Effects of Forest Windbreaks deployed in Arid Lands, Turpan, Northwest China

1. Effect on climatic improvement

Taichi MAKI[a], Borong PAN[b], Mingyuan DU[c], Makoto NAKAI[c] and Kenji UEMURA[d]

[a, c] *Marginal Land Research Division, Tropical Agriculture Research Center (Tsukuba, Ibaraki, 305 Japan)*

[b] *Turpan Desert Research Station, Xinjiang Institute of Biology, Pedology and Desert Research, Chinese Academy of Sciences (Urumqi, China)*

[d] *Faculty of Agriculture, University of Tokyo (Bunkyo-ku, Tokyo, 113 Japan)*

Received April 30, 1993

Abstract

Meteorological observations relating to the alleviation of the effect of adverse climatic conditions in arid lands were carried out at the Turpan Desert Research Station, Xinjiang located in the northwestern part of China from 1990 to 1992. It was demonstrated that the use of tamarisk forest windbreaks alleviated the adverse effect of wind velocity, and improved the air temperature, surface soil temperature and relative humidity under very dry conditions. The use of two rows of tamarisk windbreaks resulted in the decrease of the wind velocity and in climatic improvement in comparison with the use of a single row of tamarisk windbreak. It is suggested that forest windbreaks could be very effective for the alleviation of adverse climatic conditions in arid lands.

Additional key words : tamarisk, wind speed, air temperature, surface soil temperature, relative humidity

[a] Present address: National Agriculture Research Center (Tsukuba, Ibaraki, 305 Japan)
[c] Present address: Japan International Research Center for Agricultural Sciences (Tsukuba, Ibaraki, 305 Japan)

Introduction

Dry lands occupy one-third of the total surface area in the world. The process of desertification has been accelerated recently by excessive cultivation, deforestation, overgrazing and excessive consumption of water. Arid or dry lands in China cover 1,308,000km^2 or 13.6 % of the total land area. The process of desertification which has been developing in China for a long time, has made rapid progress recently. Prevention of desertification and greening of the desert may be achieved through the improvement of meteorological conditions by the use of forest windbreaks.

Meteorological observations related to the improvement of climatic conditions were carried out in an arid area at the Turpan Desert Research Station, Xinjiang Institute of Biology, Pedology and Desert Research, Chinese Academy of Sciences in spring, summer, autumn and winter using a single row of tamarisk windbreak and again in spring using two rows of tamarisk windbreaks[4,5,6,7].

Analysis of the improvement of the meteorological conditions will be outlined.

Observation Methods

Observation area is located at 42° 51'N, 89° 11'E, in Turpan, 200 km southeast of Urumqi. The elevation is 80 m below the sea level. The climate is of the continental type, arid with large differences in the temperature, the maximum and minimum air temperatures being 48° C and -28° C, respectively, and an annual precipitation of 16.4 mm. Low relative humidity below 10% is very frequently observed. The period of strong WNW wind lasts from April to June.

Observations were carried out on July 1 to 2, 1990, May 4, Aug. 24, Nov. 29, 1991, and April 25, 1992. The height of the tamarisk (*Tamarix elongata* L.) shrub (Plate 1) covering an area extending over a distance of 1 km (11 m width) was 4.6 m and the density of the windbreak which was expressed by a value corresponding to 100% - porosity was 85%. Another windbreak located at 570 m from the windward windbreak during the period of strong wind, consisted of huyang (*Populus euphratica* O.) and shazao (*Elaeagnus angustifolia* L.) trees with a height of 6 to 8 m.

Plate 1. A tamarisk windbreak at Turpan, China

The meteorological parameters measured included the wind direction and wind speed (U) at 1.5 m, air temperature (Ta) and relative humidity (RH) at 1.0 m, and surface soil temperature (Ts) at 0.0 m.

For the observation of the single row of tamarisk windbreak, the relative wind speed (Ur) was expressed in percentage (%) by taking the value recorded at 1.5 m height at -20 H as 100%. Observation points on the windward side were located at -20, -10, -7, -5, -2, -1, -0 H and on the leeward side at 0, 1, 2, 5, 7, 10, 15, 20, 25, 30 H from the forest windbreak, and also in the center of the windbreak.

The symbol nH indicates the distance from the windbreak represented by the multiple of the height (H) of the forest windbreak. The negative sign corresponds to the windward side and the positive sign to the leeward side.

