Bull. Univ. Osaka Pref., Ser. B, Vol. 41,
大阪府立大学紀要，農学・生物学，1989

Nature of Frost Damage Distribution in Tea Gardens —A Case Study of the Frost Damage on 9 May 1988 in Nara Prefecture—

Masuyuki TAKAICHI

Laboratory of Agrometeorological Environment, College of Agriculture

(Received October 31, 1988)

Abstract

To examine the relationship between frost damages in tea plants (*Camellia sinensis* L.) and undulations in topography, frost damage occurred on 9 May 1988 in Nara prefecture was investigated in detail. Two sites were chosen for this study: Higasa-cho tea garden, Nara city and Enga tea garden, Tsukigase village.

At the frost night the minimum air temperatures were 4.0°C (Nara) and 1.0°C (Hari) and new buds with two to four leaves were damaged. Since the damage occurred late in spring, differences in the degree of damage among tea varieties were not seen. The damages were severer at relatively lower places at the sites. The orientations of damaged side of tea rows indicated that the damages could not be attributed to rapid thawing of frozen leaves by sunshine. The damage orientations of rows across the contour seemed to have been affected by the larger scale cold air drainage (mountain breeze). On the other hand the damages on the rows along the contour occurred on the lower sides and they are considered to have been affected not by the large scale cold air drainage but by the smaller scale downslope air motions induced by the undulations in the garden.

Introduction

Frost damage of tea plants, in which new buds or leaves are damaged in early spring, occurs almost every year in the northern part of Nara prefecture. This causes the variation in first pluck production to be considerably large in this area. Frost damage reported here occurred on 9 May 1988 and first plucking was planned in one or two weeks of the day. Damage at this time severely reduces the first pluck productions, since there is not sufficient time for the recovery of new leaves from the lateral buds by the plucking date. As in many cases of frost damage in tea garden, it was seen at many places that the damages on tea bushes were limited on one side of rows and that the another sides were not damaged[1),2)]. Directions of the damaged sides were different from place to place.

The purpose of this study is to examine the relationship between nature of frost damage distributions and comlex undulations in tea gardens. Two sites in the northern part of Nara prefecture were chosen to investigate the distributions of the damage in detail. The effect of sunshine in the morning on the damage is also discussed.

Study Area and Method of Investigation

Investigations were conducted at two sites in the northern part of Nara prefecture: Higasa-cho tea garden, Nara city and Enga tea garden, Tsukigase village (Fig. 1). Higasa-cho tea garden is located about 9 km east-southeastward from the urban center of Nara

city. The topography is undulating with elevations ranging from 380 to 420 m ASL. The another, Enga tea garden is located about 20 km east-northeastward from the urban center. The topography is simply conical with the elevations ranging from 350 to 385 m ASL., but the surroundings are considerably undulating. The varieties of tea plant (*Camellia sinensis* L.) in the gardens were mainly 'Yabukita' and the other varieties such as 'Sayama-kaori', 'Oku-midori' and 'Yamato-midori' were planted little. The plants in the gardens were planted in rows with the width of 1.5 – 2.0 m and their ages were 10 – 20 years old, so called mature plants.

Investigation of the damage was conducted on 14 may 1988, 5 days after the damage occurred and the complementary investigations were made a few times furthermore. First, degrees of the damage were classified into four levels: 'severe', all of new leaves were damaged; 'middle', one side of tea bush was damaged; 'slight', only near the top of bush was slightly damaged and 'no' damage. Second, orientations of damaged side relative to the row directions were investigated where the degree of damage was 'middle' or 'slight'.

In Enga tea garden, an observation of air temperature distribution was carried out on 20 March 1988. The measurement was made by means of car traversing in the garden. Temperature was measured with aspirated copper-constantan thermocouple thermometers. Wind speed was measured with hot-wire anemometer. The results were compared with the frost damage distribution in the garden.

