Meteorological Conditions and Agricultural Water Use in Oasis in Fukang

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Abstract

Meteorological conditions at two meteorological stations, one in an oasis and the other in a nearby desert, were compared. Small differences were detected in the daily course of air temperature in summer. In winter, daily mean temperature in the oasis was higher due to higher minimum temperature. Humidity in the oasis was higher over the whole period. Air temperature rapidly decreased as the ground became covered by snow, and vice versa. Minimum wind speed and rainfall were observed mostly during early morning. Agricultural activity in the oasis apparently causes meteorological alleviation (i.e. lower air temperature and higher humidity in an oasis), particularly evapotranspiration from farm land as the major cause of humidity increase.
To monitor water use in a conventionally-managed cotton field in the oasis, evapotranspiration, transpiration and evaporation were measured. The empirically-determined interval of irrigation was too short, and the amount of water for each irrigation was too large and leaching out of the soil profile occured. The amount of water and interval of irrigation needed to meet crop water needs without loss were estimated with a simple water balance calculation.

Our year-round half-hour meteorological data in 3.6MB text files are available for scientific use.

Key words : meteorological alleviation, reclamation, irrigation

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Introduction

The study area of this research is Xinjiang in China, specifically Fukang district. In an arid area like this region, agricultural water use affects surrounding meteorological conditions leading to meteorological alleviation, *i.e.* lower air temperature and higher humidity in an oasis, which, in turn, has a counter effect on water use, *e.g.* through the amount of evaporation from farm fields. For planning land reclamation from desert, it is essential to understand how agricultural activity alleviates meteorological conditions, as it affects potential evaporation, etc. Comparative meteorological observations in oasis and nearby desert can contribute to this objective. However, only a few data have been obtained in this region[2,4].

In this study, we first made year-round observations in an oasis and a nearby desert in Fukang, and examined the observed differences in meteorological conditions to identify the alleviation. Analyzing the mechanism of the interaction between water use and alleviation, however, is outside the scope of this study.

In Fukang, there are plenty of areas with available land for agriculture, but the amount of water resources limits expansion of farm fields[1], and more effective water use is needed. Although there are some water-saving cultivation methods[6], the most easily implemented approach is to apply only the necessary-and-sufficient amount of water at the optimum time for the crop. We measured water use in a cotton field, estimated the fraction of irrigated water used for the crop production, and propose a quick calculation method to determine an irrigation schedule that minimizes water waste.

Materials and methods

1) Oasis and desert meteorological observations

Fukang is 76 km north east of Urumuqi, the capital of Xinjiang Uygur Autonomous. As shown in Fig.1, the district is located between the Tienshan Mountains and the Kurbantonkut Desert of the Jungael Basin, and includes a part of the San-gong river valley, stretching 31 km by 72 km in east-west and south-north directions. Snow water comes from the mountains through three rivers: the San-gong, the Shui-mo and Si-gong river. Annual precipitation is 530 mm in the middle mountain belt, 188 mm in the plain and 145 mm in the northern desert area[1]. Agricultural land was reclaimed from wasteland by military group No. 222. Irrigation consists largely of ground water. The chinese Academy of Sciences has an experimental station for desert ecosystem observation in Fukang, with information on soil and agricultural conditions in the area[1, 3, 5, 9].

Two meteorological stations (Station 1 and 2) were constructed in the study area (Fig. 1). Station 1 was built on bare ground, surrounded by Tamarix shrubs of about 1 m height (Fig. 2), at the Fukang experimental station (44°17'N, 87°73'E, 47m above sea level), 8 km south from the southern border of the Kurbantonkut Desert. Station 2 was built in the nearby desert (44°19'N, 87°69'E, 466 m above sea level), 5 km north from the border of the same desert, where the prevailing vegetation was Haloxylon shrubs of 2 to 3 m height (Fig. 3). Sensors were set on a brick box (Fig. 4).