For the observation of the double row of tamarisk windbreaks with a windbreak interval of about 50 m, there were 17 points on the windward side, leeward side from and inside the windbreak.

Results

1) Examples of meteorological improvement

by the use of a single row of tamarisk windbreak

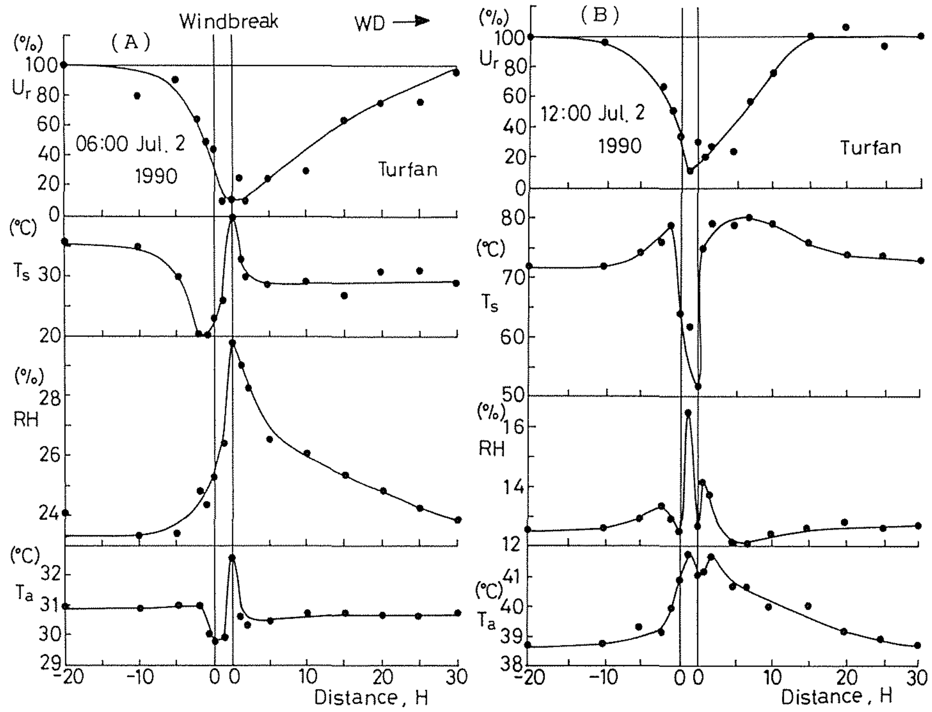
(1) Data recorded on July 1 to 2, 1990

The decrease of the wind speed and improvement of the meteorological conditions induced by the tamarisk windbreak in summer at 6:00 and 12:00 on July 2, 1990 are shown in Fig. 1, under high temperature and low relative humidity conditions in Turpan, China.

(a) As shown in Fig. 1 A (6:00 July 2), the relative wind speed (Ur) decreased from -10 H and returned to the original value at 30 H. The main effects occurred at distances of -5 H to 20 H from the windbreak. The minimum value of Ur was 10% on the leeward side near the windbreak. The value ranging from 10 to 20% was very small and the effect of the forest windbreak was pronounced in the center of the windbreak up to 5 H. Then, the Ur value gradually increased after 5 to 30 H. Wind direction changed to the opposite direction in the range from 0 to 5 H.

The surface soil temperature (Ts) and air temperature (Ta) which decreased in the range from -1 to -2 H due to radiation cooling and shading brought about by the windbreak, increased markedly at 0 H or on the leeward side near the windbreak by solar heating. The Ts value for sandy soils at 0:00 on July 2 (figure omitted) decreased significantly due to radiation cooling and the wind velocity on the leeward side also decreased until 20 H.

Relative humidity (RH) increased from -2 to 25 H, particularly inside the windbreak and at 0 to 5 H due to the increase in the humidity associated with the transpiration from tree leaves of the windbreak and evaporation from the soil surface of the windbreak belt under light winds at 6:00, reflecting the beneficial effect of the windbreak. The RH value on the leeward side near the windbreak was also slightly higher at 18:00 on July 1 and at 0:00 on



WD: Wind direction, Ur: Relative wind velocity,
Ts: Surface soil temperature, RH: Relative humidity and Ta: Air temperature
(A) 6:00 July 2 and (B) 12:00 July 2, 1990

Fig. 1. Improvement of meteorological conditions caused by a tamarisk windbreak

July 2.

