Observation of Water Use in an Irrigated Cotton Field in Xinjiang, China

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Abstract

The water use in a conventionally-managed cotton field was observed in an arid region in Xinjiang Uygur Autonomous Region, P.R.China.

Evapotranspiration and transpiration rates of the cotton community (*ET, Tr*) were measured by the Bowen ratio method and the stem heat balance method, respectively. Evaporation from the soil surface under the cotton canopy was calculated by the formula: $Ep = ET - Tr$. Soil moisture was monitored by soil samplings.

Evaporation from the soil surface, *i.e.* loss of water that did not contribute to the cotton production, was substantial after irrigation. The empirically-determined interval of irrigation was too short and irrigation tended to be applied even when soil moisture was available. The amount of water supplied each time irrigation was applied was larger than that necessary for crop production, and a considerable amount of water was lost by downward percolation. A water balance calculation was undertaken for determining the suitable amount of water and interval of irrigation.

Additional key words : Xinjiang, evaporation, transpiration, evapotranspiration, furrow irrigation, cotton

Introduction

This study was conducted under a collaborative research program between JIRCAS and XIBPDR in Fukang district, located on the southern edge of the Junggar Basin in Xinjiang Uygur Autonomous Region, P.R.China. This region is arid with an annual precipitation of about

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190mm. There are three major rivers (the Shuimo, Sangong, and Sigong rivers) carrying about $9.8 \cdot 10^7 m^3 \cdot year^{-1}$ of snow-water from the Tienshan Mountains located at a distance of 80km south into this alluvial area[4]. A total area of $3.8 \cdot 10^8 m^2$ of farm land had been reclaimed in this district by the so-called military group or "Bingtuan" No.222[5] over a period of 30 years. Major crop is cotton and irrigation is needed. The water requirement is large and an efficient method of water use is required. For the major part of irrigation, groundwater (artesian aquifer from 30~40m deep pump wells) is used[10].

At the beginning of reclamation, the salinity of the soil was as high as 1.5%, and it had been reduced to 0.6%. The groundwater table (free water) is currently rising at a rate of about $0.2m \cdot year^{-1}$ to 1.7m~2.5m from 7m~8m depth about 30 years ago. The salinity of the groundwater is high and may cause salt accumulation in the top soil[2].

There were two problems concerning irrigation in this area. The first was that the water quantity each time irrigation was applied and the interval between the application of irrigation were inadequate because they were determined based on empirical criteria leading to a low efficiency of irrigation. The second was that the irrigation efficiency was reduced by the large evaporation from the soil surface (*Ep*) in the furrow irrigation method commonly employed there. Although the advantage of the drip irrigation method had been pointed out to minimize *Ep* [1], improvement of the irrigation efficiency could not be quantitatively estimated because of the lack of data relating to *Ep*.

The purpose of this study was to develop a simple method of water balance calculation to investigate the water use in irrigated land through the observation of transpiration, evaporation and soil moisture in a conventionally-managed cotton field in this region.

Materials and Methods

This study was conducted in the experimental fields of Fukang Desert Ecological Station (44°17'N, 87°73'E, 474m above sea level). The soil was clasified into *gray desert soil* which contained 30%, 50% and 20% of clay, silt and sand, respectively[6], and 1.5% of organic matter[3]. Cotton (*Gossypium* spp. cv. Daling Mian) was used for the following experiments.

Experiment 1

Cotton was seeded on May 5 (Day Of Year: *DOY*125), 1994 in an experimental field (EW20m x SN10m). The field was surrounded by vegetable fields. The cross section of the field perpendicular to the row direction is shown in Fig.1. The crop spacing was 0.1m~0.2m. Nitrogen ($54kg \cdot ha^{-1}$) and phosphoric acid ($138kg \cdot ha^{-1}$) were applied one week after seeding, and $54kg \cdot ha^{-1}$ and $69kg \cdot ha^{-1}$, respectively were applied after one month.