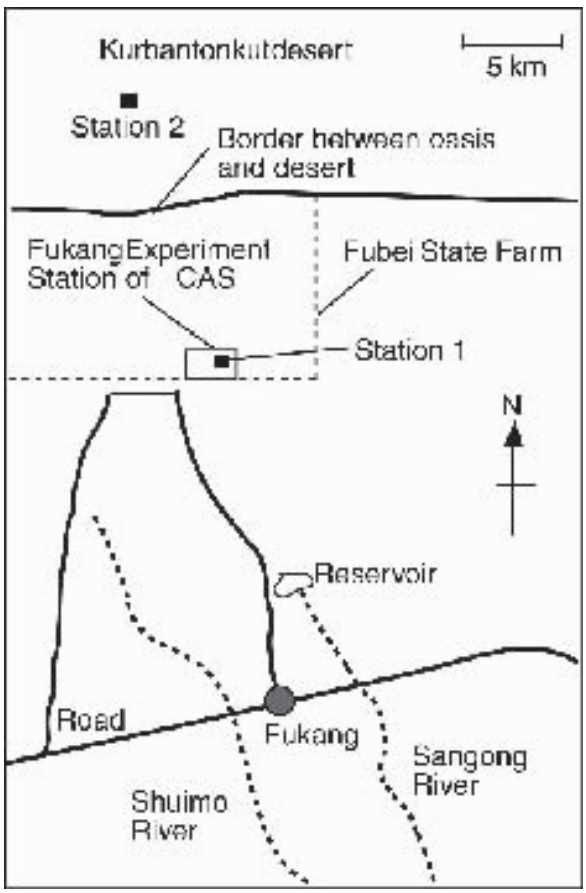


Fig.1 Map of the study area.

Fig. 2 Station 1.

Fig. 3 Station 2.

Fig. 4 Base for sensors (Station 2)

Meteorological observations were started on Jul 26, 1994 (NOD207, NOD refers to the number of days from Jan. 1, 1994) at Station 1, and Aug. 16 (NOD228) at Station 2. Beijing standard time was employed. This report uses data until Sep. 24, 1995 (NOD632), except for the periods from Sep. 8 to 9 (NOD251, 252) at Station 1, and from Oct. 12 to 21 (NOD285 to 294) at Station 2, due to mechanical failures.

Equipment and sensors were checked and cleaned weekly until Nov. 3 (NOD307), and after Apr. 17 (NOD472). In the winter between these two dates, the stations were visited and checked on Dec. 27 (NOD361), Jan. 10 (NOD375), 25 (NOD390), Feb. 10 (NOD406), and Mar. 25 (NOD449).

Output from the sensors was scanned by data loggers (Campbel CR-10). Signals were averaged over 30 minutes and recorded. The following parameters were measured. *Air temperature (Ta) and relative humidity (RH)*: A Copper-Constantan thermocouple of 0.3 mm diameter and humidity sensor (TDK CHS-PS) was used. These were placed in radiation shelters (Campbel 41044) mounted at two heights, 0.75 m/1.2 m (Station 1), and 2.8 m/3.7 m (Station 2), above the ground. The respective heights were changed to 1.2 m/1.7 m, and 3.7 m/4.2 m on Apr. 17 (NOD472). Before initiating observations, ten humidity sensors were tested and four which gave identical values were selected. These sensors were replaced with new sensors on Apr. 17 (NOD472). The valid temperature range of the sensor is above 0℃ according to its specifications, but when we compared it with a Vaisala HMP45 humidity sensor, we found that both gave equivalent output in the range from -20℃ to 0℃ (at Sapporo (Japan), in February 2001). *Net radiation* (Rn) : A net radiometer (REBS Q6), mounted at 1.5 m height at Station 1, and 2.5 m at Station 2 was used. *Global radiation (Rs) and reflected radiation from the ground (Rr)*: LI-COR LI-200SZ sensors were mounted at 1.5 m (Station 1), and 2.5 m (Station 2) above the ground. At Station 2, observation of reflected radiation began from Apr. 17 (NOD472). Soil heat flux (HF): REBS-HF3 sensors were placed 1 cm under the soil surface. Two sensors were used at each station. *Soil temperature (Ts)*: Copper-Constantan thermocouples of 0.3 mm diameter were set at 1 cm depth. *Wind direction (WD) and wind speed (WV)*: YOUNG 0301 and 03001 sensors were placed at 2 m (Station 1) and 4.2 m (Station 2) above the ground. Wind direction was categorized into 16 directions. *Precipitation (Pr)*: TEXAS ELECTRONICS TE525MM was installed at only at Station 1, from Apr. 17 (NOD472).

