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Investigations on Some Meteorological Conditions and Evaluation of the Effects of Tree Windbreaks on the Improvement of Meteorological Conditions in Turpan Oasis, China

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Abstract

Turpan is an oasis in the arid land of Northwest China. It is generally considered that agriculture would be impossible in arid lands without the oases, which contribute to the improvement of the meteorological conditions. To identify the characteristics of the velocity and direction of the wind in Turpan, and the effect of tree windbreaks on the improvement of the meteorological conditions in this oasis, investigations were carried out from August 27 to September 12, 1997. The prevailing directions of wind with a velocity of more than 5 m/s were W and WSW. The stronger wind in Turpan was attributed to an inflow of cold air mass after the passage of a depression. The effect on the improvement of the meteorological conditions varied considerably depending on the arrangement of the tree windbreaks. In an area of the oasis with strong windbreaks 1 km distant from the desert, where trees were arranged at intervals of more than 10 trees /10 m and the tree height exceeded 10 m, the air temperature decreased by about 5ºC and the relative humidity increased by 14% compared with the outside desert. Air temperature and relative humidity were constant in any area of the oasis 1 km apart from the desert. In another oasis area with weak windbreaks, in which trees were arranged at intervals of less than 10 trees /10 m and the tree height was less than 10 m, the effect of the windbreaks on the improvement of the meteorological conditions was negligible.

Discipline: Agro-meteorology
Additional key words: arid land, local wind

Introduction

Arid and semi-arid lands occupy about 14% of the country in China and a large number of people live in such regions. Turpan is an oasis in the arid land of Northwest China where good quality grapes and cotton plants are grown due to favorable meteorological conditions such as abundant solar radiation and high temperature. However, high temperature injury and wind damage on crop occur in this region in some seasons. Especially, August and September are very important months because harvest of grapes, which account for 30% of the total agricultural output in Turpan, takes place at that time[9]. In Turpan, due to the presence of a dry hot wind, the maximum air temperature can be as high as 48ºC, minimum relative humidity is almost 0% and annual precipitation is 16.4 mm[7].

Consequently, it is considered that agriculture would be impossible in Turpan without the use of windbreaks which contribute to the improvement of the meteorological conditions.

Although many windbreaks are actually used in Turpan, in some cases, the improvement of the meteorological conditions is not sufficient, mainly because the arrangement of the windbreaks is inadequate. Although several investigations have been carried out on the effects of windbreaks in general[1,3,10] and some investigations on the effects of windbreaks have even been carried out in

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Turpan[5,6], the beneficial effect of an oasis on the improvement of the meteorological conditions has not been investigated. To analyze the effects of windbreaks on the improvement of the meteorological conditions, some investigations were carried out throughout the oasis and the desert by using the mobile observation method.

In addition, to analyze the characteristics of the velocity and direction of the wind in Turpan, meteorological observations were carried out from August 27 to September 12, 1997.

Observation and method of analysis

1) Surface observation

Fig. 1 shows the meteorological observation sites, Turpan Desert Research Station (Turpan site) and Xinjiang Institute of Biology, Pedology and Desert Research (Urumqi site). The Turpan site is located at the southern end of the Turpan oasis. The elevation of the site is 80 m below the sea level. The Urumqi site is located at 8 km north-northwest of downtown Urumqi. The elevation of the site is 670 m above the sea level. The Turpan and Urumqi sites are located at the southern foot and on the northern midslope of the Tianshan Mountains, respectively.