The following variables were measured during the period from Jul.20 (*DOY*201) to Aug.14 (*DOY*226): solar radiation and net radiation at 1.0m above the canopy (Licor LI200SZ and REBS Q6); wind speed and direction at 2.0m above the ground (Young 03101 and 03001); air temperature and relative humidity at a level just above and 0.5m above the canopy (Cu-Co thermocouples and TDK CHS-PS placed in a radiation shelter (Campbel 41044)); vertical heat flux at 1cm depth under the soil surface (REBS HF3); sap flow rate (*SFR*) in three cotton plants (using the stem sap flow

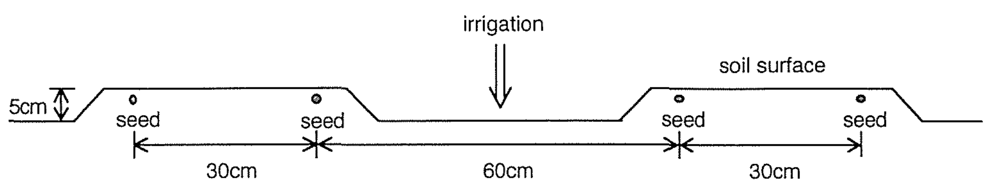

Fig. 1. Cross-section of the experimental field (vertical to the row direction)

gauge[7]). Signals of these sensors were scanned every 10 seconds and averaged over 30minutes (Campbel CR-10). In the bare field, 500m apart from the experimental field, the same micrometeorological observations were conducted.

Evapotranspiration rate (*ET*) and transpiration rate (*Tr*) in the cotton field were calculated by the Bowen ratio method, and by using the following equation, respectively:

$$Tr = PD \times SFR$$

where, *PD* is the averaged planting density of the field (described later in this report). Evaporation rate from the soil surface (*Ep*) was expressed as:

$$Ep = ET - Tr$$

An amount of about 100mm of irrigation water was supplied on both Jul.25 (*DOY*206) and Aug.11 (*DOY*223).

On Aug.16, the cotton plants, in which the sap flow rate was measured, were harvested and the leaf area was measured (Kiya GA3).

Experiment 2

Cotton was seeded on Apr.17 (*DOY*107), 1995 in an experimental field (EW60m x SN30m). In addition to the same measurements as those performed in Experiment 1, the following variables were observed during the period from Jul.6 (*DOY*187) to Sep.5 (*DOY*248): precipitation (Texas Electronics TR525M), and thermal conductivity of the soil at 0.2m, 0.5m and 1.0m depth (Soiltronics TC2). Soil samples at 0.2m depth were collected approximately once a week to measure the volumetric water content (*VWC*). The relationship between *VWC* and the water potential of the soil (*Ψsoil*) was determined (Daiki DIK3400). Leaf length of three plants was measured about once a week to obtain the leaf area using an empirical conversion equation.

An amount of about 180mm, 300mm and 100mm of irrigation water was supplied on Apr.20 (*DOY*110), Jul.6 (*DOY*187) and Aug.24 (*DOY*236), respectively. Other experimental conditions were the same as in Experiment 1.