(b) As shown in Fig. 1 B (12:00 July 2), the Ur value decreased from -10 to 15 H. The area with the decrease, however, was smaller at 6:00 than at 12:00, because the wind direction did not form an acute angle with the windbreak, although the minimum values of Ur did not change.

Ts was very high and ranged from 70 to 80℃ on both the windward and leeward sides, and exceeded 80℃ near the forest windbreak. However, the decrease of Ts ranged from 20 to 25℃ and the minimum was 52℃ inside the shaded windbreak, indicating the beneficial effect of the windbreak.

The variation of the amplitude of Ta was smaller than that of Ts. Ta decreased slightly at 0 to 1 H due to the shading effect of the windbreak. This beneficial effect was also observed in the case of RH which increased considerably in the center of the windbreak and slightly near the leeward side. The increase of Ta by 2 to 3℃ from -2 to 15 H and the decrease of RH from 5 to 15 H exerted an adverse effect on crop cultivation in summer.

(c) The remarkable decrease of Ur associated with the wide effective area of the windbreak forest (30 H at 6:00) was due to the fact that the direction of the wind formed a 90° angle with the windbreak. On the other hand, the effective area was not wide (15 H at 12:00) when the wind formed a 45° with the windbreak.

Although the Ta value increased inside the windbreak on the leeward side in the daytime, at night it decreased on both the windward and leeward sides, and increased in the early morning on the windward side due to sunshine. The use of windbreaks in summer resulted in the decrease of the wind velocity and increase of the relative humidity, in particular when the wind was light and in the decrease of the temperature at night, unlike in the case of the daytime temperature.

RH was high inside and near the windbreak due to the evapotranspiration from the tree leaves and soil of the windbreak forest.

The changes in Ts were similar to those of Ta. However, Ts inside the windbreak was about 25° C lower compared with Ts outside the windbreak due to the shade of the trees.

(2) Data recorded on May 4, 1991

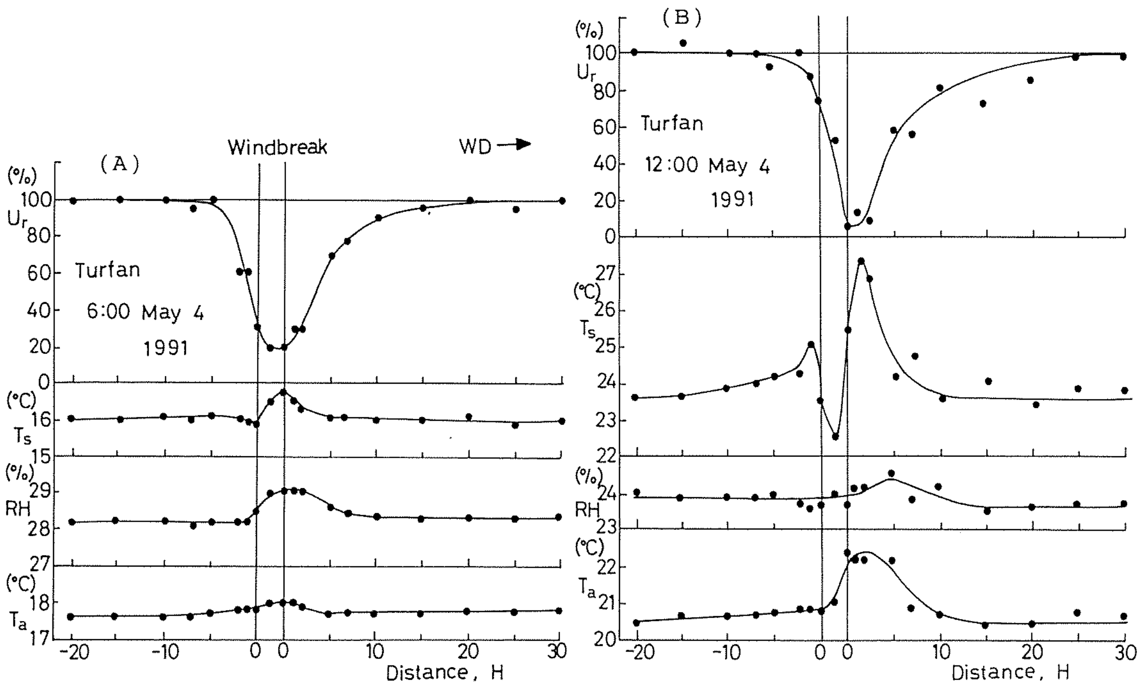
(a) 6:00 (Fig. 2 A): The decrease in the Ur region was minimal due to the direction of the wind which formed a 60° angle with the windbreak. Ts increased due to the sunshine on the leeward side near the windbreak. RH increased by 1% due to the transpiration of the leaves of the windbreak trees. Ta slightly increased due to the decrease of the wind velocity near the windbreak.