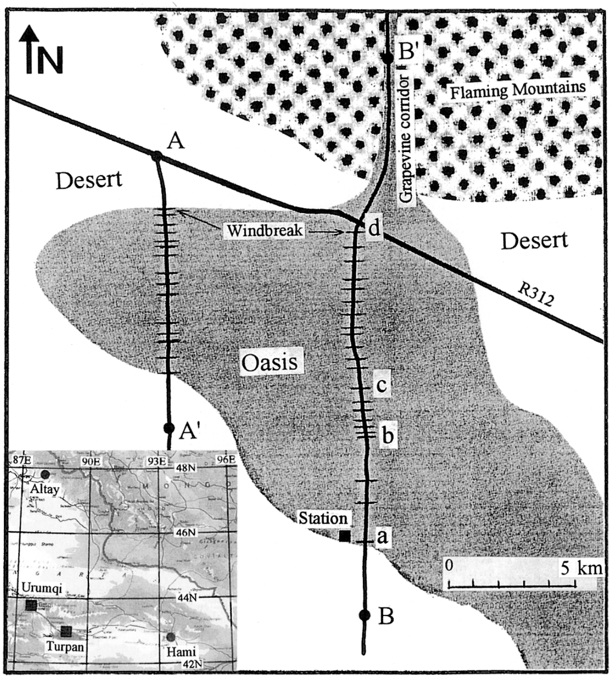

Fig. 1. Map of the observation field in Turpan

■ : Observation site,
● : Upper air observation station.
Lines A–A' and B–B' indicate the routes of mobile observations. Thin lines along routes A–A' and B–B' indicate the location of the east-west windbreaks.

A thermistor thermometer and capacitive hygrometer with a shelter were set up at 1.6 m height at these sites. The air temperature and relative humidity were recorded at intervals of 10 min from August 27 to September 12, 1997. Moreover, the wind direction and velocity were observed at the Turpan site at a 6.0 m height. The mean wind velocity and most frequent wind direction during the 10 min period were recorded.

2) Mobile observation

Using mobile observations, horizontal variations in the air temperature and relative humidity were determined along 2 routes throughout the oasis to the desert in Turpan. Fig. 1 shows the observation routes and location of east-west windbreaks along the routes. The 2 routes were in the same oasis, about 8 km apart in the east and west directions. The thermistor thermometer and capacitive hygrometer with a shelter were installed on the antenna of a car at a 1.6 m height, and the air temperature and relative humidity were measured at intervals of 10 s. The speed of the car was about 40 km/h. To obtain the position and altitude in the mobile observation, the distance covered by the car was measured with a tripmeter and the altitude was measured with an altimeter at intervals of 1 km. The mobile observations were carried out from 14:00 to 15:30, on September 2 and 4, 1997. The weather on September 2 and 4 was fine without strong wind. The air temperature was the highest and relative humidity was the lowest on a mobile observation day. Therefore, it was considered that this time zone was suitable for investigating the difference in the meteorological conditions between the desert and the oasis. In addition, the changes in the air temperature and relative humidity of the background were assumed to be negligible in this time zone.

The mean wind speeds were 1.0 m/s and 1.6 m/s, and wind directions were WNW and NNW in the time zone of the mobile observations conducted on September 2 and 4, respectively. The characteristics of the windbreaks such as tree species, height and density were determined. The investigation on the windbreaks was carried out for the east-west windbreaks which intersect at right angles to the observation routes.

3) Synoptic analysis

The relation between the wind velocity in Turpan and synoptic meteorology was analyzed by using the upper air observation data. At first, the relation between the atmospheric pressure and wind velocity in Turpan was analyzed. The atmospheric pressure in Turpan was investigated using a Northern Hemisphere Surface

Weather Chart. In addition, the relation between the atmospheric pressure distribution around Turpan and wind velocity in Turpan was analyzed. The atmospheric pressure distribution was investigated using the Asia Pacific Surface Weather Map. The daily variations in the air temperature, the wind direction and velocity in the upper atmosphere in Turpan were determined based on the upper air meteorological data, which had been collected in Altay and Hami (Fig. 1). Altay is located at the southern foot of the Altay Mountains, 540 km north of Turpan. Hami is located at the southern foot of the Tianshan Mountains, 350 km west of Turpan.

Results and discussion

1) Characteristics of wind at Turpan

Fig. 2(A) shows the changes in the air temperature with time at the Turpan and Urumqi sites, and (B) shows the changes in the 10-min mean wind velocity (m/s) at the Turpan site. The hatched areas represent the period when the difference in the air temperature between the Turpan and Urumqi sites exceeded 15ºC. As shown in Fig. 2, the difference in the air temperature increased on August 29 and September 6 to 9, and the wind velocity was high during this period at the Turpan site. During the observation period, when the difference in the air temperature between the Turpan and Urumqi sites exceeded 15ºC, wind with a velocity of more than 5 m/s blew at the Turpan site.