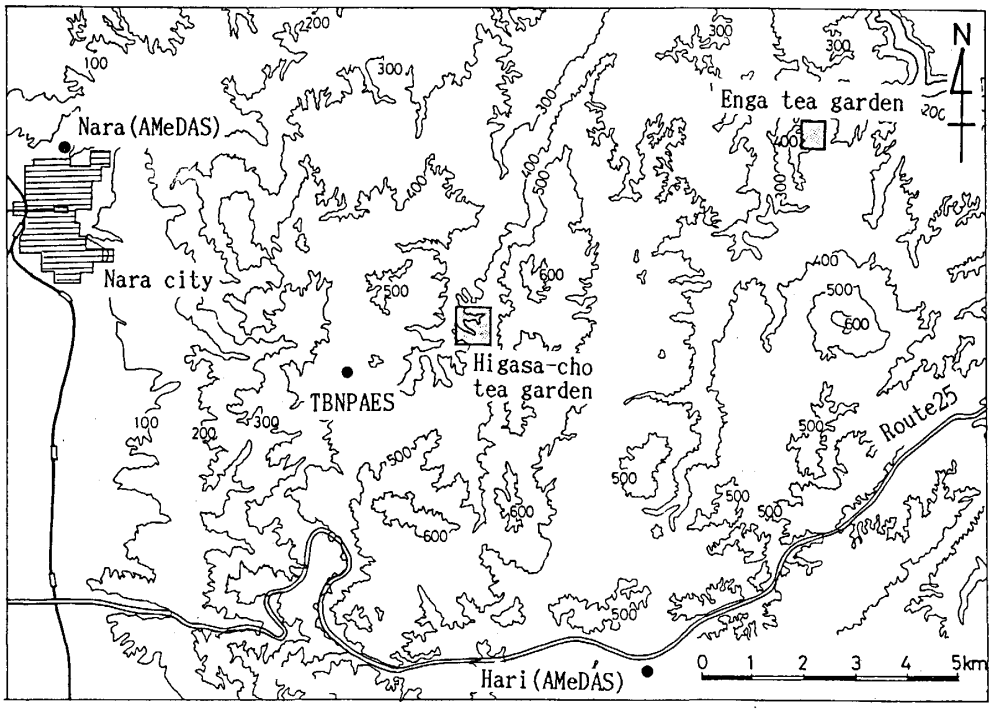


Fig. 1 Topographic map showing investigated sites in the north Nara Prefecture.

Weather Conditions and Tea Growth Before the Damage

Weather data of Nara Local Meteorological Observatory, AMeDAS Nara and Hari stations, and Tea Branch of Nara Prefectural Agricultural Experiment Station (abbreviated to TBNPAES) are available for this study. Tea plant growths described in the followings are those observed at TBNPAES.

It was relatively warm and there were few days with strong winds in January and February 1988. Winter dessication damages which usually occur in January were not seen on both young and mature plants until middle of February. This warm condition in the winter allowed the beginning of water absorption and bud growth of tea plants earlier than usual. However, the period during the latter half of March to the first ten days of April was rather cold all around Japan, so that the new leaf emergence from buds (23 April) was almost the same as that in the last 5 years (24 April).

After the emergence, low temperatures and frosts on tea bushes were observed on 24, 25 April, then slight damages occurred partly in Tsukigase village, where bud growth progressed relatively earlier. On 9 May when the frost damage occurred, the new leaves already expanded by 2 – 4 leaves per bud in Nara prefecture. The first pluckings were planned in about ten days.

On 5 May, a cold air mass covered northern part of Japan and a cold spell began. On 7 and 8 May, a cyclone with cold front passed through Japan with high speed. During the two days, 39.5 mm of rainfall was observed at TBNPAES. The temperature at the 500 mb height, in the morning of 8 May, was as low as −30.3°C, which became the lowest record in May. Figure 2 shows the surface weather map of 0900 9 May 1988. After the cyclone moved to the east of Hokkaido, a migratory anticyclone covered Japan. By radiative cooling during the night of 8 – 9 May, together with cold air mass, the temperature in the early morning of 9 May fell to a low value enough to damage new leaves of tea plants. Frost damages in tea plants occurred at many places in Kinki district this night.

