Climatic Differences between an Oasis and its Peripheral Area in Turpan Basin, Xinjiang, China

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Received May 9, 1994

Abstract

In order to analyse the climatic differences between an oasis and its peripheral area to evaluate the climatic improvement in an oasis, meteorological data recorded at two stations in the Turpan Basin, China were compared. One of the stations was an automatic meteorological station set up in the peripheral area of an oasis (1 km) and the other was the meteorological observatory of Turpan, which was surrounded by the oasis. Differences were observed in the data recorded in the two stations. Some analyses of the climatic characteristics of the oases were performed in terms of heat balance. The results showed that plantation of vegetation and irrigation in oases reduced the wind velocity and air and soil temperature variations and increased the evapotranspiration and the humidity in oases. Both the air temperature and soil temperature increased very rapidly after rainfall in the peripheral area, while inside the oasis they increased slowly due to the effects of the oasis and higher water content in soil and higher air humidity inside the oasis.

Additional key words : climate improvement, evaporation, heat balance,windbreak

Introduction

Windbreak forests play an important role in the cultivation of crops in oases. It is considered that agriculture would be impossible without the use of windbreaks in the arid lands of China due to the climate improvement effects of windbreak forests and oasis itself. Although many studies have been carried out on the effects of windbreak forests or nets[1, 6, 9, 12, 13] and some studies have been carried out in Turpan Basin[4, 10, 11], few studies[7, 8, 14] have dealt with the climatic improvement by oasis, due to the lack of meteorological data. Some authors have pointed out that oases lead to the increase of humidity and precipitation and decrease of temperature, due to the presence of water in oases[8, 14]. In order to analyse the climatic differences between an oasis and its peripheral area to evaluate the climatic improvement in an oasis, an automatic meteorological station has been set up by TARC (JIRCAS) in the peripheral area (42° 51' N, 89° 11' E, - 80 m) of an oasis in Turpan, Xinjiang, China since June, 1990. In the present paper an analysis of some of the climatic characteristics of an oasis and its peripheral area was carried out in Turpan, Xinjiang, China by comparing the data inside an oasis and in the peripheral area of the oasis.

Data

The Turpan basin is located in a very dry area in Northwestern China. Annual precipitation is 16.4mm and minimum relative humidity is almost 0%. The maximum air temperature can be as high as 47.9℃ and minimum air temperature as low as -28.0℃.

Fig. 1 shows a schematic map of the area observed. The Turpan basin is located in the southeastern part of the Tianshan Mountains. The lowest elevation in the basin is -154m (Aydin Lake) and the elevation of the surrounding mountains ranges from 4, 000 - 5,445 m in the north and 600-1,500 m in the south. In addition, the Flaming Mountains are situated in the center of the basin with a length of 90 kilometers from west to east and a width of 5-6 kilometers from north to south. The relative elevation of the mountains is about 300-400m.

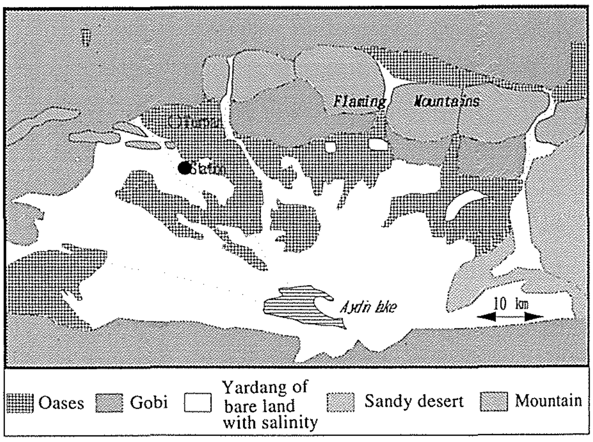

Fig. 1. A schematic map of the observation field. There was no vegetation in the gobi area, sandy desert and mountains and only a sparse vegetation or bare land with salinity in the Yardang area

The Meteorological observatory of Turpan is located inside a small town named Turpan (42° 56'E, 89°12'N, 34m) and is surrounded by an oasis (○Turpan in Fig. 1). Oasis agriculture in Turpan has a very long history, due to the abundance of the water supply from Tianshan Mountains through karez. There are about 1000 karez in the Turpan basin. Most of them are still in use although a large number have been abandoned. The automatic observation station was set up in the Yardang area which is characterized by the absence of vegetation (desert) and strong wind erosion and is located 10 km apart from the observatory in the town and 1 km from the oasis (● Station in Fig. 1). Due to the absence of water supply, the land in the Yardang area is bare with salinity or covered with a sparse vegetation consisting of Alhagi sparsifolia and Tamarix ramosissima. There is no vegetation in the gobi area, sandy desert and mountains as shown in Fig. 1.