2) Meteorological and soil water observations in a cotton field

Cotton plants (*Gossypium* spp. cv. Da Ling Mian) were seeded on May 5 in 1995 (NOD490) in an experimental field (NS30m x EW60m) of the Fukang

Station. The planting density *(PD)* was 9.3 plants m^{-2}. Meteorological observation in the field was conducted during the period from Jul. 5 to Sep. 5 (NOD551 to 613), in which about 300 mm and 100 mm of irrigation water were supplied on July 6 (NOD552) and on Aug. 24 (NOD601), respectively. A preliminary irrigation of about 180mm was supplied on Apr. 20 (NOD475).

The following parameters were measured: solar radiation, reflected radiation, net radiation 1.0 m above the canopy, wind speed and direction at 2.0 m above the ground, air temperature and humidity at just above and at 0.5 m above the canopy, vertical heat flux at 1 cm below the soil surface, and precipitation, sensors and recording methods were the same as the meteorological observations.

Sap flow rate in the cotton stem was measured with three sap flow gauges (Sakuratani, 1981). Soil samples at a depth of 0.2 m below the soil surface were collected approximately once a week to measure volumetric water content *(VWC)*. Soil water potential *(Ψsoil)* was measured (Daiki DIK3400), and the relationship between the two parameters VWC and Ysoil was established from the measured values.

The evapotranspiration rate *(ET)* of the field and the transpiration rate *(Tr)* of cotton were calculated by the Bowen ratio method and the equation $Tr = PD \times$ *(sap flow rate)*, respectively. The evaporation rate from the soil surface *(Ep)* was expressed as $Ep = ET\text{-}Tr$.

Results and discussion

1) Oasis and desert meteorological observations

The monthly mean value of 10 meteorological parameters are shown in Table 1. Air temperature inside the oasis was almost the same as that in the desert in the summer, but it was higher in the oasis in winter. Humidity in the oasis was higher throughout the year. The most frequent wind direction was WNW, and wind speed was low in winter (December to February) and strong in spring (April to Jun). Wind speed was lower in Station 2, probably due to taller surrounding vegetation.

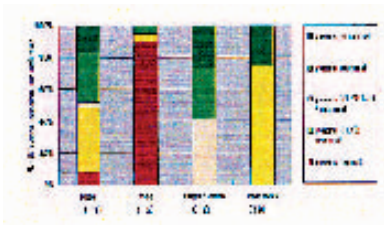


Fig. 5 Variation in air and soil temperatures (five-day-running mean).
Soil sensor cable was sometimes cut by mice in Station 2.

Table 1. Monthly mean values of 10 meteorological parameters in oasis and desert stations

	Station1										Station2								
Month, yr	WV	WD	Rs	Rr	Rn	HF	Ta	RH	Ts	Pr	WV	WD	Rs	Rr	Rn	HF	Ta	RH	Ts
Jul, 94	1.9	15	24.3	5.5	8.1	1.5	25.8	38.8	37.2										
Aug, 94	1.7	15	21.5	4.9	6.0	1.0	22.8	40.1	27.8		1.2	15		3.1	8.1	0.3	22.6	34.7	
Sep, 94	1.6	12	18.7	4.0	5.4	0.5	13.7	48.7	18.6		1.0	13		2.4	6.1		13.2	44.7	
Oct, 94	1.4	15	11.9	3.4	4.3	-0.2	5.0	61.4	6.1		0.8	15		1.3	3.4	-0.7	5.2	66.5	
Nov, 94	1.4	15	6.2	1.4	1.8	-0.1	1.7	78.4	1.5		0.7	15		0.4	1.9	-0.6	0.9	76.5	
Dec, 94	1.1	12	3.6	3.1	0.0	-0.4	-13.6	74.5	-5.4		0.5	12		1.3	0.6		-14.5	89.5	
Jan, 95	1.1	11	6.7	5.2	-0.1	-0.3	-22.5	70.4	-11.4		0.5	9		2.6	1.7	-0.7	-23.1	70.1	
Feb, 95	1.1	11	7.9	6.7	0.5	0.0	13.7	61.6	7.9		0.6	16		4.1	2.4	0.3	14.8	76.8	10.6
Mar, 95	1.5	15	14.5	7.7	7.1	0.6	-3.7	72.4	-0.2		0.9	14		4.2	6.3	0.1	-4.1	70.5	-2.1
Apr, 95	2.2	15	19.9	8.9	6.6	1.2	10.8	40.4	19.4		1.3	14		2.9	8.9	1.5	10.2	38.5	13.4
May, 95	2.3	15	22.7	6.4	8.6	1.2	17.1	43.6	20.2	19.7	1.5	15	22.8	3.3	11.2	1.2	16.7	42.1	21.3
Jun, 95	2.0	10	26.4	8.7	10.6	1.0	23.2	54.4	28.4	0.6	1.5	14	26.3	3.8	13.2	1.4	23.1	31.0	
Jul, 95	1.3	11	22.6	5.3	10.0	1.0	21.3	47.4	27.2	37.6	1.5	14	22.7	3.1	12.3	1.3	21.2	44.1	
Aug, 95	1.9	15	21.8	5.0	9.8	1.0	23.0	45.9	26.5	22.6	1.4	15	20.9	3.2	11.8		23.0	41.6	
Sep, 95	1.5	10	17.3	4.5	7.5	0.7	15.6	42.0	21.0	3.7	1.0	14	17.2	2.6	8.7	0.7	15.4	37.4	