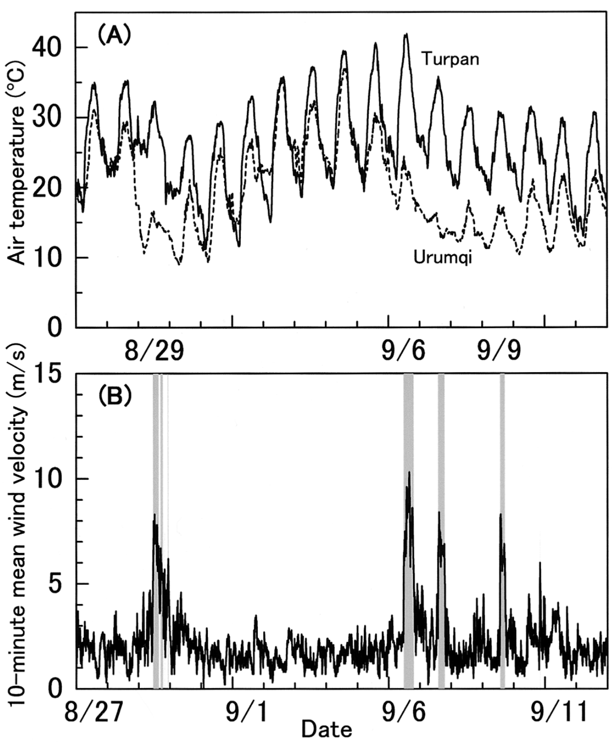

Fig. 2. Time series of (A) air temperature at 1.6 m at the Turpan and Urumqi sites and (B) 10-minute mean wind velocity at 6.0 m at the Turpan site from August 27 to September 12, 1997

The hatched areas denote the periods during which the difference in air temperature between the Turpan and Urumqi sites exceeded 15ºC.

The frequency distribution of the wind directions during the observation period at the Turpan site is shown in Fig. 3. The prevailing wind direction differed depending on the wind velocity. The prevailing wind direction was NE with less than 5 m/s. On the other hand, the prevailing directions of the wind with a velocity of more than 5 m/s were W and WSW. Maki et al.[7] carried out meteorological observations in Turpan for one year, and obtained similar results. From these results, it is suggested that the arrangement of wide windbreaks from the western side to the northern side of the oasis, is necessary to prevent high temperature injury and wind damage on crop in Turpan. Actually, a wide windbreak was arranged from the western side to the northern side of this oasis.

Fig. 4(A) shows the changes in the atmospheric pressure with time in Turpan, and (B) shows the changes in the upper air temperature with time in Hami and Altay. The hatched areas represent periods with a wind velocity of more than 5 m/s at the Turpan site. The wind velocity at 850 hPa pressure altitude (about 1,500 m sea level) was 10 m/s or less in Hami and Altay during the observation period and there was no relation between the wind with a velocity of more than 5 m/s at Turpan and the upper air wind in Hami and Altay. When the atmospheric pressure increased in Turpan, the wind velocity exceeded

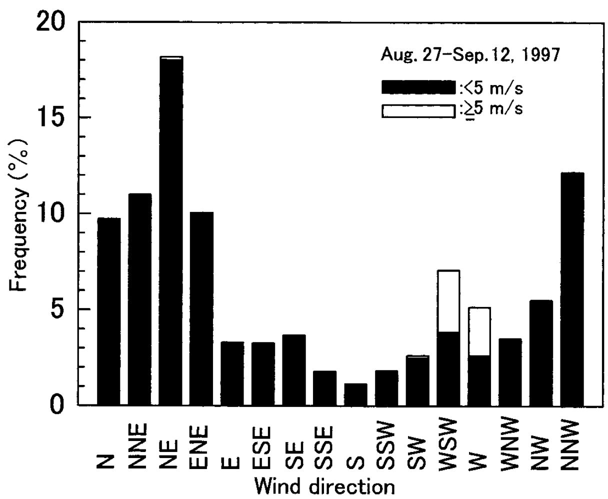

Fig. 3. Frequency distribution of wind directions from August 27 to September 12, 1997 at the Turpan site