(b) 12:00 (Fig. 2 B): Ur recovered a value of 80% at 10 H and the decreasing area was small due to the wind direction that formed a 45° angle with the windbreak. The minimum was almost the same compared to the value of 5% recorded in other observations. Ts was 1.5℃ higher on the windward side because of the decrease of the wind velocity and 4 to 5℃ on the leeward side due to the decrease of the wind velocity and solar heating. However, Ts was 1℃ lower due to the shading inside the windbreak. RH increased by 1% due to the transpiration of the leaves of the windbreak trees, mainly because the effect of the increase of RH was more pronounced than that of dryness associated with the increase of Ta. Ta increased by 2.0℃ at 0 to 5 H due to the effects of the windbreak and solar heating.

(3) Data recorded on August 24, 1991

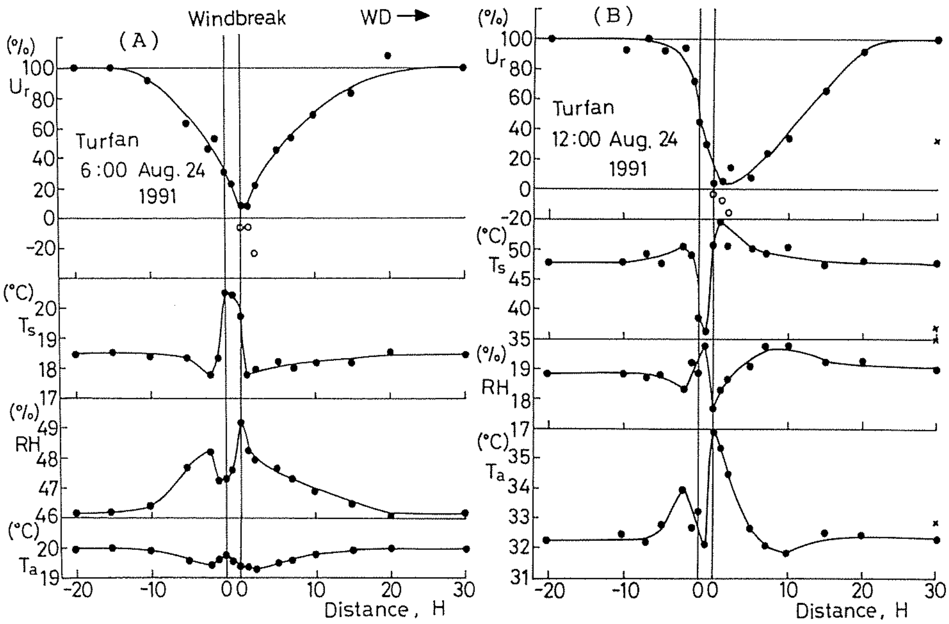
(a) 6:00 (Fig. 3 A): Ur was lower at distances of -10 H to 15 H from the windbreak. Minimum value of Ur was 10%. This value and the other two values (white circles) indicated a negative value for the wind velocity due to the change of the direction of the wind opposite to the windbreak (nor shown in Figs. 1 and 2). Ts was higher inside the forest windbreak, but slightly lower due to radiation cooling near the windbreak in the early morning. RH was higher at distances of -5 H to 15 H from the windbreak due to the transpiration of the leaves of the windbreak trees. Ta was lower near the windbreak due to radiation cooling.

(b) 12:00 (Fig. 3 B): The decrease of Ur was large (30%) at 10 H and the affected area was wide. Wind direction changed and was opposite to the



WD: Wind direction, Ur: Relative wind velocity,
Ts: Surface soil temperature, RH: Relative humidity and Ta: Air temperature
(A) 6:00 May 4 and (B) 12:00 May 4, 1991

Fig. 2. Improvement of meteorological conditions caused by a tamarisk windbreak



WD: Wind direction, Ur: Relative wind velocity,
Ts: Surface soil temperature, RH: Relative humidity and Ta: Air temperature
(A) 6:00 Aug. 24 and (B) 12:00 Aug. 24, 1991
Cross notation x indicates the value in another forest.