* Air temperature and humidity is the average of two heights.
WV: wind speed (m second^{-1}), WD: wind direction (in 16 directions), Rs: global radiation (MJ m^{-2} day^{-1}),
Rr: reflected radiation (MJ m^{-2} day^{-1}), HF: soil heat flux (MJ m^{-2} day^{-1}), Rn: net radiation (MJ m^{-2} day^{-1}),
Ta: air temperature (°C), RH: relative humidity (%), Ts: soil temperature (°C), Pr: precipitation (mm month^{-1})

Annual variation in air and soil temperatures is shown in Fig. 5. Air temperature dropped rapidly around Dec. 10 (NOD344) and rose sharply around Mar. 20 (NOD444). The first and last date of snow cover was Dec. 9 (NOD343) and Mar. 20 (NOD444), as determined by the value of albedo, corresponding to the time of rapid changes in air temperature. Soil temperature was almost the same in the two stations except in January and February (NOD366 to 424).

Figure 6 shows the seasonal course of the difference in daily mean air temperature calculated as oasis temperature minus desert temperature. Temperature was higher in the oasis, particularly in the period with snow cover (NOD344-444), identified in Fig. 5, when it averaged +1.0°C. In midsummer in July and August (from NOD547 to 608), the mean temperature difference was zero.

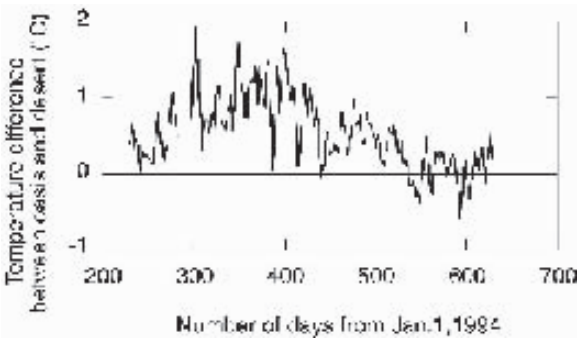


Fig. 6 Difference in air temperatures, oasis minus desert. Five-day-running mean.

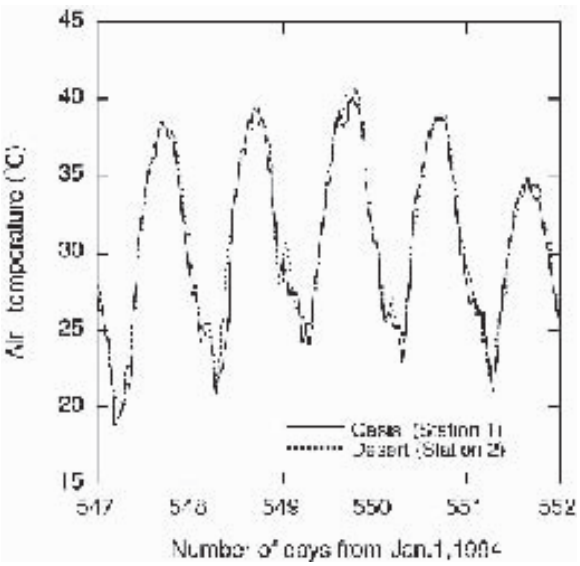


Fig. 7 Air temperatures in oasis and desert stations in summer (Jul. 1 - Jul. 5).