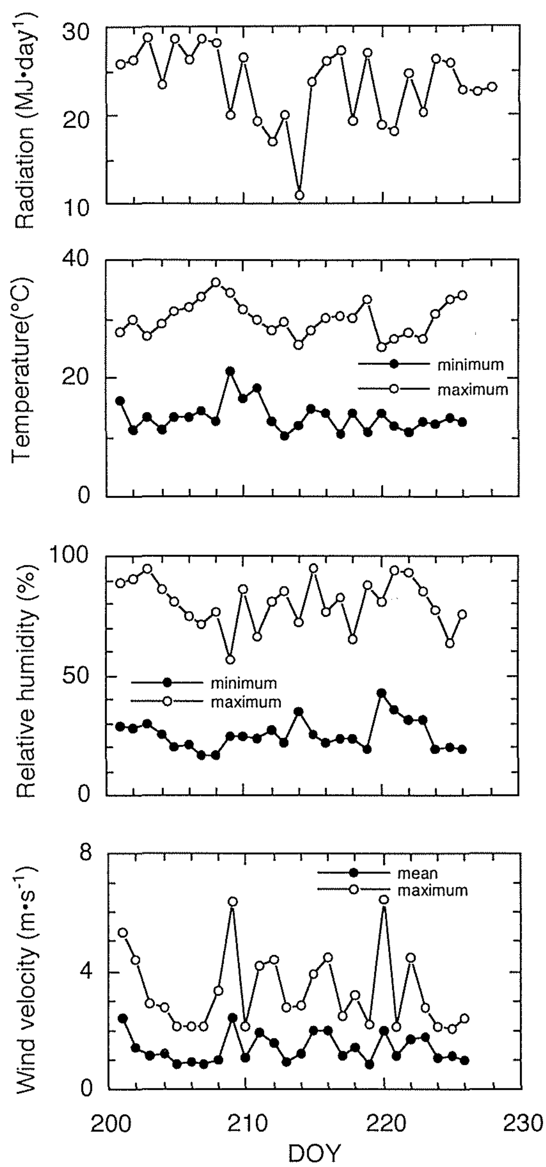

Fig. 2. Weather conditions in 1994

Results and Discussion

Experiment 1

Fig.2 shows the weather conditions in the cotton field. Temperature and humidity in the bare field were 0.9°C higher and 7.2% lower in an average, respectively than those in the cotton field.

Rainfall occurred on Jul.15 (*DOY*196), Jul.28 (*DOY*209), Aug.3 (*DOY*215) and Aug.10 (*DOY*222).

The amount of rain was very small except on Jul.15.

The cotton canopy was most dense when irrigation was first applied and its coverage was 0.9 by visual estimation. Leaf area was $1448 cm^2 \cdot plant^{-1}$ and the coverage was 0.6 on *DOY*228 when some leaves had fallen off.

The uniformity of the cotton field was poor, and therefore the planting density (*PD*), required to calculate *Tr*, was estimated $9.3 plant \cdot m^{-2}$ based on the following criteria: (1)The soil surface was very dry just before irrigation was first applied, (2)*Ep* was assumed to be negligible at that time, (3)Then, *PD* had to satisfy the condition: $ET = Tr = SFR \times PD$.

Ep rapidly increased after irrigation was first applied and gradually decreased thereafter (Fig.3). One week after irrigation the *Ep* value became nearly zero, which agreed with the very dry soil surface visually observed at that time and supported that the above-mentioned calculation for *PD* and *Ep* was valid. *Tr* (illustrated by the broken line in the figure) showed a decreasing trend throughout the experiment period (Fig.3), mainly due to senescence and abscission.

On the day following the application of irrigation for the first time (*DOY*207), the Bowen ratio (β) was nearly zero and most of the net radiation (*Rn*) was used for the latent heat transfer (Fig.4 and Fig.5). After 18hours, *Tr* became larger than *ET* suggesting that some part of the sap that had been detected by the sap flow sensor was stored in cotton fruits but did not transpire.

On *DOY*208, *ET* was about 125% of *Rn* in midday hours (Fig.4(c)), when β was negative (Fig.5(c)) and there was a downward sensible heat flux caused by advection. Comparison of Fig4(b) and Fig4(c) shows that *Ep* was affected by the advection unlike *Tr*. Windbreak net and forest will reduce *ET* by reducing the advection[8].