Fig. 3. Improvement of meteorological conditions caused by a tamarisk windbreak. White circles indicate the velocity of the wind in the opposite direction

windbreak at a distance of 0 H to 4 or 5 H from the windbreak. Ts was lower inside the windbreak due to the shade and higher near the windbreak. RH was higher inside the windbreak and lower just near the windbreak. Ta was higher on the windward side near the windbreak and very high from 0 to 5 H on the leeward side due to the increase of the temperature in the windbreak.

(4) Data recorded on November 29, 1991

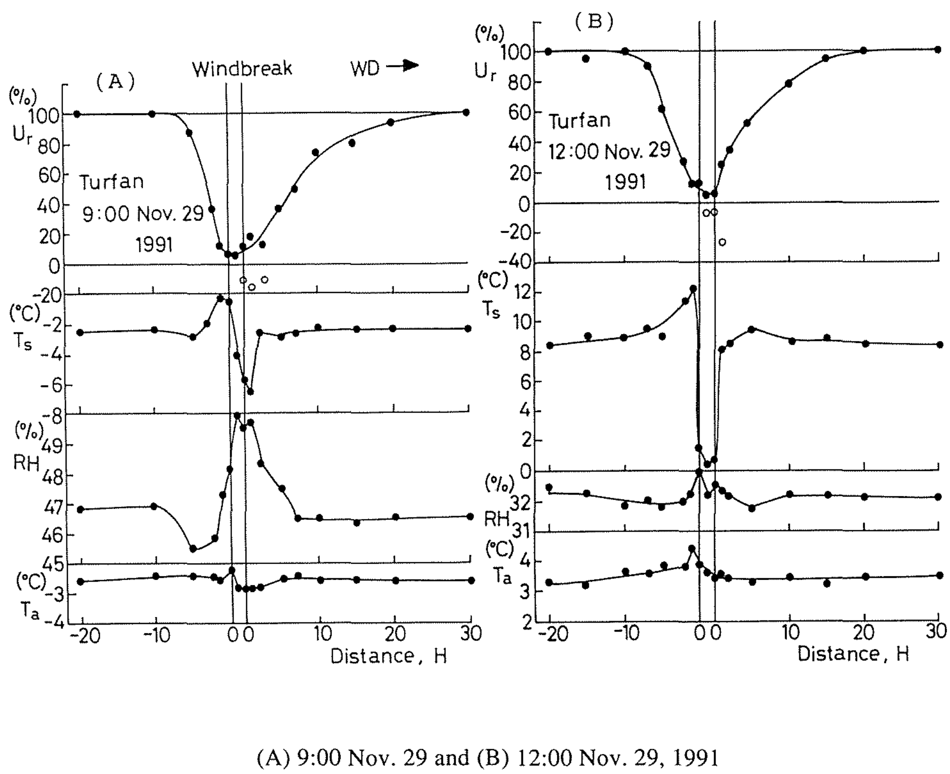
(a) 9:00 (Fig. 4 A): Ur was lower from -5 H to 20 H and the decreasing area was relatively wider. Wind direction was opposite to the windbreak at a distance of 0 H to 4 or 5 H from the windbreak. Ts was higher on the windward side and lower just on the leeward side near the windbreak due to sunshine and shade, respectively. RH was fairly high on the leeward side due to the effect of the windbreak, but the changes of Ta were limited under cold temperature conditions.

(b) 12:00 (Fig. 4 B): Ur was lower from -7 to 15 H and the affected area was not wide. Ts was higher on the windward side near the windbreak due to sunshine, but, significantly low inside the windbreak due to the shade of the windbreak. RH and Ta were slightly high around the windbreak.

2) Example of meteorological improvement by the use of two rows of tamarisk windbreaks

The results recorded on April 25, 1992 are shown in Fig. 5. Schematic diagrams of the two rows of tamarisk windbreaks and sand accumulation are shown in Fig. 6. The observation points in the figures indicate the actual distance in meter.