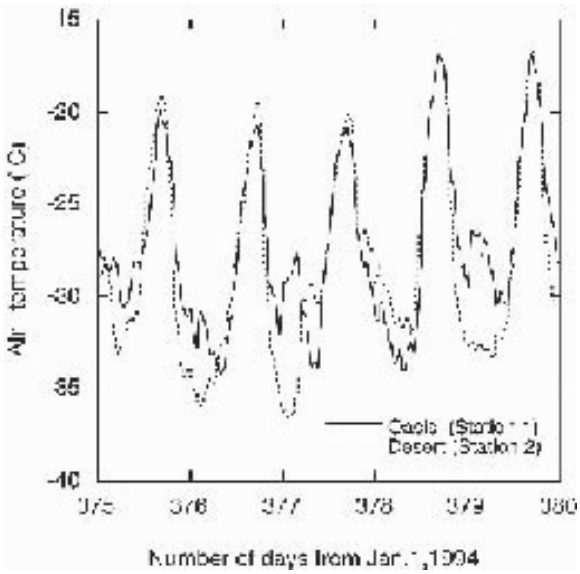


Fig. 8 Air temperature in oasis and desert stations in winter (Jan. 10 - Jan. 14).

Two examples of the variation in daily air temperatures at the two stations are shown in Fig. 7 and 8. There was a significant ($p<0.0001$) but small difference between the two stations in the summer (desert temperature was 0.37℃ higher as shown in Fig. 7). In Turpan, meteorological alleviation, as much as 5℃ lower air temperature in an oasis than that of nearby desert, was reported in summer[4], but such a large difference was not detected in our observations, probably due to the presence of vegetation in the desert. In winter, minimum daily temperature in desert was lower in four out of the five days shown in Fig. 8 (the mean difference was 3.0℃, significant at ($p<0.0001$)). Maximum daily temperature in the desert, on the contrary, was higher than that in the oasis (the mean difference was 0.8℃, significant at ($p<0.0001$)).

As shown in Fig. 9, humidity in oasis was slightly larger throughout the day in summer (the mean difference was 2.8%, significant at ($p<0.0001$)). Minimum daily humidity in the desert showed lower values in early winter as shown in Fig. 10 (the mean difference was 9.0%, significant at ($p<0.0001$)). Data were not available in mid winter (NOD344-444), because functioning of the humidity sensor was stopped, presumably due to snow.

The minimum daily wind speed was observed in the early morning, while the maximum daily wind speed was around 18h (Fig. 11), which was a few hours earlier than that in Turpan[4].

Precipitation was measured only in the oasis (Station

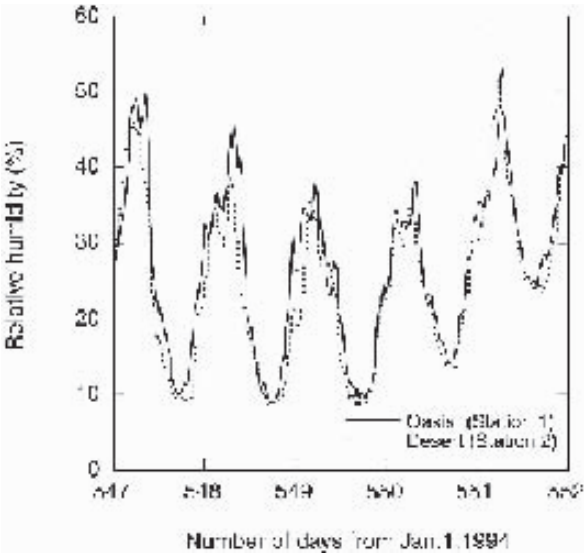


Fig. 9 Air humidity in oasis and desert stations in summer (Jul. 1 - Jul. 5).