Air temperature and humidity at two levels, wind velocity at five levels and wind direction, radiation, soil temperature and heat flow, sunshine and precipitation, etc. were measured at the automatic station in the peripheral area. Air temperature and humidity were measured using two sets of wet and dry bulb thermometers at two levels, 1m and 1.6m, at intervals of 30 minutes. Soil temperature at 1cm and 5cm underground and soil heat flow at 1cm, 5cm and 10cm were measured at intervals of one hour with soil thermometers and soil heat flow plates, respectively. Wind velocity at 5 levels was measured at intervals of 10 minutes. Integrated solar or global short-wavelength radiation and short-wavelength reflected radiation were obtained using two solarimeters at intervals of one hour. For some short periods (for example from August 22 to September 6, 1991), net radiation (including both short-wavelength and long-wavelength) was obtained using a net radiometer. All the data were recorded automatically by using a solar cell. In this paper, the data obtained from July 1, 1991 to December 31, 1991 were used because in this period only the data from the Meteorological Observatory of Turpan were available (from August 18 to 21, 1991. the records were not available).

These data were compared with the data of the Meteorological Observatory of Turpan, which were recorded at intervals of 6 hours for the soil temperature and at intervals of 3 hours for the temperature and humidity and at intervals of one hour for the wind velocity and wind direction.

Climatic differences between oasis and its peripheral area

1) Wind

Due to the presence of windbreaks and increase of roughness (vegetation and buildings), the reduction of the wind velocity in the oasis was very obvious as shown in Fig. 2. Daily mean wind velocity and daily maximum wind velocity in the oasis (V_{om} and V_{omax}) in relation to the peripheral area (V_{dm} and V_{dmax}) were as follows, respectively:

$$V_{om} = 0.407\ V_{dm} \quad (1)$$

$$V_{omax} = 0.536\ V_{dmax} \quad (2)$$

Thus, the wind velocity inside the oasis was almost half of that in the peripheral area of the oasis. Fig. 2 also shows that when the wind velocity was high in Turpan such as in July, the decrease of the wind velocity inside the oasis was more pronounced.

Wind direction also changed in the oasis. The difference in the maximum wind direction between the peripheral area and the oasis was not very large in July because the wind velocity was high while it was conspicuous in January when the wind velocity was low.

2) Temperature

As shown in Fig. 3, both the diurnal and annual variations of the air temperature became smaller inside the oasis. In July, daily mean, daily maximum and daily minimum air temperatures were lower inside the oasis. Monthly mean maximum air temperature in July was 1.3℃ lower in the oasis than in the peripheral area, while monthly mean minimum air temperature in the oasis was only 0.9℃ lower than in the peripheral area. This decrease in temperature in summer is very important for the vegetation since the air temperature is too high (near 40.0℃) for vegetation growth. In contrast, when it became colder from September to October, the daily minimum air temperature was higher inside the

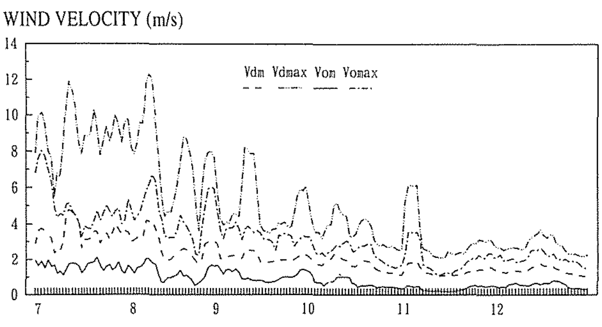

Fig. 2. Time series of daily maximum and daily mean wind velocity with 5 days running means in an oasis (o) and its peripheral area (d) in Turpan, Xinjiang, China from July 1 to Dec. 31, 1991