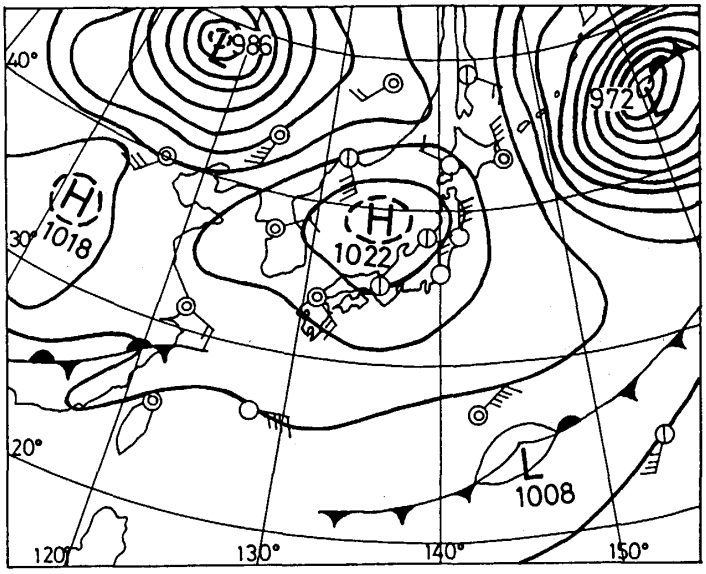


Fig. 2 Surface weather map for 0900 9 May 1988

The changes of air temperature, wind speed and wind direction at the frost night at Nara and Hari (AMeDAS), and at TBNPAES are shown in Fig. 3. The maximum air temperatures of 8 May were 17.0°C (Nara), 13.5°C (Hari) and 13.5°C (TBNPAES). Temperatures fell to minimum values at 0500 9 May, i.e., 4.6°C (Nara, 104 m above the sea level), 1.0°C (Hari, 468 m ASL) and 1.1°C (TBNPAES, 420 m ASL). The AMeDAS data indicate the values on the hour, however, the continuous temperature record at TBNPAES showed the minimum also at about 0500, so the values of AMeDAS stations could be regarded as minimums.

The data of wind direction and wind speed at the AMeDAS stations showed that the winds over the study area were rather weak after 2100 8 May and the local cold air drainage is considered to have developed sufficiently. Since the relative humidities at TBNPAES were 98 – 99% after the evening of 8 May, it is considered that dew on the tea bush surface formed and that frozen dew occurred at midnight.