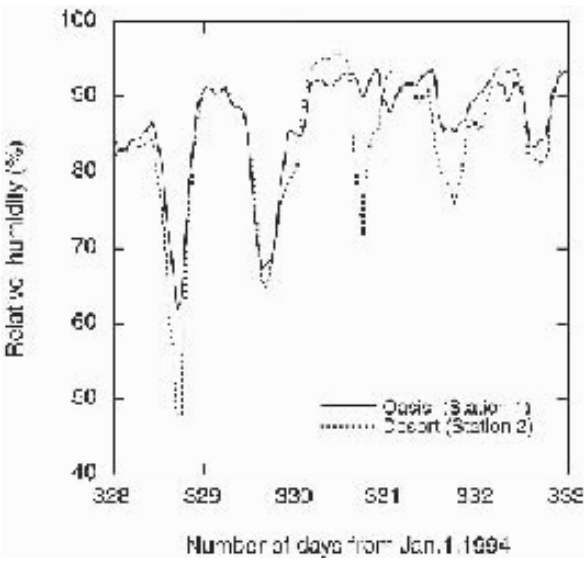


Fig.10 Air humidity in oasis and desert stations in winter (Nov. 4 - Nov. 8).
(Air temperature ranged from -7.7°C to +6.2°C during this period.)

1) for 160 days from April 17 to Sep. 25 (NOD472 to 633). The total precipitation during this period was 93.1 mm, with 36 days with precipitation over 0.1 mm, and 25 days with over 0.5 mm. As shown in Fig. 12, the highest rainfall (>15 events) was observed between 0 and 6h.

2) Meteorological and soil water observations in a cotton field

The total amount of precipitation was 50.3 mm between the two irrigations (on NOD552 and

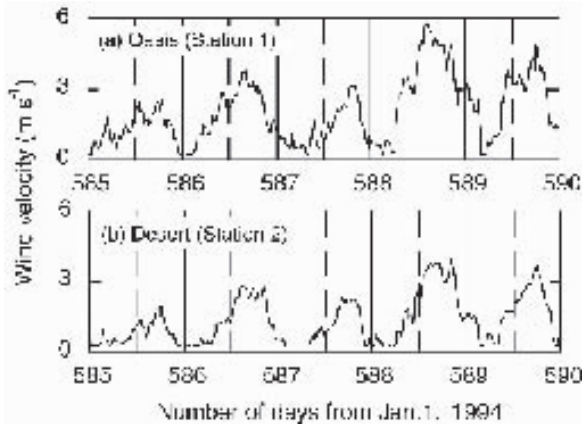


Fig.11 Changes in wind speed.

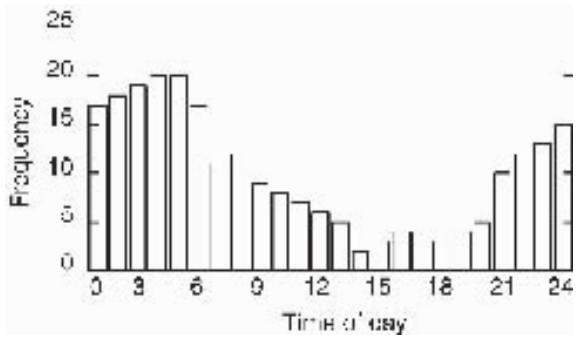


Fig.12 Frequency distribution of hours with precipitation. (during 3888 hours from Apr. 17 to Sep. 25)

NOD601). The maximum LAI of the canopy was 0.8 on Aug. 10 (NOD587) and decreased thereafter.

After the first irrigation on Jul. 6 (NOD552, I_1 in Fig. 13), volumetric water content (*VWC*) rapidly decreased due to downward percolation (Fig. 13). *VWC* at field capacity (*VWCfield*) was about 0.42, observed on Jul. 9 (NOD555). *VWC* at wilting point (*VWCwilt*) was estimated to be 0.20 from the relationship between *VWC* and water potential ($\Psi soil$) , shown in Fig. 14, with *VWC* corresponding to $\Psi soil$ of -1550kPa or pF4.2.

On Aug. 3 (NOD580, I_E in Fig. 13), a local agricultural engineer indicated that his decision would be that irrigation was urgently needed in the experimental field based on empirical criteria from visual assessment of field conditions. *Tr* was, however, not low on this day as shown in Fig. 15, which suggests that the cotton plants were not suffering from strong water stress. We decided, therefore, that irrigation was not required on that day for the cotton plants. There was precipitation of 9.5 mm on Aug. 8 (NOD585), but *Tr* did not increase even after the rain, which also suggests that the cotton

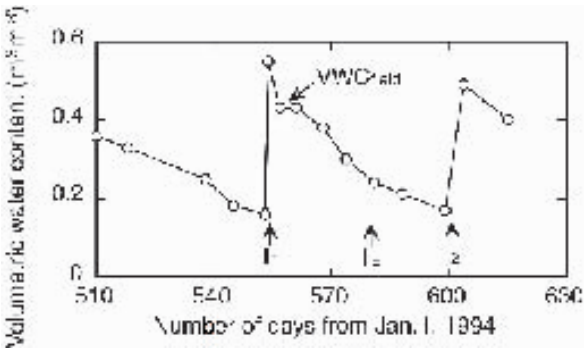


Fig.13 Changes in volumetric water content in a cotton field over 105 days.