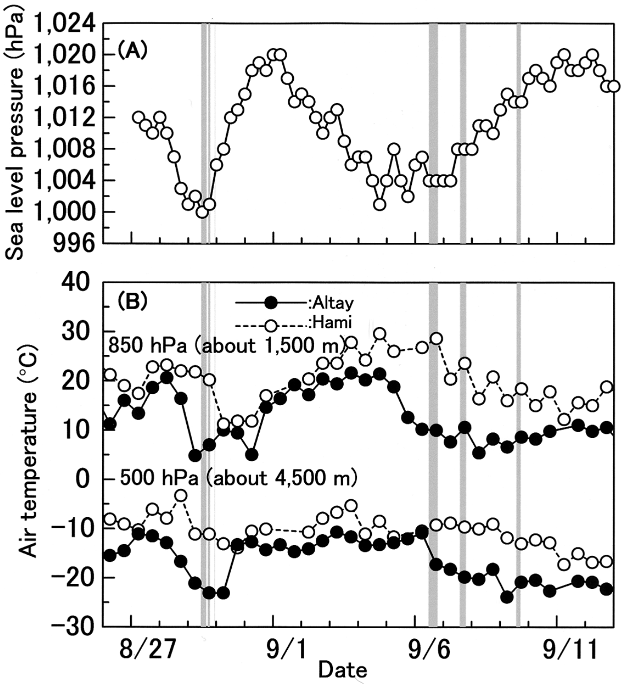

Fig. 4. Seasonal variations in (A) sea level pressure in Turpan and (B) air temperature of the upper atmosphere in Altay and Hami

The hatched areas denote the periods during which the wind velocity exceeded 5 m/s at the Turpan site.

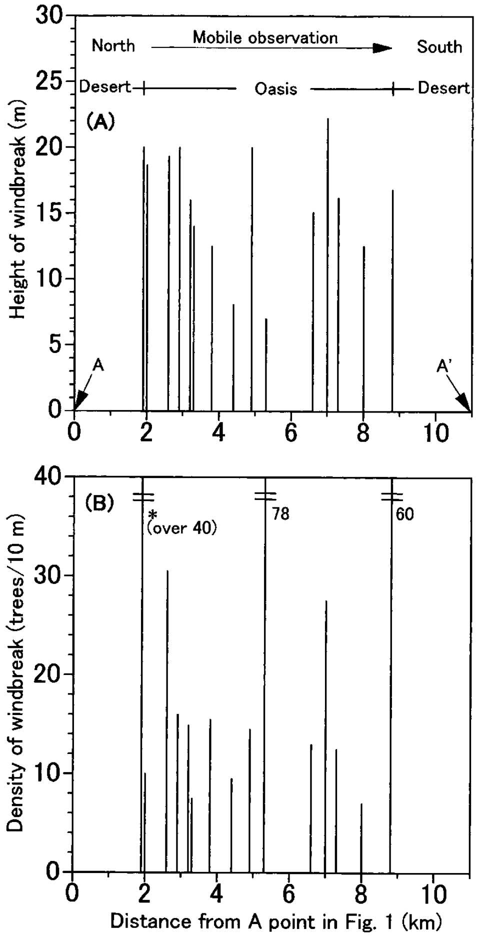

Fig. 5. Location and characteristics of windbreaks along the route A–A' in Fig. 1

Solid lines indicate (A) the height and (B) the density of the windbreaks. A and A' on the X-axis indicate points A and A' in Fig. 1.

*:The density of this windbreak could not be determined, because it was very wide.

5 m/s at the Turpan site. The atmospheric pressure in Turpan increased after the depression passed through the north of Turpan on August 29 and September 4, 1997. As shown in Fig. 2(A) and 4(B), a cold air mass flew from the northern part of the Tianshan mountains after the passage of the depression. In another report, Kurose et al.[4] carried out mobile observations from Urumqi to Turpan on August 29 and September 9, 1997. When a cold air mass flew from the northern part of the Tianshan mountains, strong wind with a velocity of more than 20 m/s blew through the valley on the southern slope of the Tianshan mountains. However, the wind became weaker at the point from 25 km on this side of Turpan and the wind velocity was less than 10 m/s at the Turpan site[4]. The wind with a velocity of more than 5 m/s in Turpan was attributed to the inflow of a cold air mass from the northern part of the Tianshan mountains, after the passage of the depression through the northern part of Turpan.