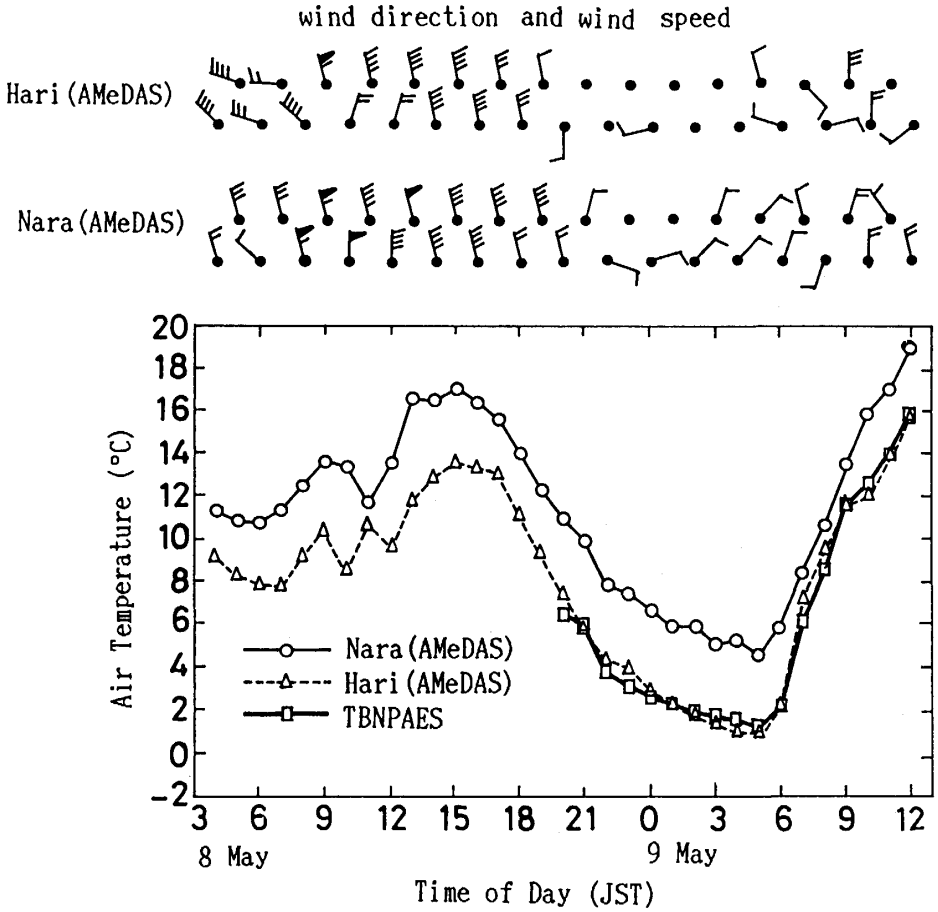


Fig. 3 The changes of air temperatures, wind directions and wind speeds at the stations (Nara, Hari, TBNPAES) on 8 – 9 May 1988.
Each bar and flag indicating wind speed are 1m/s and 5m/s, respectively.

Result and Discussion

According to the survey of the frost damage distribution made by Tenri Agricultural Extention Station, the damage was severest in Tawara area, Nara city (370 – 420 m

ASL), Fukuzumi area, Tenri city (about 450 m ASL) and Hari area, Tsuge village (about 450 m ASL). In Yagyu area, Nara city (250 – 300 m ASL) and Yamazoe village (300 – 400 m ASL), the damages were not so severe as those in the three areas above. In Tsukigase village the damages were relatively slight. From the viewpoint of altitude, the higher the tea garden was located, the heavier the damage levels on the bushes were. In a small area such as a ravine, however, it was found that damages were heavier at the lower places than upper parts of slopes or ridges.

The damage did not differ among the tea varieties because the damage date was late in spring and all varieties already have expanded new leaves. The mature leaves under the plucking table of bushes were not damaged at all in the sites because they can tolerate to much lower temperature than new leaves[3].

(1) Higasa-cho Tea Garden, Nara city

Figure 4 shows the distribution of the damage cassified into four degrees in this site, i.e., 'severe', 'middle', 'slight' and 'no' damage. Only the areas in which the fans for frost protection were not installed were investigated and they are shown as shaded areas.

There are two mounds at the site and a path with a few houses runs between them.