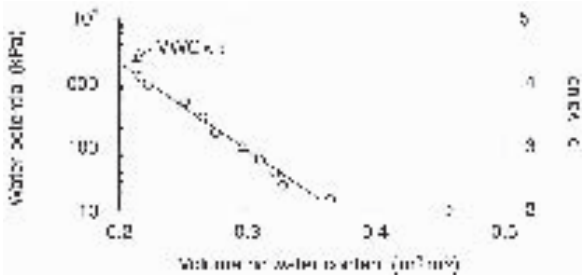
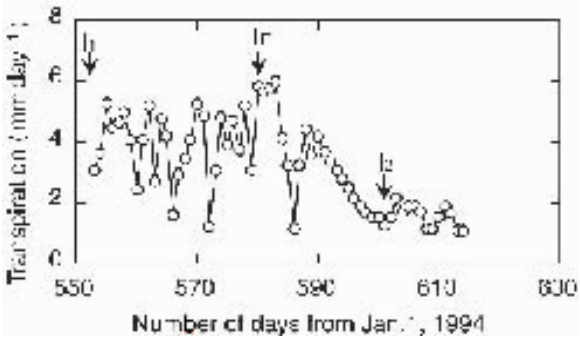


Fig.14 Relationship between VWC and water potential.

plants were not suffering from water stress at that time. Better criteria for deciding the timing of irrigations were needed. *Tr* gradually became smaller after Aug. 13 (NOD590), which was attributable to not only water stress, but also to senescence and abscission. The cotton leaves looked wilted on Aug. 18 (NOD595). After the second irrigation on Aug. 24 (NOD601, I_2 in Fig. 13), the cotton plants recovered from wilting.

Accumulated *Tr, Ep* and *ET* changed as shown in Fig. 16. Evaporation from the soil surface was active for about 20 days after the first irrigation on July 6 (NOD552) and amounted to 40 mm. In the 49 days between the first and the second irrigations, the amounts of transpiration and evapotranspiration were 180 mm and 220 mm, respectively. Soil moisture was nearly the same before the two irrigations of Jul. 6 and Aug. 24 (NOD552 and 601). A total of 80 mm (= 300 mm - 220 mm) of water from the 300 mm of water used for the first irrigation on Jul. 6 (NOD552) was lost by downward percolation without contributing to cotton production. This phenomenon was also indicated by the rapid decrease in *VWC* in the few days after irrigation (Fig. 13).

The maximum water used for one irrigation which results in no loss by downward percolation *(IRRmax)* can be calculated as:



.Fig.15 Changes in transpiration in a cotton field over 62 days.

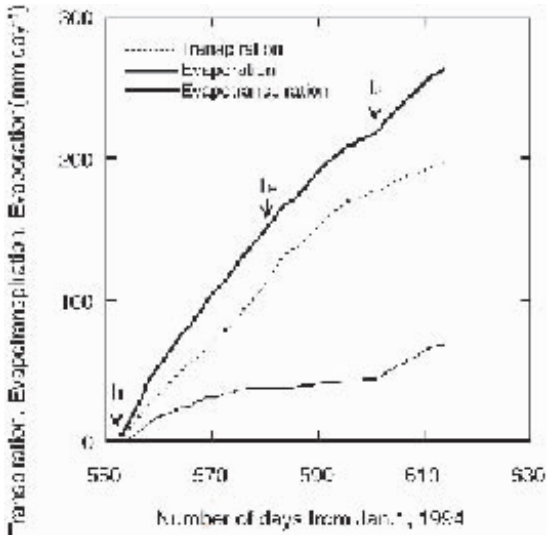


Fig.16 Changes in accumulated transpiration, evapotranspiration and evaporation in a cotton field over 62 days.

$$IRRmax = Droot \times [\, VWCavail - (VWCpresent - VWCwilt) \,] \qquad (1)$$

where *Droot* is the depth (mm) of the effective root zone for the absorption of the major part of water by the cotton root, *VWCavail* is the available soil moisture determined by field capacity and the wilting point, and *VWCpresent* is *VWC* on the day of irrigation. The excess amount of irrigated water beyond *IRRmax* will be lost by downward percolation.