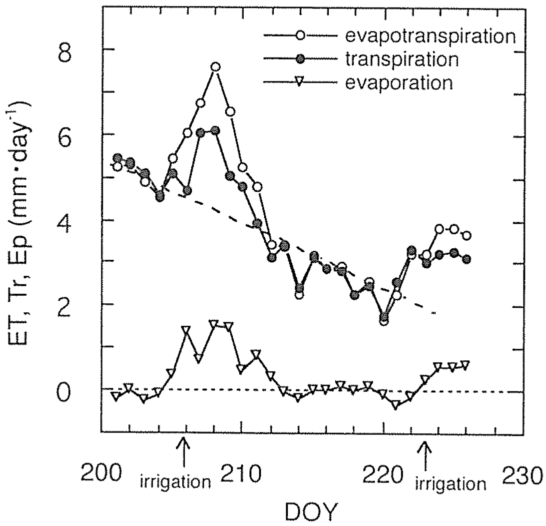

Fig. 3. Evapotranspiration, transpiration and evaporation (1994)

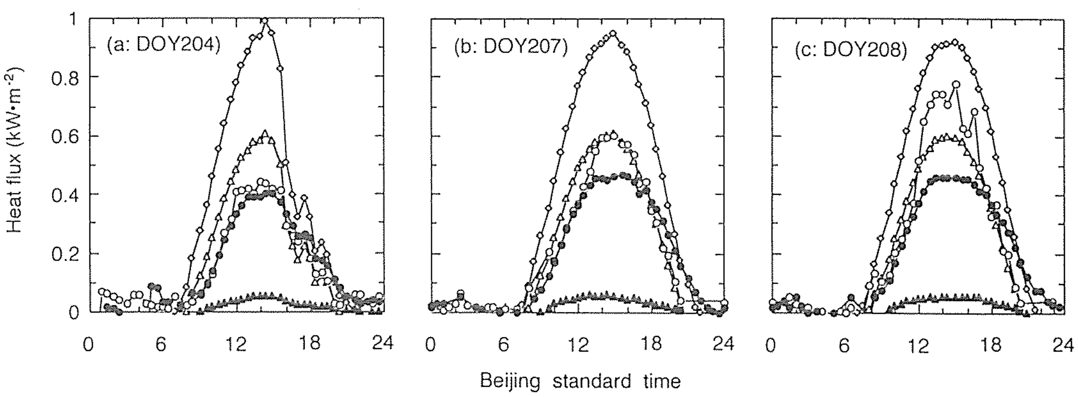

Fig. 4. Changes of fluxes in a day (1994)
◇: solar radiation
△: net radiation
○: evapotranspiration
●: transpiration
▲: soil heat flux

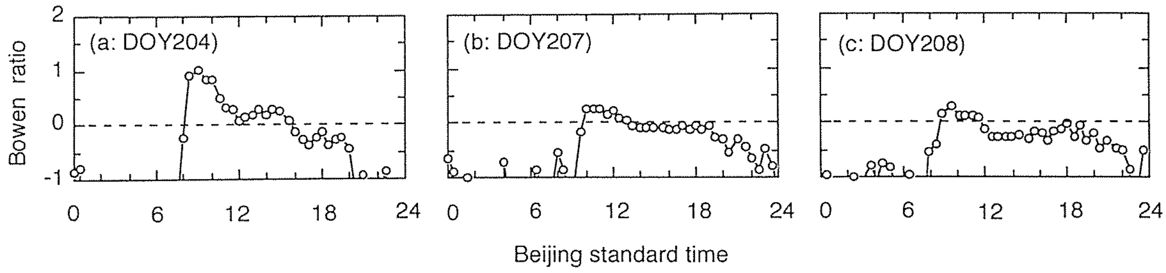

Fig. 5. Changes in the Bowen ratio in a day (1994)