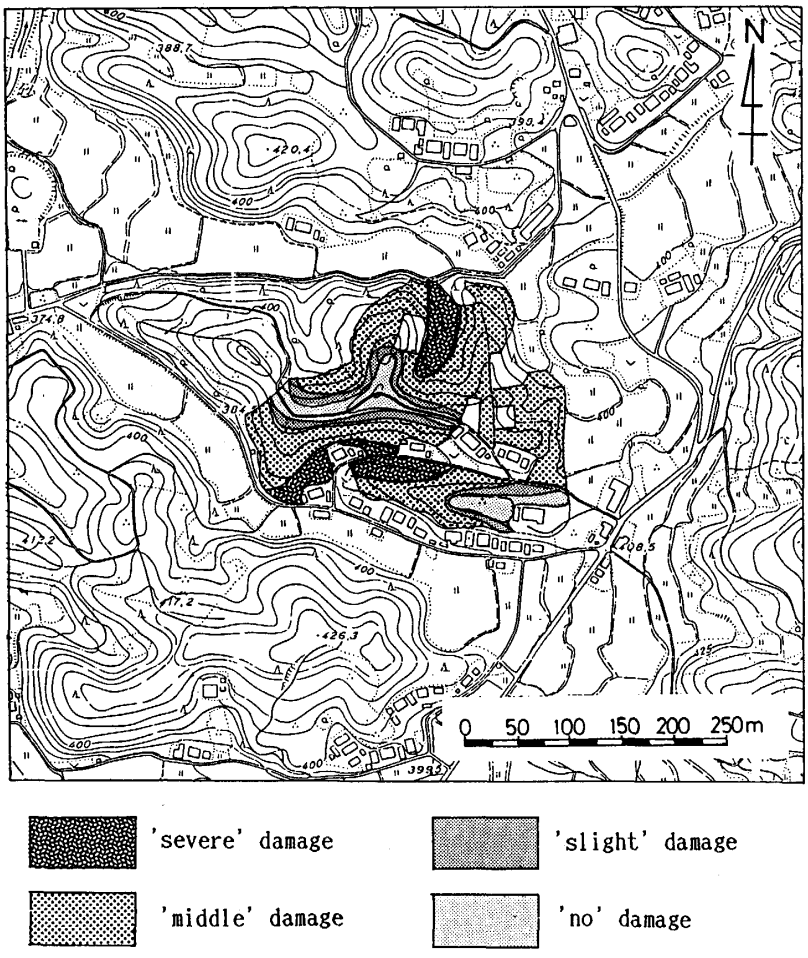
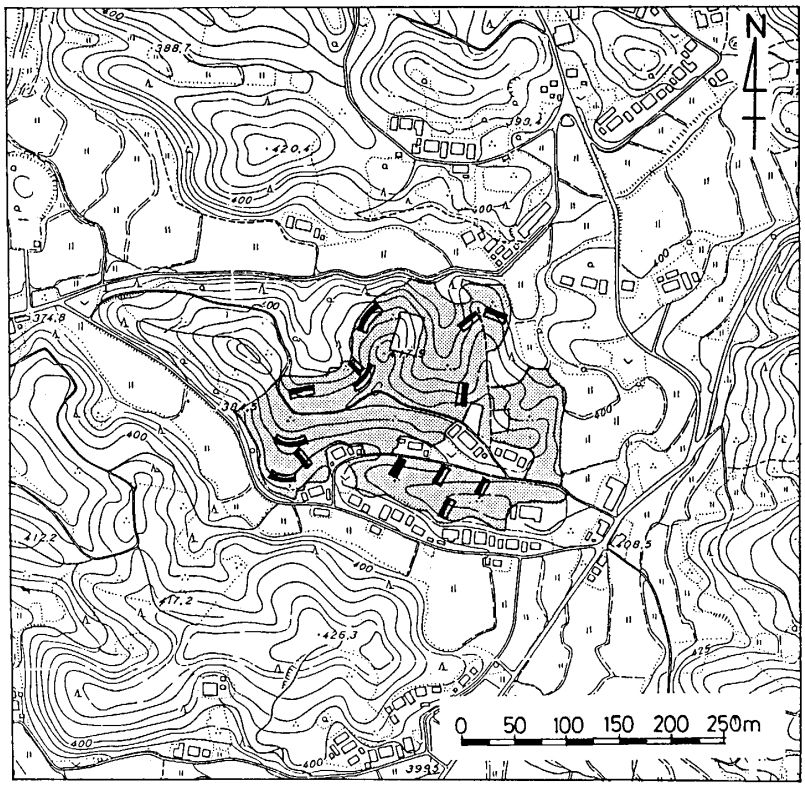


Fig. 4 Frost damage distribution in Higasa-cho tea garden, Nara city. Investigated areas are shaded.



Investigated area

Long side indicates the row direction;
White: no-damaged side; Black: damaged side

Fig. 5 Orientations of the damaged sides on tea bushes in Higasa-cho tea garden

The smaller mound located at southeast edge at the site has its top height of 416 m ASL, and the larger mound that occupied most of the site has its top height of 418 m ASL. Damages were heaviest at the bottom between the mounds, especially at the western part (classified as 'severe'). Since the bushes at the bottom have much fewer new buds than the other, it is considered that the new buds had already been damaged in some degree on 24 – 25 April. While in the larger mound tea bushes at the north trough also showed 'severe' damages.

The places of 'middle' damage occupied a large area of the mounds. The three unshaded areas without houses were where the cheeseclothes were expanded over the bushes for shaded cultivation and the damages there were lighter than the surroundings.

