sudden rises of solar radiation are indicated in Tables 8 and 9, respectively.

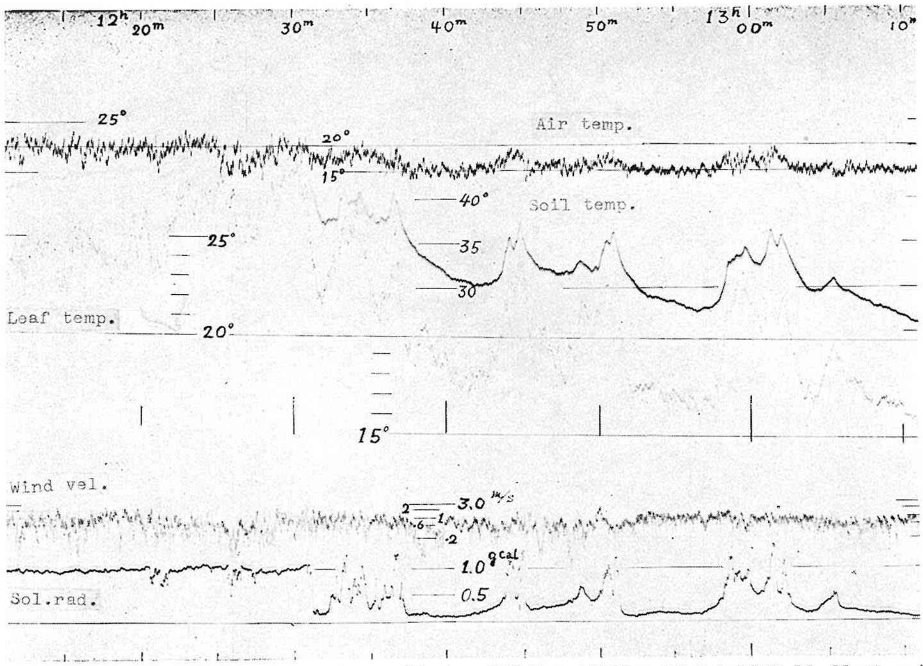
Table 8. Maximum and mininum temperatures.

	Lefe temp. (15cm) max.	min.	Air temp. (15cm) max.	min.	Air temp. Height) max.	min.	Water temp.	Sol. rad. (max)
11h51m	32.0°	28.0°	30.3°	25.5°	(1 m) 27.0°	23.5°	27.0°	gcal. 1.70
12h33m	31.0	24.8	29.5	25.5	(5cm) 27.7	24.4	28.0	1.37
13h02m	31.5	27.0	31.0	25.8	(25cm) 30.0	24.7	28.3	1.70
13h43m	30.7	27.7	29.4	25.6	(40cm) 26.8	24.0	27.4	1.68
14h10m	29.3	27.0	28.2	25.3	(70cm) 26.7	24.0	27.0	1.20

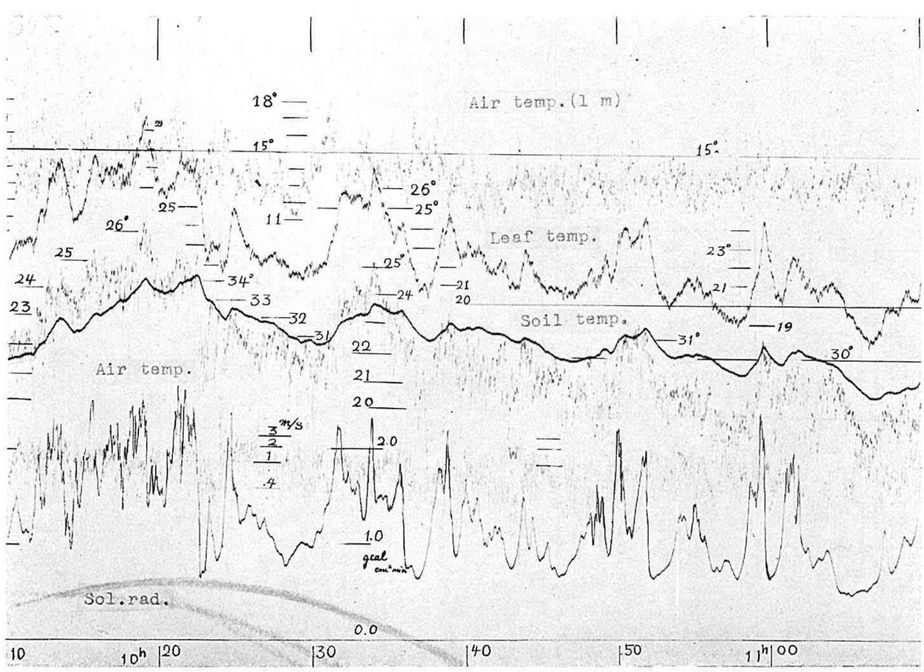
Table 9. Temperature rise due to sudden rise of solar radiation.