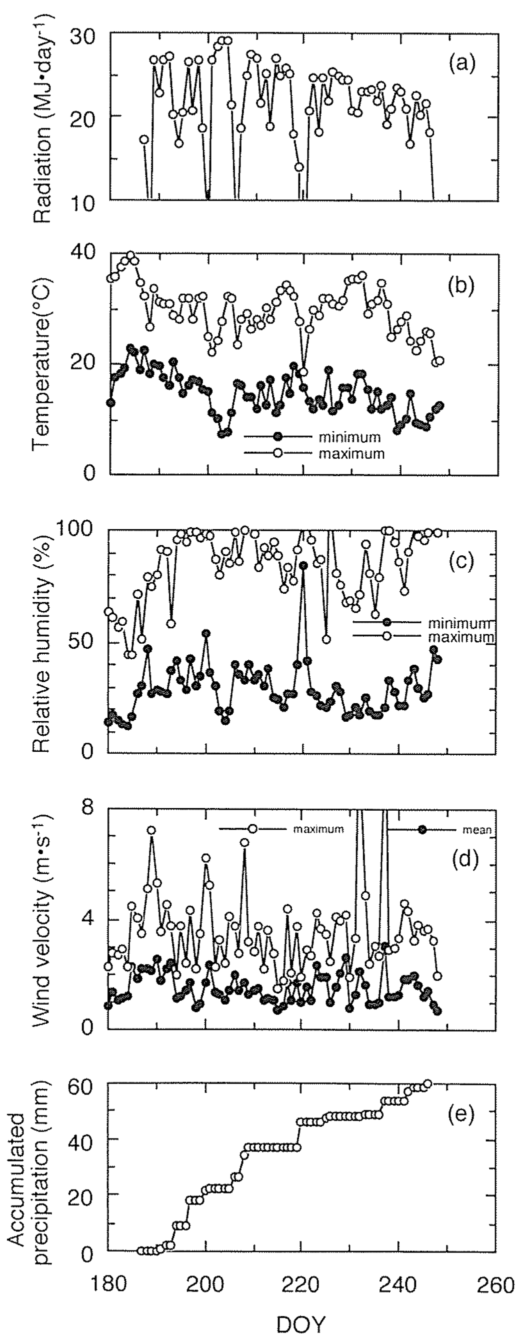

Fig. 6. Weather conditions in 1995

Experiment 2

Weather, cotton growth and soil moisture

Fig.6 depicts the weather conditions in the experimental field. Predominant wind direction was SW during the period of observation.

Leaf area of cotton changed as shown in Fig.7(a). Although no measurement was made during the period from *DOY*222 to *DOY*239, the changes in albedo (Fig.7(b)) suggested that the leaf area decreased gradually during this period.

VWC at a 0.2m depth changed as shown in Fig.8(a). *VWC* wich corresponded to the field capacity (*VWCfield*) was about 0.42 which was observed on *DOY*190. There was a relationship between *VWC* and *Ψsoil* (Fig.9). Wilting point (*VWCwilt* which corresponds to *Ψsoil* of -1550kPa or *pF*4.2) was about 0.20. The *VWC* value on the day preceding irrigation on *DOY*187 and *DOY*236 was lower than the *VWCwilt*.

Fig.8(b) shows that the heat conductance of the soil (λ) did not agree with the trend of *VWC* shown in Fig.8(a). For instance, *VWC* on *DOY*190 was definitely larger than on *DOY*150 (Fig.8(a)), which was not obvious in Fig.8(b). This discrepancy was ascribed to the fact that irrigation presumably changed the relationship between λ and *VWC* due to the large amount of water supplied. It was, therefore, impossible to determine *VWC* from λ in this case. However, λ indicated the relative change of the soil moisture during the interval between the application of irrigation.

Evapotranspiration (ET), transpiration (Tr) and evaporation (Ep)

The uniformity of the cotton field was as poor as in Experiment 1. A *PD* value of 9.3 was obtained by the same method as that employed in Experiment 1. The maximum leaf area was $870cm^2 \cdot plant^{-1}$ when the *LAI* was 0.8 (Fig.7).