Next, the orientations of damaged sides of tea bushes relative to the row directions were investigated at the 'middle' damaged places (Fig. 5). It has been reported in some researches on the frost damage in tea plant that damages were likely to occur on the eastside of rows[1),2),4)], however, in the smaller mound, where tea rows were across the contour line in north to south direction, it was seen that new leaves on the westside surfaces were damaged and those on the eastside were not. This indicates that the damages in the mound were not caused by the rapid thawing of frozen leaves by sunshine because the

sunny surface of eastside had no damage.

In the larger mound tea plants were planted in rows both along and across the contour. At the northeastern part where rows were across the contour, the damages were seen on the northsides of rows. On the other hand, in the rows along the contour tea bushes were damaged on their lower side, and not damaged on the upper side. Although the slopes with the rows along the contour faced to various directions, the damage on the lower side of rows occurred in a similar way. This agrees with observations for frost damages of tea on slopes[1].

Since the effects of radiative cooling on the both sides of tea rows are considered as the same on the rows across the contour, the occurrence of damage on one side is considered to be caused either by the difference in frost tolerances of new buds or by the difference in effects of winds between the two sides. Although the effects of tolerance could not be estimated here, it seems that the effects of winds could account for the damage pattern in the garden without a great inconsistency. Since the damages are considered to occur on lee side of rows, the damages in the rows across the contour indicate that winds blew from between east and southeast at the frost night. However, this winds are considered to have been weak because it did not affect the damage pattern on the rows along the contour. Considering the topography around this area that there are mountains more than 600 m ASL to the east, and that a river runs to NNE directions to the west, the wind which blew from between east and southeast might have been cold air drainage over a relatively wide area that blew from mountains to the river (mountain breeze). Since the damages on westsides of rows across the contour were seen near at the top of the smaller mound, this wind might have affected more than about 20 m from the bottom plane. The height is reasonable considering the other works of cold air drainage[5),6)].

(2) Enga Tea Graden, Tsukigase Village

In Enga tea garden the topography is simply conical, but the terrain around the garden is very undulating. Fans for frost protection were installed all around the garden and were operating at the frost night. The frost damage on 9 May occurred at the lowest place around a ditch (Fig. 6). The top height is 385 m ASL and the eastern bottom where a loop road crossing over the ditch is 353 m ASL. Young tea trees were planted in a unshaded area at the height of about 375 m ASL. In the large unshaded areas to the east tea bushes were covered with transparent films for early plucking and no damage was seen there. At the east of the ditch only 'slight' damage took place.

Figure 7 shows the directions of rows and orientations of the damaged sides. Around the severely damaged area, where the rows were across the contour, orientations of the damaged sides were between north and northeastward. The orientations differed from the case of Higasa-cho tea garden. However, it was similar in the point that the damage was not attributed to rapid thawing by sunshine. The damages on the rows along the contour were seen on the lower sides. This accorded with the case of Higasa-cho tea garden.

In Enga tea garden, an observation of nocturnal temperature distribution was carried out on 20 – 21 March 1988. The results were compared with the damage pattern. In the evening of the day observed, the winds at the height of 150 cm were relatively strong (0.5 – 2.5 m/s) and sky was cloudy. After 21h the sky began to be clear and winds weakened. The air temperature distribution obtained with a car traverse during 2330 –

0100 (the time lag has been corrected) is shown in Fig. 8. Although not shown in this Figure, during the traverse the winds were generally weak (0.2 – 1.5 m/s) and blew from the top of the garden and spreaded radially, but at the place near the ditch they blew along it. The lowest temperature was observed at the bottom around the ditch and this area almost coincided with the damaged area shown in Fig. 6.

Since Enga tea garden was sorrounded by the mountains of about 380 – 410 m height, it is considered from the undulation that the winds in the garden might have been weakened and the cold air was likely to stagnate at the bottom. Fans for frost protection did not prevent the damage at the bottom, where the number of fans installed were the same as the other place. This might suggest the necessity to increase the number of fans or to use other prevention methods together with fans at the damaged place.