2) Effects of tree windbreaks on the improvement of the meteorological conditions

A group of tree windbreaks was arranged on the route A–A' as shown in Fig. 1. These windbreaks can be described as strong windbreaks in Turpan. Fig. 5 shows the location and characteristics of the windbreaks along route A–A'. Fig. 5(A) and (B) depict the height of the windbreaks and the tree density of the windbreaks, respectively. The tree density of the windbreaks is denoted by the number of trees for every 10 m in the east-west direction. A and A' on the X-axis correspond to points A and A' in Fig. 1. Incidentally, there are various types of windbreaks in the Turpan oasis. For example, a wide windbreak (about 50 m) was arranged at the northern end of the oasis. The tree density of this windbreak could not be determined since it was too wide. The windbreak located at the southern end of the oasis was about 10 m wide. And in this connection, Fig. 6 shows a photograph of a windbreak in the central area of the oasis which is characterized by trees arranged in a row. However, in this central area of the oasis, the windbreaks with a height of less than 10 m consisted of several rows. On

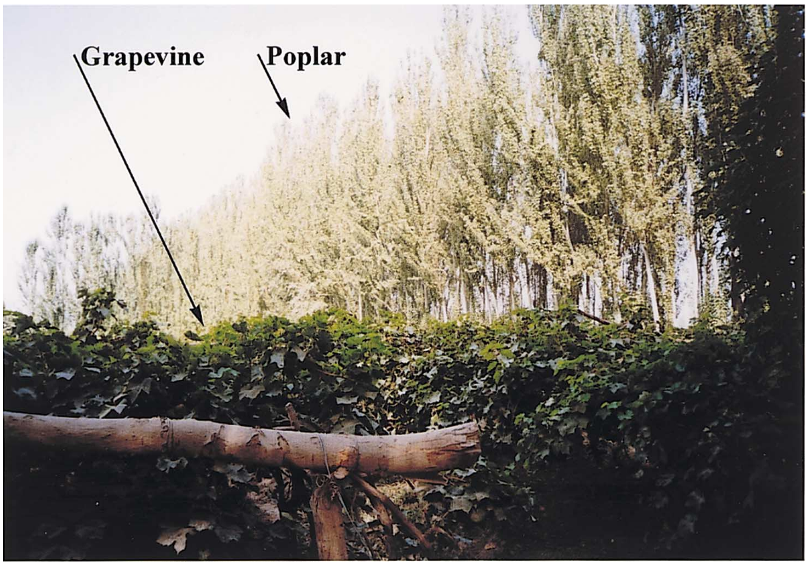

Fig. 6. Windbreak made of poplars and grapevine trellis along route A–A' in Fig. 1

the other hand, the mean height of the trees in the windbreaks along the route A–A' was 15.9 m and the tree species consisted of poplars or elms. The windbreaks were arranged at 490 m intervals on the average.

Fig. 7 shows the horizontal variations in the air temperature and relative humidity along route A–A' on September 2 and 4. As shown in Fig. 7, similar horizontal variations were observed on both days. The observations were considered to represent typical cases of a higher air temperature and lower relative humidity in the year in this area. The air temperature was converted into the sea level air temperature based on the temperature lapse rate of 0.007ºC/m. The air temperature of the oasis was 4.7ºC (maximum) and 3.6ºC (on the average) lower than that of the desert on September 2, and 5.9ºC (maximum) and 4.8ºC (on the average) lower on September 4. The relative humidity of the desert was 15 or 16% on the same days. The relative humidity of the oasis was 25% (on the average) on September 2, and 29% (on the average) on September 4, respectively.

In the oasis at a distance of 1 km from the desert, the air temperature decreased and the relative humidity increased. On the other hand, the air temperature and relative humidity were constant at a distance of more than 1 km from the desert.