Daily transpiration (*Tr*) changed as shown in Fig.10(b). On *DOY*215, a local agricultural engineer decided, based on empirical criteria, that irrigation was urgently needed in the experimental field. *Tr* was, however, not low on that day as shown in Fig.10(b), which suggested that the cotton plants were not experiencing severe water stress, and therefore that irrigation was not required on that day for the cotton plants. There was a rainfall of 9.5mm on *DOY*220 which increased the soil moisture at 0.2m depth as shown in Fig8(b), but *Tr* did not increase even after the rain, which also suggested that the cotton plants were not experiencing water stress even at that time. Better criteria for determining the timing of irrigation are required. *Tr* gradually decreased after *DOY*225, which was attributed to water stress, senescence and abscission. It appeared that the cotton leaves were wilting on *DOY*230. After irrigation was applied on *DOY*236, the cotton plants recovered.

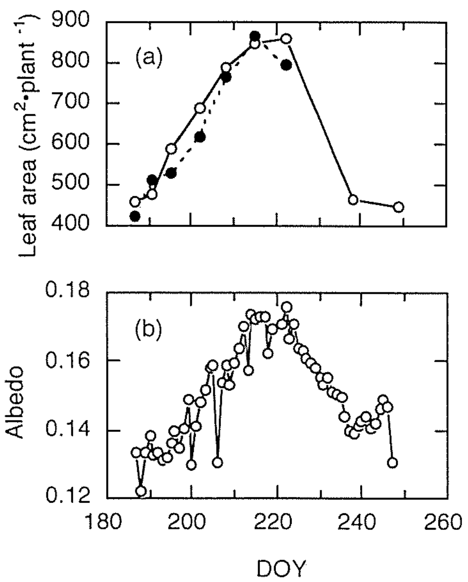

Fig. 7. Leaf area and albedo (1995)

The amount and interval of irrigation

Accumulated values of *Tr*, *Ep* and *ET* from *DOY*187 are shown in Fig.11. Evaporation from the soil surface was substantial for about 20 days after irrigation was applied for the first time, and amounted to 40mm. In the 49-day interval between the application of irrigation, the amount of transpiration and evapotranspiration was 180mm

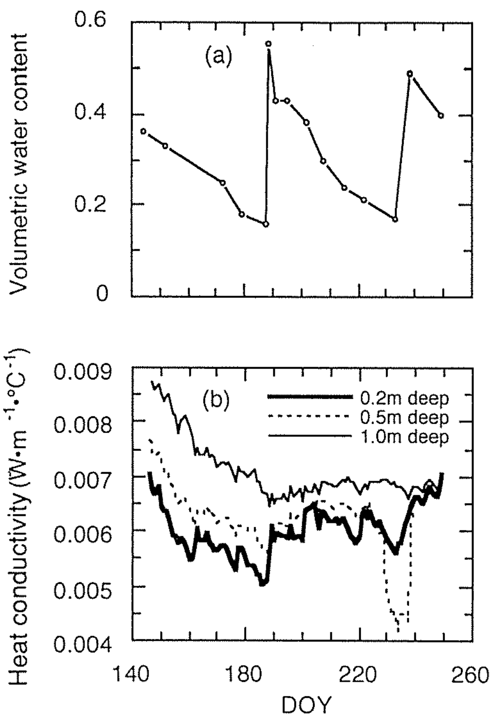

Fig. 8. Changes in volumetric soil water content and heat conductivity (1995)

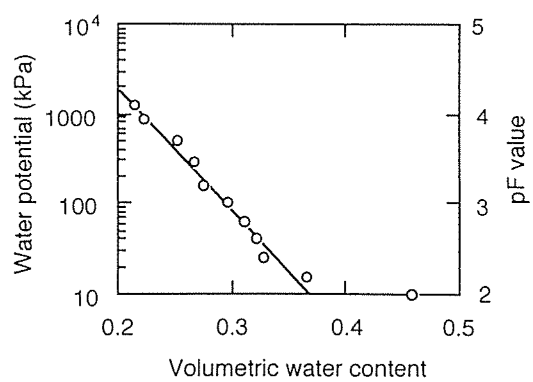

Fig. 9. Relationship between volumetric water content and water potential of the soil