	Leaf temp °C	Air temp °C	Air temp. (Height)	Water temp °C	Sol. rad. gcal/cm²m
11h57m	28.5°→32.1°	26.0°→29.5°	(1m) 23.7°→27.0°	26.8°	0.55 → 1.70
12h35m	28.8 →31.0	26.7 →29.5	(5cm) 26.5 →27.6	27.9 →28.1	0.4 → 1.37
13h03m	27.0 →31.5	27.0 →29.0	(25cm) 24.7 →29.3	27.9 →28.1	0.5 → 1.67
13h46m	27.8 →31.7	25.6 →29.3	(40cm) 24.2 →26.7	28.3 →28.4	0.5 → 1.68

The writer wishes to show his appreciation to Prof. Emeritus Dr. K. Kôriba for valuable advices, by whose suggestion this study was undertaken. He is also indebted to Prof. J. Ashida of the Botanical Institute for constant encouragement.

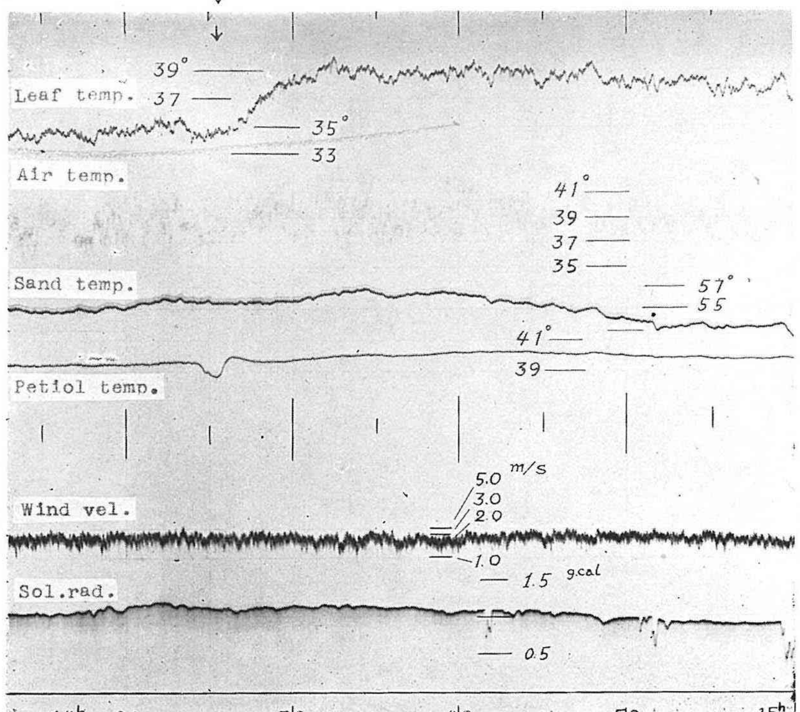


(a) Leaf temp. of Veratrum stamineum Maxim. (12h11m–13h11m, 18 July 1950, Mt. Norikura)