(a) 6:00 (Fig. 5 A): Wind velocity (U) decreased by the use of the first row of tamarisk windbreak and decreased further by the use of the second row. Ts was higher inside the windbreak



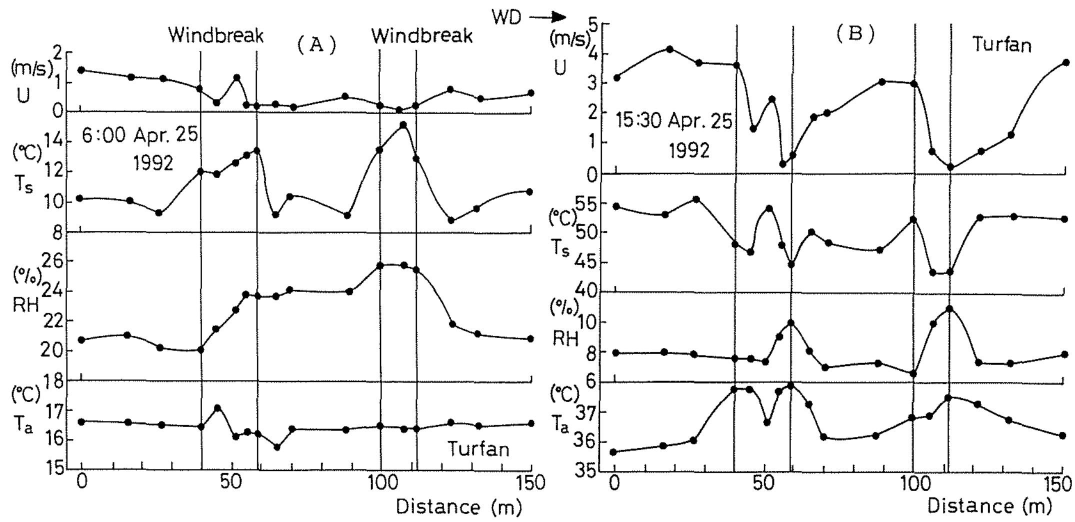
(A) 9:00 Nov. 29 and (B) 12:00 Nov. 29, 1991

Fig. 4. Improvement of meteorological conditions caused by a tamarisk windbreak. White circles indicate the velocity of the wind in the opposite direction

due to the maintenance of the temperature. RH increased from the first to the second rows and the effect appeared to be significantly additive. Ta was slightly high inside the windbreak.

(b) 15:30 (Fig. 5 B): U decreased to almost zero due to the effect of the two rows of windbreaks. Ts was lower inside the windbreak due to the shade, but higher at the top where sand of the windbreak accumulated due to the higher position of the observation point. RH increased from inside the windbreak to the leeward side of the windbreak. Ta was higher due to the effect of the increase of the temperature except for the top of the windbreak because of the stronger wind.

The cumulative effect of the windbreak, in particular on RH was observed when the interval between the windbreak rows was 50 m. The increase of RH is important for the improvement of



WD: Wind direction, U: Wind velocity, Ts: Surface soil temperature,
RH: Relative humidity and Ta: Air temperature
(A) 6:00 Apr. 25 and (B) 15:30 Apr. 25, 1992

Fig. 5. Improvement of meteorological conditions caused by the two rows of tamarisk windbreaks

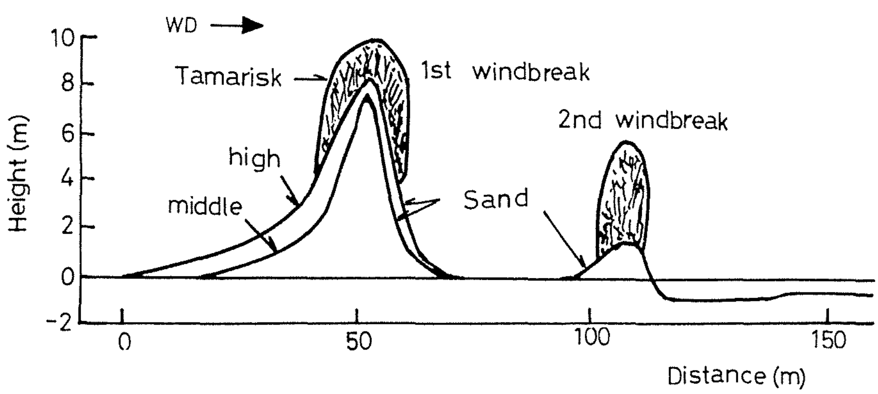


Fig. 6. Schematic representation of two rows of tamarisk windbreaks and sand accumulation in April, 1992

the meteorological conditions in arid lands.

Discussion

There are several studies on the improvement of the climatic conditions of arid lands and prevention of desertification[9,10,11,12]. It was reported that the air temperature at the height of 1.5 m at night ranged from 0.7 to 3.4℃, while the relative humidity increased from -3 to 22%[2]. However, there are few reports on the improvement of the air temperature, soil temperature, humidity, etc. under hot and dry conditions.