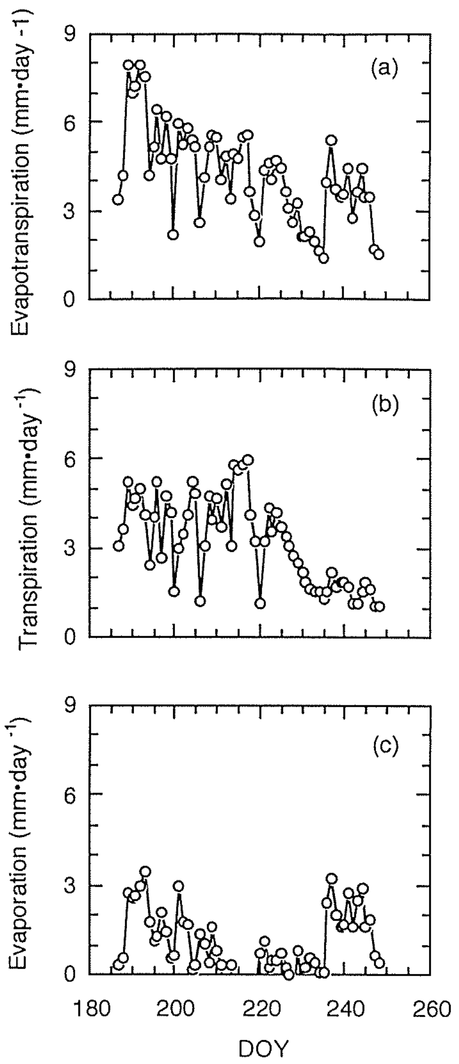

Fig. 10. Evapotranspiration, transpiration and evaporation (1995)

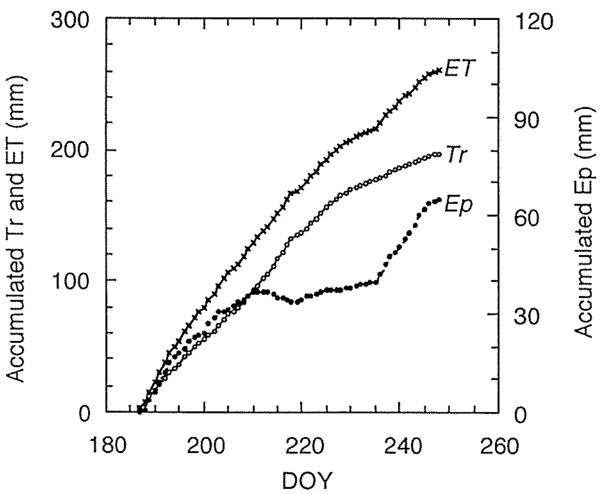

Fig. 11. Accumulated value of evapotranspiration, transpiration and evaporation (1995)

and 220mm, respectively. Soil moisture was nearly the same before irrigation was applied on *DOY*187 and *DOY*236 (Fig.8(a)). An amount of 80mm (= 300mm - 220mm) of water out of the 300mm supplied on *DOY*187 was lost by downward percolation without contributing to cotton production as evidenced by the rapid decrease of *VWC* within a few days after the irrigation (Fig.8(a)). The maximum amount of water for irrigation which did not lead to loss by downward percolation (*IRRmax*) was estimated by the following formula:

$$IRRmax = Droot \times VWCavail - (VWCpresent - VWCwilt)$$

where, *Droot* is the depth (mm) of effective root zone where the major part of water absorption by cotton root occurs, *VWCavail* is the available soil moisture (*VWCfield* - *VWCwilt*), and *VWCpresent* is *VWC* just before irrigation. The excess amount of irrigated water beyond *IRRmax* will be lost by downward percolation.