Droot of the experimental field was estimated using the following four assumptions: (1) *VWC* was uniform throughout the effective root zone; (2) *VWCavail* was 0.22; (3) *VWCpresent* on Aug. 24 (NOD601) was at the wilting point; (4) All the water of evapotranspiration (220 mm) during the period between the two irrigations (NOD552 and NOD601) was from the effective root zone. Then, an equation of *Droot* x 0.22=220 was derived, which gave *Droot*=1000 mm.

Assuming that an irrigation of *IRRmax* is made and

the next irrigation is made when soil moisture becomes *VWCwilt*, then the interval of the two irrigations is:

$$INT = IRRmax / ETave \quad (2)$$

where, *INT* is the interval (days) and *ETave* is averaged *ET* which was 4.5 mm day^{-1} (= 220 mm / 49 days) in this observation. If a drip irrigation system is introduced, *Ep* can be treated as zero in practical terms and the interval (*INTdrip*) will become longer to give an equation of

$$INTdrip = IRRmax / Trave \quad (3)$$

where, *Trave* is the mean *Tr* of 3.7 mm day^{-1} (= 180 mm / 49 days) for formalizing arrangemenks these observations. For a more precise estimation of *INT* and *INTdrip*, the effect of LAI on *ETave* and *Trave* should be taken into consideration.

The maximum value of *IRRmax* (*MaxIRRmax*) is 220 mm, from equation (1) with *VWCpresent* equal to *VWCwilt* , which gives the longest *INT (INTlngst)* of 49 days together with equation (2). In our experiment I_2 minus I_1 coincided with *INTlngst*, because an amount of water greater than *MaxIRRmax* was supplied on I_1 and *VWC* = *VWCwilt* on I_2 as the cotton was wilted. The empirically determined *INT* ($INT_E = I_E - I_1$) was 28 days whereas the maximum value of *INTdrip* (*INTdrip*) is 59 days (=*MaxIRRmax* / *Trave*), which indicates that more than double the current area can be irrigated by the same amount of water if drip irrigation with precise irrigation planning is introduced.

3) Concluding remarks

Our observations identified meteorological alleviations in a reclaimed land in Fukang. Agricultural activity in the oasis apparently caused the meteorological alteration, particularly evapotranspiration from farm land, which appears to be a major cause of the humidity increase. Potential evaporation in this district is large, as as much as 2290mm[1)], but local water resources are limited. Effective water use is essential to improve agricultural production. The results of our field monitoring suggested that more efficient water use is possible with simple estimation. In addition, more study is needed to identify the optimal irrigation schedule based on crop physiology, such as root expansion response to soil moisture depending on developmental stage.

Note: The authors can make available the meteorological data, consisting of a 3.6MB text file, for scientific use. Part of this research had been reported[7,8)] elsewhere.

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新疆のオアシス内外の気象条件とワタ圃場における水の利用

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摘　要

新疆阜康荒のオアシスと近傍の沙漠で通年の気象観測を実施し、両地点の気象条件の特徴を比較した。夏季日中の気温は両地点でほぼ同じ、冬季はオアシスの気温が高く、特に夜間気温が高かった。オアシスの湿度は一年を通して高かった。両地点とも冬季積雪期間は気温が顕著に低下した。最低風速は早朝、降雨は夜間に多く観測された。オアシスによる気象緩和効果には、農業活動とくに水利用の寄与が大であると考えられる。オアシス農業での水利用の実態をワタ畑で観測したところ、従来当地域で用いられる経験的な潅漑時期の判断基準では、有効水分が存在してワタが水ストレス下にない時期において潅漑が必要と評価されていた。一回の潅漑量も多く、下方への浸透による水損失が生じていた。単純な水収支計算から効率的な潅漑量と潅漑間隔を評価できることを示した。

なお、この研究で行った気象観測のデータは提供可能である。

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