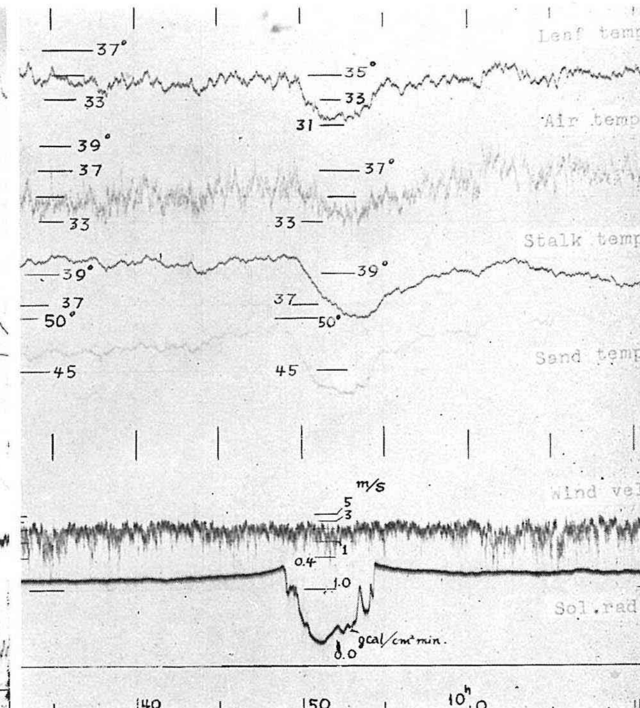
(b) Leaf temp. of Lagotis glauca Gaertn. (10h10m–11h10m, 16 July 1943, Mt. Shirouma)

Cutting the petiole to stop the water supply



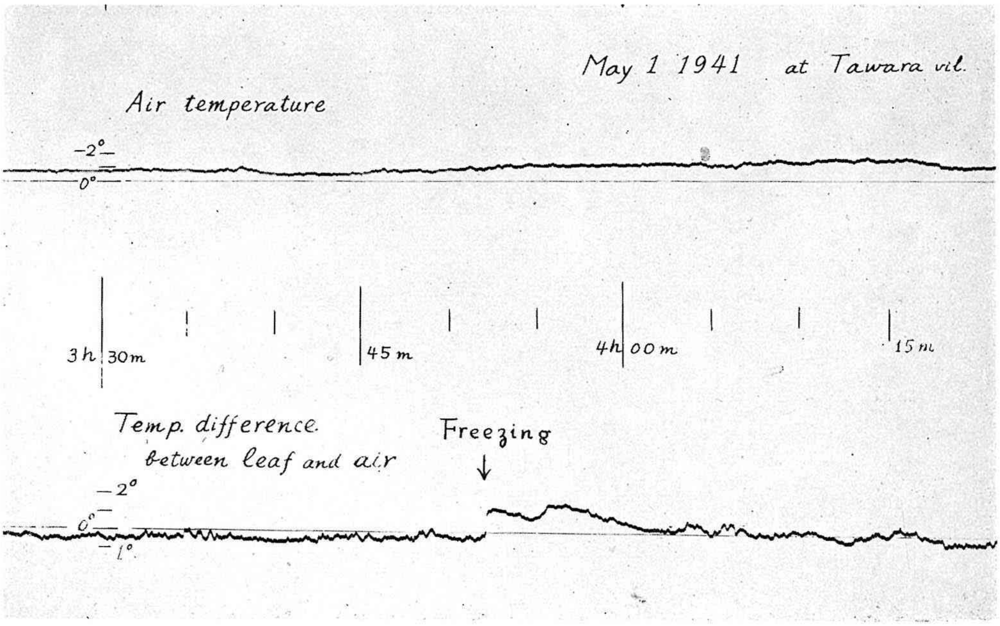
(a) Leaf temp. of Phellopterus littoralis Fr. Schm.

(14h15m–15h, 2 Aug. 1947, Karo-dune)