Fig. 8 shows the results of investigations on the route B–B', B and B' on the X-axis representing points B and B' in Fig. 1. Fig. 8(A) shows the height of the windbreaks and (B) shows the density of the windbreaks. The solid line shows the windbreaks made of poplars or elms, and the dotted lines show the windbreaks made of tamarisks. The decrease in the air temperature from the a to c windbreaks over 6.1 km was 0.7ºC, and the increase in

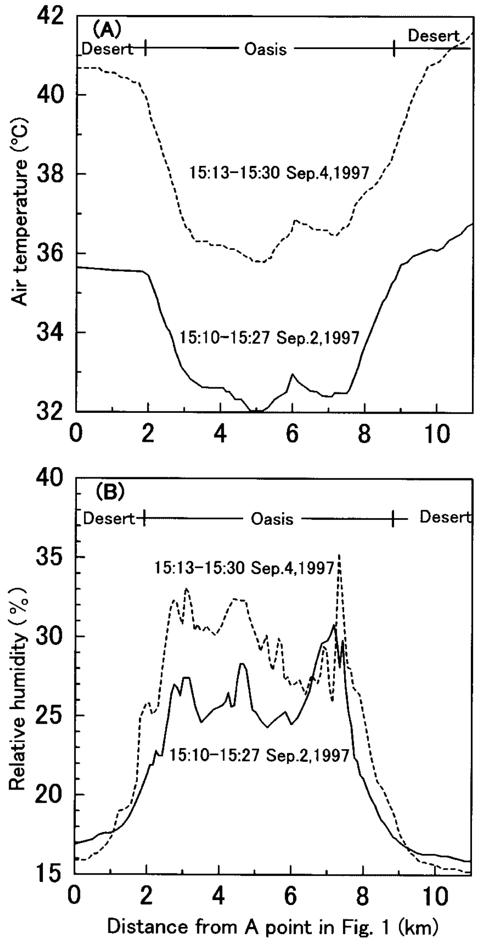

Fig. 7. Horizontal variations in (A) air temperature and (B) relative humidity along route A–A' in Fig. 1
Solid and dotted lines indicate the variations in meteorological components on September 2 and 4, 1997. X-axis is the same as that in Fig. 5.