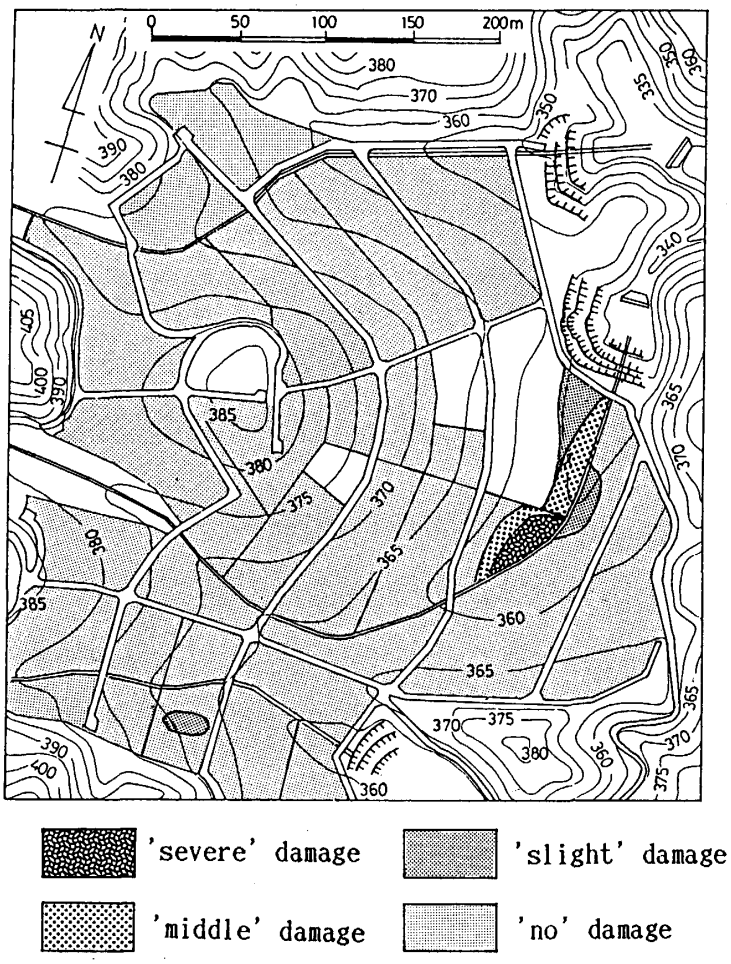


Fig. 6 Frost damage distribution in Enga tea garden, Tsukigase village. Investigated areas are shaded.