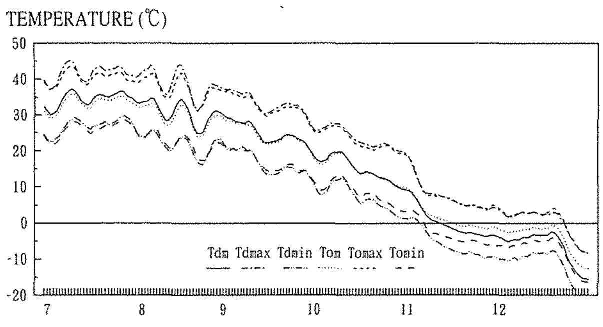

Fig. 3. Time series of daily mean, maximum and minimum temperatures with 5 days running means in an oasis (o) and its peripheral area (d) in Turpan, Xinjiang, China from July 1 to Dec. 31, 1991

oasis than in the peripheral area, while daily mean and daily maximum air temperatures were still lower inside the oasis. From November to December, daily mean and daily minimum air temperatures were higher inside the oasis than in the peripheral area, especially the minimum air temperature was much higher inside the oasis than in the peripheral area. Monthly mean

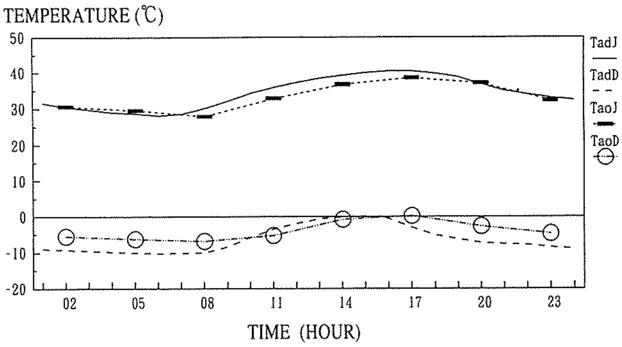

Fig. 4. Comparison of diurnal variations of air temperature (Ta) between an oasis (o) and its peripheral area (d) in Turpan, Xinjiang, China for July (J) and December (D)

minimum air temperature in December was about 3.7℃ higher inside the oasis than in the peripheral area. This increase in temperature in winter is also important since the air temperature is very low (below -10.0℃). These characteristics were evident based on the monthly means of diurnal variations of air temperature for July and December shown in Fig. 4.

It was obvious, as shown in Fig. 4, that the air temperature inside the oasis was lower than in the peripheral area from 8 BST in the morning until 20BST at night in July. However, the air temperature was lower inside the oasis than in the peripheral area only from 11 BST to 14 BST in December. The air temperature at 14 BST in the oasis was 2.5℃ lower than in the peripheral area in July. The air temperature at 8 BST in oasis was 3.2℃ higher than in the peripheral area in December. The daily range of the air temperature in the oasis was 0.4℃ smaller in July and 3.3℃ smaller in December. The annual range of air temperature in the oasis was 3.5℃ smaller than in the peripheral area. This range of temperature variation is very convenient for agricultural and human activities in Turpan.

Soil temperature differences between the

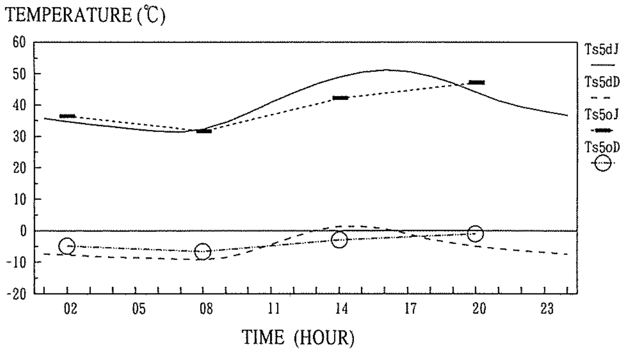

Fig. 5. Comparison of diurnal variations of soil (5cm) temperature (Ts5) between an oasis (o) and its peripheral area (d) in Turpan, Xinjiang, China for July (J) and December (D)

oasis and the peripheral area showed similar characteristics to those of air temperature and the differences were more significant as shown in Fig. 5. Soil temperature at 5cm underground at 14 BST was 6.8℃ lower in July while 2.5℃ higher at 8 BST in December inside the oasis than in the peripheral area.