During the dry and hot period in summer like on July 2, the increase of RH mainly associated with the presence of trees was very important for the improvement of the microclimate in fields where crops are cultivated. The increase of RH from -2 to -0 H is due to the change of the direction of the wind with the formation of eddies and the transpiration from the trees, particularly at night and the early morning. However, the increase of RH in the daytime was minimal based on the evaporation from the sand surface due to the very small amount of evaporation.

Ts on sandy soil decreased due to radiation cooling and the decrease of Ur on the leeward side during the night, particularly in the early morning.

There are several reports on the increase of RH and decrease of evaporation near windbreaks[1,8]. However, there are few reports about the decrease of RH in the daytime under extremely high and dry conditions[4], due to the lack of precise observations.

Although the shade provided by tree leaves and absorption of latent heat by transpiration of tree leaves decreased the values of Ta and improved the climatic conditions, the excessive increase of Ta near the windbreak due to the decrease of Ur in the daytime exerted an adverse effect on crop cultivation during the dry and hot period in summer[7]. The total effects on crops in summer must be evaluated over a long period of time, even if there is a negative effect for a short period of time. In the night in summer, the decreases of Ta and Ts by radiation cooling are beneficial for the decrease of crop respiration and consequently for crop cultivation. Although the increase of RH from the transpiration of trees during the period of strong wind was minimal, the decrease of Ur is more important for crop cultivation under strong wind conditions.

Under the cool and dry conditions in spring and autumn, the increase of Ta associated with the decrease of Ur can be observed due to the effect of windbreaks. The improvement of the microclimate occurred near the forest windbreak. The relative humidity of air associated with the transpiration of trees was higher compared with the dryness of the air due to the increase of Ta by the windbreak under the conditions of cool air.

Wind turbulence and the formation of eddy regions were negligible and the function of sand filtration was effective on the leeward side of the windbreak. The observations and investigations carried out from 1990 to 1992[3,4,5] revealed that tamarisk trees display a high tolerance to wind, drought, heat, cold and salinity.

It is suggested that forest windbreaks could be very effective in arid lands over wide areas of cultivated fields under the prevailing wind and dry conditions.

Concluding Remarks

(1) The observations made in the arid lands of Turpan, Northwest China revealed that windbreaks exert multiple beneficial functions.

(2) The effects on the decrease of the wind velocity and improvement of the meteorological conditions were conspicuous under a tamarisk canopy with high density stems and small leaves. On the leeward side of the windbreak, the wind turbulence and the formation of wind eddies were negligible and the function of sand filtration was effective.

(3) The excessive increase of the air temperature on the windward and leeward sides close to the windbreak in the daytime in summer was not desirable. However, the increase of the

temperature was alleviated to a certain degree by the shade of the windbreak and absorption of the latent heat by the transpiration from the tree leaves.

(4) The decrease of the soil temperature by radiation cooling observed in the region where the wind velocity decreased in the night in summer exerted a favorable effect on the meteorological conditions for crop growth. The increase of transpiration from the leaves of the windbreak trees, the humidity or water vapor also affected favorably the meteorological conditions for dry farming, particularly during a period of light wind.

(5) In spring, autumn and winter, the beneficial effects of the decrease of the wind velocity, increase of temperature and of humidity for crop cultivation were significant while the adverse effects were negligible.

(6) The effects of the use of two rows of windbreaks on the decrease of the wind velocity and on climatic improvement were cumulative in comparison with the effect of a single row of windbreak.

References

1) Brandle, J.R., Hintz, D.L. and Sturrock, J.W. (1988). Windbreak Technology. Elsevier, Amsterdam. 598 p.

2) Board of Sand Control and Forestation (1984). Sand Control and Forestation. Chinese Forestry Publ. 323 p. [In Chinese].

3) Maki, T. (1991). Clarification of characteristics of meteorological evapotranspiration and protection of wind erosion by windbreaks in dry lands in China. *Inform. Assoc. Inter. Coop. Agric. Fore.* 14 : 31-40 [In Japanese].

4) Maki, T., Pan, B., Huang, P. & Yan, G. (1992). Micrometeorological modification by tamarisk windbreak forest at the arid land in Turfan, China. *J. Agric. Meteorol.* 48 : 157-164 [In Japanese with English summary].