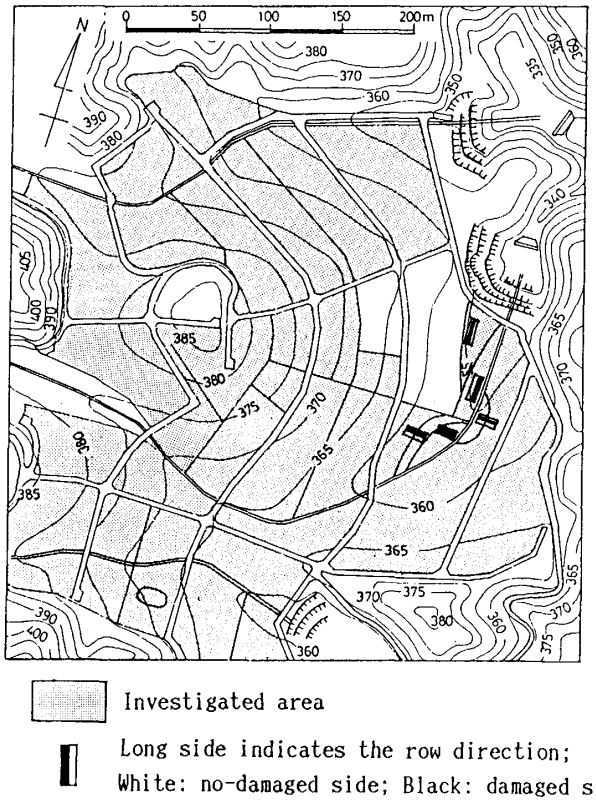


Fig. 7 Orientations of the damaged sides on tea bushes in Enga tea garden

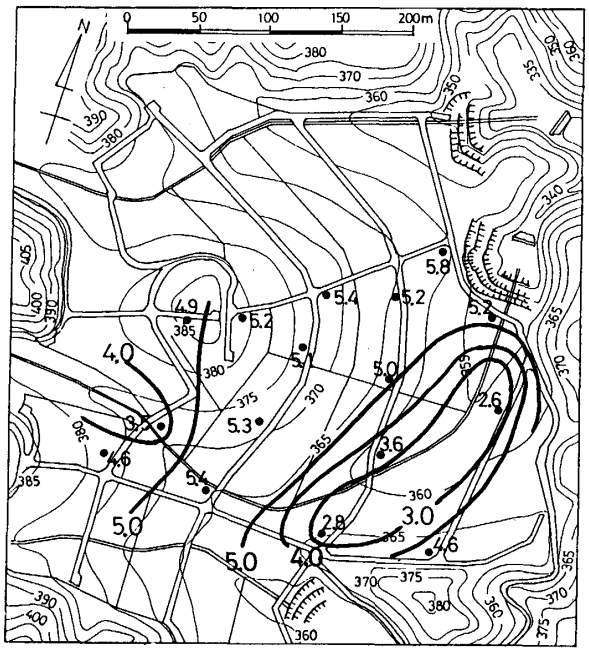


Fig. 8 Temperature distribution in Enga tea garden at 2330 20 May 1988. Temperature (°C) was measured at the height of 150cm.

Conclusion

The frost damage described here occurred on 9 May 1988, when new buds of all varieties of tea plant had already expanded 2 – 4 leaves per bud. The differences of the degrees of damage among varieties were little.

The directions of damaged sides of tea rows across the contour in Higasa-cho tea garden were mainly between west to the northwest. This indicates that the damage could not be attributed to rapid thawing of frozen new leaves by sunshine. In the rows along the contour the damages were seen on the lower sides. These damage characteristics appeared to be determined by cold air drainage which was induced both by the undulations of tea gardens and by the larger scale topography. The cold air drainage in relatively larger scale (mountain breeze) appeared to affect the area of up to about 20 m high above the bottom plane.

Acknowledgement

The auther would like to thank Y. NAKA, Director of Tea Branch, Nara Prefectural Agricultural Experiment Station, for his advice of temperature observation in Enga tea garden, and T. YONETANI for his kind arrangement for the observation. Thanks are also due to Dr. Y. OMOTO, University of Osaka Prefecture, for valuable suggestions, to Dr. N. MONJI for helpful comments on the manuscript and I. YOSHIZAWA for assistance with the nocturnal observation in Enga tea garden.

References

1) Shizuoka Tea Experiment Station (1980): Report of the Frost Injury of Tea plant in 1979. *Bull. Shizuoka Tea Exp. Stn.* **10**, 1–83 (*in Japanese*).
2) Kouji TAKAHASHI, Hideya AONO, Shizuo TANAKA, Yoshimitsu YANASE and Shigeru YOSHIKAWA (1961): Studies on the Frost Damage of Tea Plant Studies on the Microclimate of Tea Garden at the Frosty Night and Emergent (Physical) or Cultural Method to Prevent the Frost Damage. *Bull. Kinki-Tokai Agri. Exp. Stn. Tea Div.*, **8**, 30–162 (*in Japanese*).
3) Hidemitsu YANASE, Hideya AONO and Shirou SUGII (1974): The Occurring Process of Some Winter Injuries to Tea Plant and the Protection Method. *Bull. Nat. Res. Inst. Tea*, **10**, 1–90 (*in Japanese*).
4) Izo ABE, Tomiko OKUYAMA, Taichi MAKI and Kenji UEMURA (1975): Reserches Regarding Frost Injury on Tea Plant in Shizuoka Prefecture in 1972. *J. Agri. Met.*, **31**, 145–148 (*in Japanese*).
5) Enshichi IMAOKA (1964): Observations and Consideration on the Structure of the Down Slope Wind. *J. Agr. Met.*, **20**, 17–24 (*in Japanese*).
6) T.W. HORST and J.C. DORAN (1985): Nocturnal Drainage Flow on Simple Slopes. *Boundary-Layer Meteorology*, **34**, 263–286.