3) Humidity

Unfortunately, the automatic dry and wet bulb thermometers used at the station in the peripheral area failed to record correct humidity data due to the freezing of the gauze of the wet bulb in winter and accumulation of sand in the gauze of the wet bulb at other times. Relative humidity at the station in the peripheral area increased from the end of October and was almost equal to 100% at the end of November due to the freezing of the gauze. Relative humidity recorded in the peripheral area was higher and the variations of the relative humidity were smaller than those in the oasis due to sand accumulation in the gauze.

However, the relative humidity inside the oasis was higher than in the peripheral area. Some authors[8, 14] have pointed out that the relative humidity was higher and precipitation more abundant in oases than in peripheral areas.

Discussion

Climate improvement associated with an oasis can be explained through the analysis of heat balance on the ground. The heat balance on the ground within a given time can be represented as follows:

$$R = LE + P + A \quad (3)$$

where R is the net radiation flux of heat; L is the latent heat of evaporation; E is the velocity of evaporation or of condensation; P is the heat flux caused by the turbulence between the surface and the atmosphere; A is the heat flux between the surface and deeper layers of soil. The net radiation flux of heat (R) was obtained by using a net radiometer and the heat flux between the surface and deeper layers of soil (A) was observed by using soil heat plates at the observation station of the peripheral area. Evaporation rate (E) and turbulence heat flux (P) can be calculated by the modified Bowen ratio method[5]:

$$E = \alpha E_b \quad (4)$$

where E_b is the evaporation rate obtained by the Bowen ratio method, α is an empirical coefficient, which is introduced mainly due to the inaccuracy of the wet bulb temperature as mentioned above.

$$LE_b = (R-A)/(1-\beta) \quad (5)$$

$$\beta = (Cp/L)(\Delta T/\Delta q) \quad (6)$$

$$P = \beta LE \quad (7)$$

where β is the Bowen ratio; Cp is the specific heat at constant pressure of air; L is the latent heat of evaporation; ΔT is the air temperature difference at two levels; Δq is the specific humidity difference at two levels.

Fig. 6 shows a time series of diurnal variations of all the components of the heat balance with incoming integrated solar radiation flux (S) at the observation station in the peripheral area before and after a rainy day, from Aug. 23 to Aug. 29, 1991. Fig. 7 shows the time series of temperature (both air temperature and soil temperature at the surface or 1cm level and at 5cm levels) during the same period at the two stations, both inside the peripheral area (Fig. 7 (A)) and in the oasis (Fig. 7 (B)). Precipitation on the night of Aug. 24 was 0.8mm. Variations in the air and soil temperatures inside the oasis and in the peripheral area were different presumably due to the reduction of the wind velocity in the oasis and to the difference in the water content in the soil and difference in the humidity in the air near the ground between the oasis and its peripheral area.

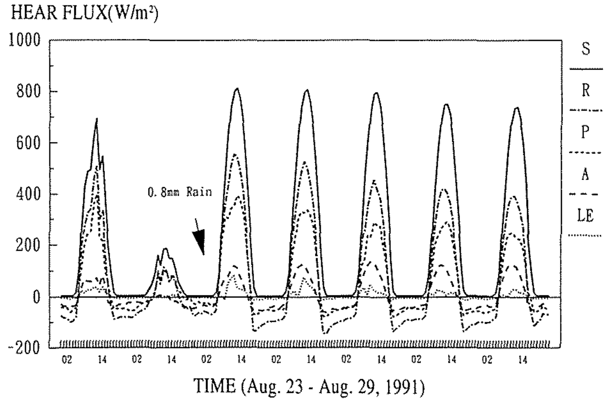

Fig. 6. Time variation of all the components of heat balance before and after rainfall in the peripheral area of an oasis in Turpan, Xinjiang, China from Aug. 23 to Aug. 29, 1991.
S : Solar radiation flux; ***R*** : net Radiation flux; ***LE*** : latent heat flux caused by Evaporation or Condensation; ***P*** : heat flux caused by the turbulence between the surface and the atmosphere; ***A*** : heat flux between the surface and deeper layers in soil.