5) Maki, T., Xia, X., Pan, B., Du, M., Nakai, M., Huang, P. & Yan, G. (1993). Effects of forest windbreak on meteorological improvement, prevention of wind erosion and crop growing in dry land. Proc. Japan-China Joint Res. Conf. Environmental Resources. 7-16.

6) Maki, T., Du, M. & Pan, B. (1993). The effect of windbreaks on meteorological improvement and the prevention of wind erosion. *J. Agric. Meteorol.* 48 : 683-686.

7) Maki, T., Pan, B., Du, M., Nakai, M. & Uemura, K. (1994). Effects of forest windbreaks deployed in arid lands, Turpan, Northwest China 2. Effects on prevention of wind erosion and on crop growth. *JIRCAS J.* 1 : 39-45.

8) Skidmore, E.L. and Hagen, L.J. (1977). Reducing wind erosion with barriers. *Trans. ASAE* 20 : 911-915.

9) Xinjiang Inst. Biol. Ped. Des. Res. (1978). Xinjiang desert and its development. Chinese Science Publ. 124 p. [In Chinese].

10) Zhu, Z. & Liu, S. (1981). Desertification and its rehabilitation in North China. Chinese Forestry Publ. 83 p. [In Chinese].

11) Zhu, Z., Liu, S., Wu, Z. & Di, X. (1986). Deserts in China. Inst. Desert Res., Lanzhou. 132 p.

12) Zhu, Z., Liu, S. & Di, X. (1988). Desertification and rehabilitation in China. Inter. Cent. Edu. Res. Des. Cont. 222 p.

中国北西部の乾燥地トルファンにおける防風林の効果

1．気候改良効果

真木太一[a)]，潘　伯栄[b)]，杜　明遠[c)]，中井　信[c)]，上村賢治[d)]

[a, c)]熱帯農業研究センター環境資源利用部
（〒305　茨城県つくば市大わし１－２）

[b)]中国科学院新疆生物土壌沙漠研究所吐魯番沙漠研究站
（中華人民共和国烏魯木斉市北京南路40号）

[d)]東京大学農学部（〒113　東京都文京区弥生１－１－１）

摘　要

乾燥・半乾燥地は地球上の全陸地の１／３を占めている。中国の乾燥地面積は130.8万km^2で，全国土の13.6%に相当する。近年，中国においては，一方では砂漠が開発され，緑化が進められているが，また一方では砂漠化が急速に進んでおり，結果的には砂漠化が緑化を上回り，大きい問題となっている。砂漠化防止と砂漠の緑化は防風林の造成による気象改良効果によって初めて可能になる。

中国北西部の新疆の中国科学院新疆生物土壌沙漠研究所吐魯番沙漠研究站で，乾燥地において乾燥気象条件の改良効果を評価するために，1990年と1991年に，春季，夏季および秋季，冬季に近い期間に１列のタマリスク防風林を用いて，また春季に２列のタマリスク防風林を用いて気象観測を実施した。得られた結果の主なものは次のとおりである。

1）中国北西部の乾燥地トルファンにおける気象観測から種々の機能をもった防風林の効果が明らかになった。

2）細かく密な枝葉を持ったタマリスク防風林による風速の減少と気象改良効果は大きかった。防風林の風下では防風林による整流作用によって気流の乱流と渦領域が小さいために砂の濾過効果が高かった。

3）防風林による日影や防風林からの蒸散による潜熱の吸収によって気温の上昇はある程度おさえられるが，夏季，日中における防風林近くの風下側では，防風林によって気温が過剰に上昇し，乾燥する，いわゆるマイナスの効果が認められた。

4）夏季，作物の生育に好適な気象条件となる放射冷却による気温の低下が，夜間，風速の減少領域で観測された。乾燥地圃場の気象改良効果として防風林の葉からの蒸散による水蒸気の増加，すなわち相対湿度の上昇効果が，特に風の弱い時に観測された。

5）春・秋・冬季においては，作物に対して風速の減少，気温の上昇，湿度の上昇効果は大きく，またマイナスの効果は小さかった。

6）２列の防風林による減風と気象改良は１列の場合の効果に加算されて，大きくなることが判った。

キーワード：タマリスク，風速，気温，地表温，相対湿度

[a)]現在：農業研究センター耕地利用部（〒305　茨城県つくば市観音台３－１－１）
[c)]現在：国際農林水産業研究センター環境資源部（〒305　茨城県つくば市大わし１－２）