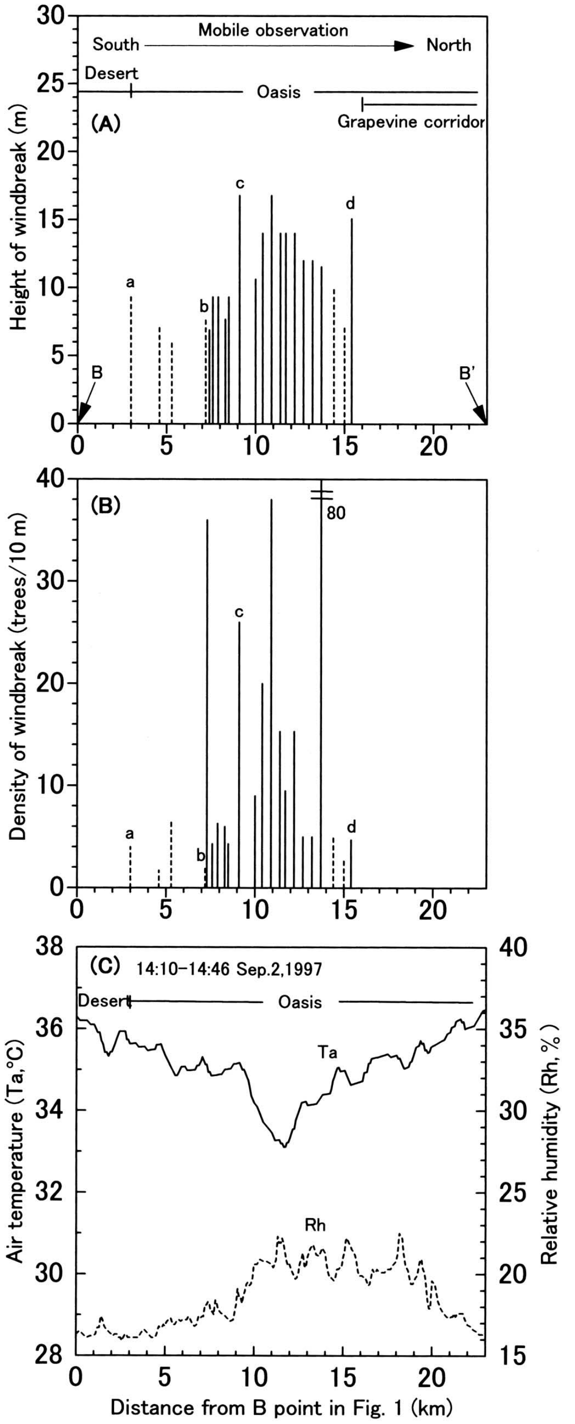

Fig. 8. Location and characteristics of windbreaks along route B–B' in Fig. 1

Solid and dotted lines indicate (A) the height and (B) the density of the windbreaks. Dotted lines indicate the windbreaks made of tamarisks, and solid lines indicate the windbreaks made of poplars or elms. B and B' on the X-axis denote points B and B' in Fig. 1. (C): Horizontal variations in air temperature and relative humidity on September 2, 1997.

relative humidity was 3.0%. The windbreaks from a to b were arranged at 1.4 km intervals on the average, and the density of the tree windbreaks was 3.6 trees /10 m on the average. The windbreaks from b to c were arranged at 320 m intervals on the average and the average height of the windbreaks was less than 10 m. Since the tree density of the windbreaks from a to c was low and the trees were less than 10 m in height, the effect on the improvement of the meteorological conditions was negligible. The effect on the improvement of the meteorological conditions was evident for the windbreaks between c to d as shown in Fig. 8. The windbreaks in this section were arranged at 530 m intervals on the average, the average height of the windbreaks was 13.0 m and the tree species consisted of poplars or elms.

Thus, as shown in Figs. 7 and 8, since the meteorological conditions were different in the marginal area and the central area of this oasis, the meteorological conditions should be given priority over other conditions for the determination of suitable landuse for crop production. For instance, sorghum can be grown under hot and dry conditions and high quality cotton can be produced under irrigated, and hot and dry conditions. Therefore, the marginal area of an oasis is suitable for cultivating sorghum and cotton, because the arid climate of the marginal area of the oasis is hotter and drier than that in the central area of the oasis. On the other hand, grapes often sustain high temperature injury and wind damage, but require a large quantity of irrigation water. Therefore, grapes should be cultivated in the central area of the oasis, where the air temperature is low, the wind velocity is low[2] and evapotranspiration of grapes is also lower. Actually, a large amount of grapes is cultivated in the central area of this oasis.

Maki et al.[8] proposed a suitable arrangement of the windbreaks in arid lands and showed that the main windbreaks should be arranged at 200–300 m intervals while the secondary windbreaks should be arranged at 100–200 m intervals. The actual intervals of the windbreaks in Turpan were wider compared with those proposed by Maki et al.[8]. It is considered that the effect on the improvement of the meteorological conditions may become more pronounced if the windbreaks could be arranged at closer intervals. Actually, in the central area of the Turpan oasis, the air temperature remains low and the relative humidity remains high as shown in the present study (Fig. 7). Therefore, the meteorological conditions prevailing in Turpan suggest that further improvement could be obtained by arranging the windbreaks at wider intervals of about 500 m, provided the windbreaks are strong, i.e. the tree density in a windbreak is higher and the trees are taller, which can be achieved by planting poplar and elms.

However, some constraints may arise, such as the decrease of the farmland area by the new arrangement of the windbreaks and the need for additional irrigation water to maintain these newly arranged windbreaks. Especially, poplars require a large amount of irrigation water.

The high temperature injury on crop occurs in Turpan because of the presence of a dry hot wind with a velocity of about 1–4 m/s[9]. The effect of tree windbreaks on the improvement of meteorological conditions under dry hot conditions was clarified in the current study. The results of the investigations may provide basic data, to determine the arrangement of the tree windbreaks and suitable land for crop production in an oasis.

However, as it is suggested that the effect on the improvement of the meteorological conditions is less conspicuous under windy conditions, further observations under windy conditions should be made.

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