In the peripheral area, it was obvious that the evaporation rate as well as the values of other parameters were very low or that there was no evaporation before rainfall occurred due to the very low water content there. However, the evaporation rate increased markedly soon after the rain and the daily evaporation amount decreased exponentially with time. Due to the increase in the water content in the soil soon after rainfall, reflected short-wavelength radiation decreased so that the net radiation increased and both the air and soil temperatures decreased (Aug. 25). However, due to the loss of the surface water

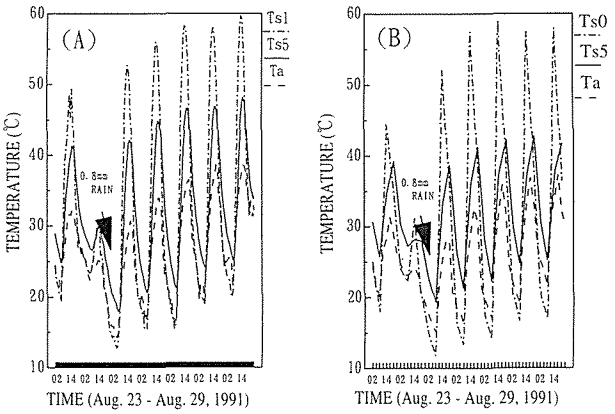

Fig. 7. Air temperature (Ta) and soil temperature (Ts) variations before and after rainfall in Turpan, Xinjiang, China from Aug. 23 to Aug. 29, 1991. (A): in the peripheral area of an oasis; (B) inside the oasis

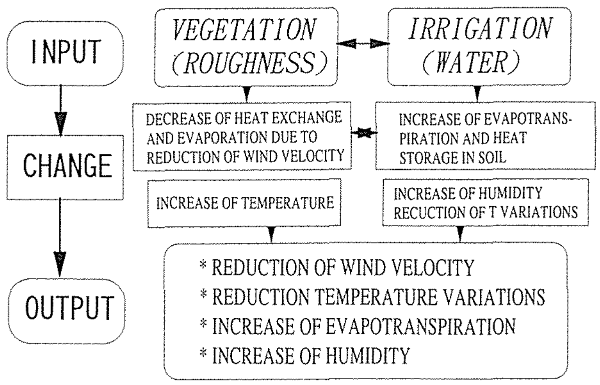

Fig. 8. A schematic representation of climate improvement approach by oases

content by evaporation, both the air temperature and soil temperature increased and reflected short-wavelength radiation increased so that the emission of long-wavelength radiation from the ground increased and the net radiation decreased with time. Although the net radiation decreased with time, there was a positive feedback in that the lower the water content in soil, the more the heat transfer to the earth and the air, and the higher the temperature in soil and in the air. Thus, both air temperature and soil temperature increased very rapidly with time (Fig. 7 (A)). In another example of time series of diurnal variations of all the components of the heat balance and temperature in the peripheral area before and after 5.5mm rainfall, from Mar. 18 to Mar. 27, 1992, it took more than one week for the 5.5mm of rainfall to evaporate water and the increase of the temperature was comparatively moderate.

In contrast, inside the oasis, both the air and soil temperature did not increase as rapidly as in the peripheral area as shown in Fig. 7 (B). The increase of the soil temperature at 5cm level was much lower than that in the peripheral area, presumably due to the effects of low wind velocity, higher water content and higher air humidity inside the oasis.

It is generally recognized that the climate improvement in an oasis is mainly caused by two kinds of input to the natural conditions in an arid area. Fig. 8 shows a schematic representation of the climatic improvement approach. One of the inputs is the plantation of vegetation, especially erection of windbreaks, which mainly increases the roughness and contributes to additional evapotranspiration. This input can decrease the heat exchange and evaporation due to the reduction of the wind speed[2, 4, 5] and can increase the air and soil temperature, especially when the ground surface is humid[3]. Another input is irrigation, which can increase the evapotranspiration and heat storage in soil, resulting in the increase of humidity or even of precipitation[8] and can reduce temperature variations as mentioned in this paper. As a result of the effect of the two inputs and exchanges in solar and heat energy, the climate in an oasis is characterized by a comparatively lower wind velocity; smaller temperature variations and higher air humidity and evapotranspiration than in the peripheral area.