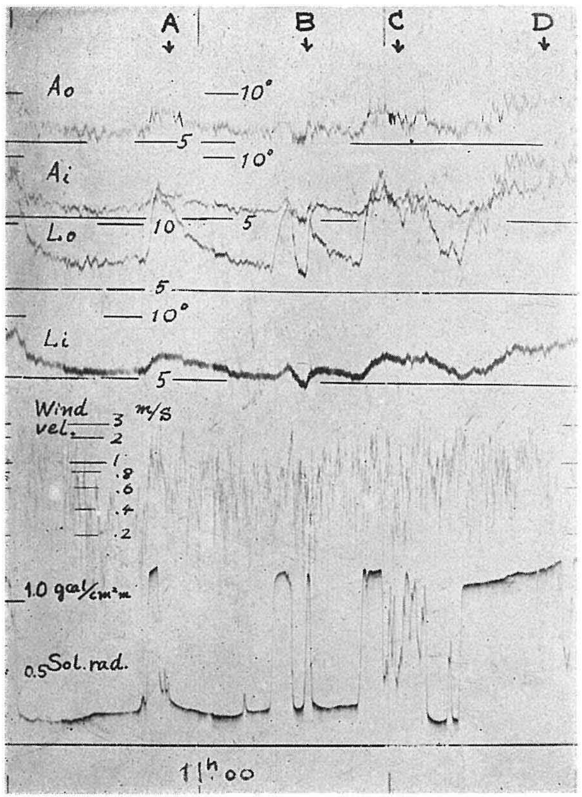
(b) Leaf temp. of Vitex rotundifolia L. fil

(9h27m–10h12m, 2 Aug. 1947, Karo-dune)



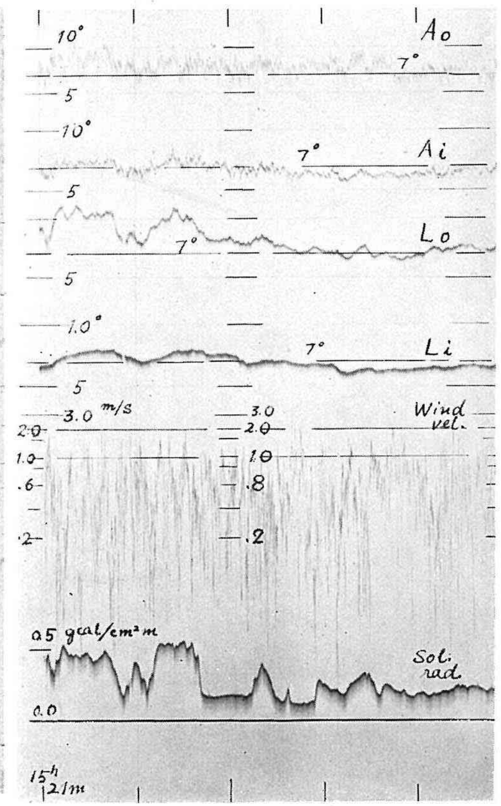
↑
Freezing

Leaf temp. of tea-plant at the time of frost formation
(3h30m–4h20m, 1 May 1941, Tawara)



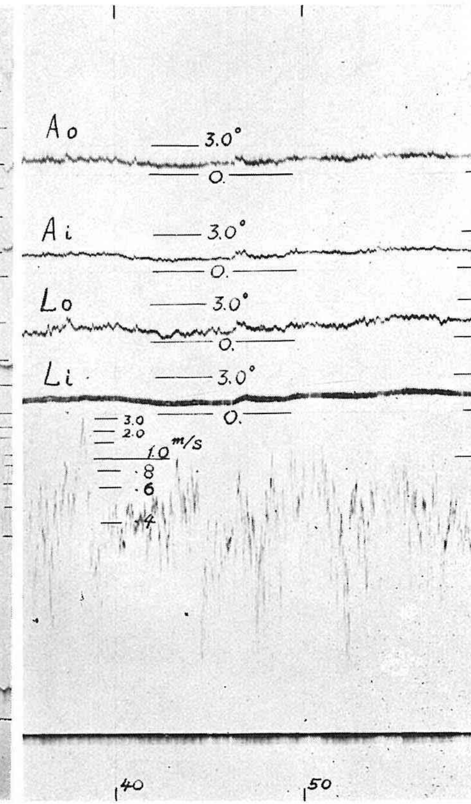
a) Daytime (11h50m–11h20m, 9 Feb.)
5/10 Cu Calm