Conclusion

Based on automatic meteorological observations in the peripheral area of an oasis in Turpan, Xinjiang, China and comparison with the data obtained at the Meteorology observatory of

Turpan inside the oasis, the climatic differences between the oasis and its peripheral area were as follows:

(1) Wind velocity inside the oasis was about 50% of that in the peripheral area due to the increase in roughness and erection of windbreaks. Wind direction also changed when the wind velocity was low.

(2) Both the annual and diurnal variations of the air temperature and soil temperature became attenuated inside the oasis compared with the peripheral area. Both the air temperature and soil temperature were lower in summer and higher in winter inside the oasis than in the peripheral area. Both the air temperature and soil temperature were lower in the day time and higher at night inside the oasis than in the peripheral area. The daily range of the air temperature in the oasis was 0.4℃ smaller in July and 3.3℃ smaller in December than in the peripheral area. The annual range of air temperature in the oasis was 3.5℃ smaller than in the peripheral area.

(3) Both the air temperature and soil temperature in the peripheral area increased very rapidly after rainfall due to the rapid loss of rain water by evaporation, while those inside the oasis increased more slowly due to the effects of the oasis and higher water content in soil and higher air humidity inside the oasis.

Irrigation and plantation of vegetation in oases results in the increase of the soil water content and roughness so that the climate in oases is characterized by a comparatively lower wind velocity; smaller temperature variations and higher air humidity and evapotranspiration than in the peripheral area. However, detailed mechanisms and the interaction between oases and desert for climate improvement require further studies.

Acknowledgement

The author would like to thank Pro. Borong Pan of the Turpan Desert Research Station, Xinjiang Institute of Biology, Pedology and Desert Research, Chinese Academy of Sciences for collecting the data of the Meteorological Observatory of Turpan.

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中国新疆トルファンにおけるオアシスとその周辺の気候差異

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摘　要

乾燥地におけるオアシス農業では，防風施設が極めて重要である。中国新疆では，防風林がないとオアシス農業ができないと言われている。これは防風林及びオアシス自身による気象改良効果のためと考えられる。防風施設による気象改良効果に関する研究は多いが，オアシスの気候に関する研究は気象データの不足のため極めて少ない。乾燥地におけるオアシスとその周辺の気候特性を知るために，日本国際農林水産業研究センター（元熱帯農業研究センター）は中国科学院新疆生物・土壌・砂漠研究所との共同研究で，中国新疆トルファン（吐魯番）におけるオアシスの境界地に自動気象観測所を設置し，1990年６月から観測が始めた。トルファンは新疆の首都ウルムチ（烏魯木斉）の南東200kmのトルファン盆地（最低点，海抜－154m）内にあり，自動気象観測所は北緯42°51'，東経89°11'の海抜－80mの地点で，オアシスから１km離れた砂漠風食地に位置する。気温は最高47.9℃，最低－28.0℃であり，年降水量16.4mm，最小湿度は０％で極めて乾燥している。

本研究では，砂漠に位置する自動気象観測所の気象データとオアシス内にあるトルファン中国国立気象観測所の気象データとの比較分析を行った。データの期間は1991年７月１日から12月31日までである。また，砂漠風食地における降雨前後の熱収支の時間変化の事例を挙げ，熱収支の観点からオアシスと周辺の気候差異及びその要因を論議した。その結果，次のことを明らかにした。

（１）防風林及びオアシスの植物の影響で，オアシス内の風速はオアシス外より約50％減った。風速が弱い時，風向が変わることもあった。

（２）オアシス内では，夏と日中の気温と地温は低くなり，冬と夜の気温と地温は高くなり，年変化と日変化とも小さくなった。

（３）降雨後の数日間に，砂漠風食地では降った雨をすぐに蒸発したため，地温と気温とも急速に上昇したが，オアシス内では土壌水分が多いと空気湿度が高いため，地温と気温の上昇が緩慢であった。

以上，乾燥地のオアシスにおいては灌漑と植被による土壌水分と地表面の粗さの増加のため，周辺より風速が弱く，温度変化が小さいなどの特徴を持つことが明らかになった。今後，オアシスの気候改良の詳しいプロセス及びオアシスと砂漠間の相互作用について，研究を進める必要がある。

キーワード：気候改良，蒸発，熱収支，防風林