Measuring heights (Ao, Lo : 65cm; Ai, Li : 80cm)



b) Daytime (15h21m–46m, 15 Feb.)
10/10 Ci Calm

Meas. height : 140 cm

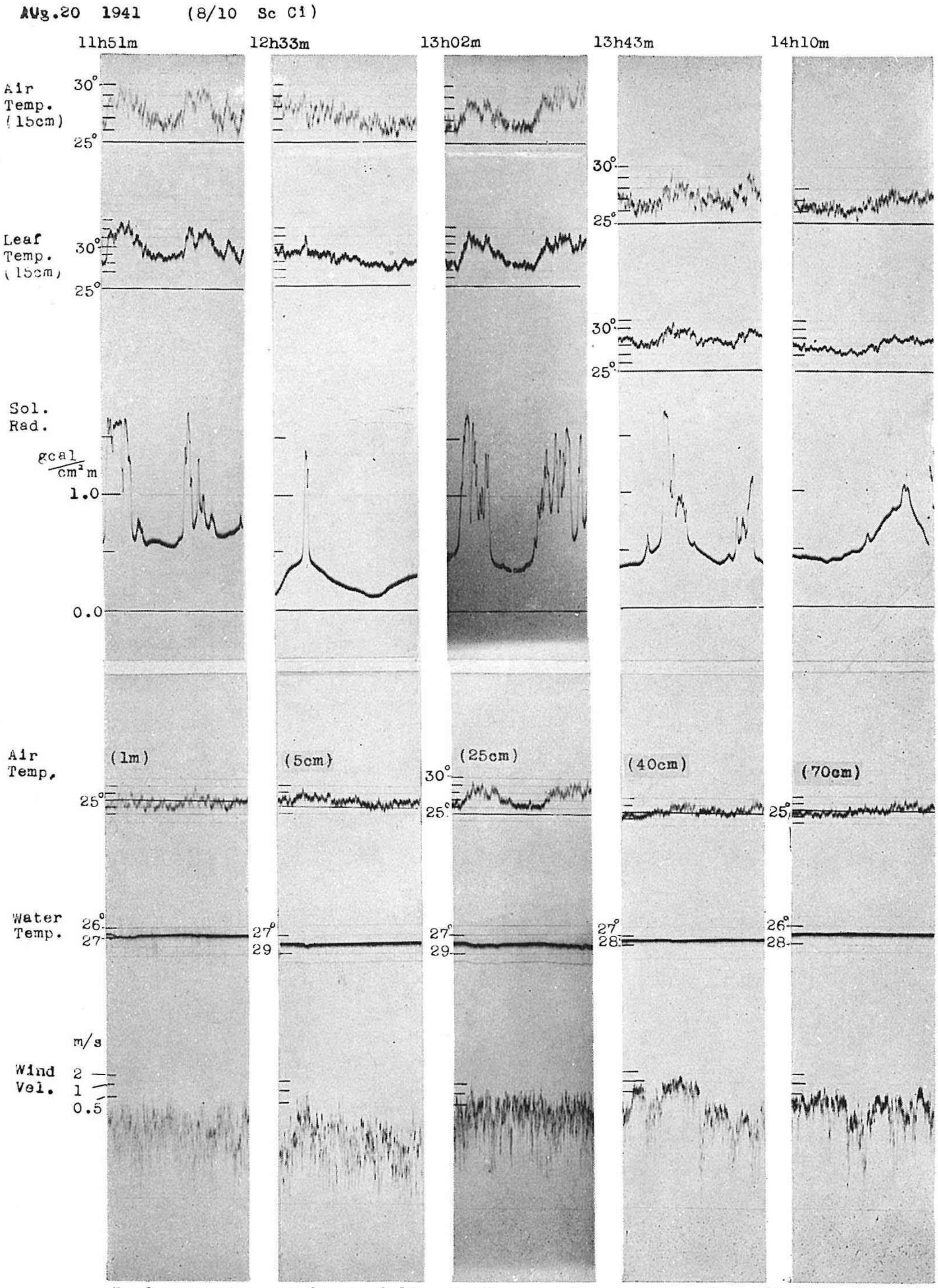


c) Night (2h35m–3h, 9 Feb.)
0/10 Calm

Meas. heights (Ao. Lo : 65cm; Ai Li : 80cm)

Temperatures in and out of the shelter at orange orchard in Wakayama, 1942

(Ao : Air temp. out of the shelter; Ai : 〃 in 〃; Lo : Leaf temp. out of the shelter; Li : 〃 in 〃)



Leaf temperatures at the rice-field under the special environment. (Aug. 20, 1941, Tairadate)