Droot in the experimental field was estimated based on the following three assumptions: (1) *VWC* was uniform throughout the effective root zone, (2) *VWC* on *DOY*236 corresponded to the wilting point, (3) All the water from evapotranspiration (220mm) during the interval between irrigation (on *DOY*187 and *DOY*236) originated from the effective root zone. Then, the equation *Droot* x 0.22=220 was derived, which gave a *Droot* value of 1000mm.

Assuming that irrigation corresponding to *IRRmax* is applied and that irrigation is applied for the second time when the soil moisture corresponds to *VWCwilt*, then the interval between irrigation (*INT* days) is

$$INT = IRRmax / ETave$$

where, *ETave* is the averaged *ET* which was 4.5mm · day^{-1} (=220mm / 49days) in this observation. If the drip irrigation system is introduced, *Ep* can practically be negligible and a longer interval (*INTdrip*) can be determined based on the following equation:

$$INTdrip = IRRmax / Tr_{ave}$$

where, Tr_{ave} is the averaged *Tr* of 3.7mm · day^{-1} (= 180mm / 49days) in this observation. For more precise estimation of *INT* and *INTdrip*, the effect of *LAI* on *ETave* and Tr_{ave} should be taken into consideration[9].

In conclusion, the conventional method of irrigation leads to a loss of water. To improve the irrigation efficiency, the amount of water supplied for irrigation and the irrigation interval should be determined by taking into account the depth of the effective root zone, the amount of available soil moisture, and the evapotranspiration rate.

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References

1) Cheng, X. and Li, S. (1992). The present situation of land-use of San-Gong River valley in Fukang district. In Proceedings of the international seminar on the Bogoda biosphere reserve., Chinese National Committee of MAB Programme, 60-65.
2) Gao, Z. and Zhou,Y. (1990). The salt characteristics of shallow ground water of Fubei State Farm and its neighbor area. Arid Zone Res., 1990(7): 63-70 [in Chinese].
3) Jiang, H. and Li, S. (1990). Soils of Fukang Desert Ecosystem Observation Research Station and its neighbor area. *Arid Zone Res.* 1990(7): 6-13 [in Chinese].
4) Li, S. (1990). Natural condition and basis for the foundation of Fukang Desert Ecosystem Observation Research Station, Academia Sinica. *Arid Zone Res.*, 7, 1990(7):1-5 [in Chinese].
5) Li, S. and Wang, Z. (1990). A primary study on the problem of ecological environment for Sangong River Basin in Fukang county. *Arid Zone Res.* 7, 1990(7):122-124 [in Chinese with English summary].
6) Nakai,M. and Zhao, G. (1992). Clay mineralogy of the soil from Fukang Area. *In* Proceedings of the international seminar on the Bogoda biosphere reserve. Chinese National Committee of MAB Programme, 90-97.
7) Sakuratani, T. (1981). A heat balance method for measuring water flux in the stem of intact plants. *J. Agric. Meteorol.*, **37**, 56-63.
8) Takami,S., O'Toole,J.C. (1983). Evapotranspiration from irrigated rice in the tropical dry season. *J. Agr. Met.*, **39**: 191-200.
9) van Keulen, H. and Wolf, J. (Eds) : Modelling of Agricultural Production: Weather, Soils and Crops, Pudoc, Wageningen, 1986.
10) Wei, R. (1992). Water resources and its eco-environmental monitoring along the Sangong River valley in Xinjiang. *In* Proceedings of the international seminar on the Bogoda biosphere reserve, Chinese National Committee of MAB Programme, 37-42.

中国乾燥地域の潅漑農地における水利用の実態

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摘　要

新疆ウイグル自治区阜康荒市において，慣行的方法により水管理されるワタ圃場の水利用の実態を把握するため，以下の観測を行なった。ワタ群落からの蒸発散速度（*ET*）を熱収支ボーエン比法により測定した。群落蒸散速度（*Tr*）を，茎熱収支法による個体蒸散速度測定値に別途評価した平均栽植密度を乗じて求めた。地面からの蒸発速度（*Ep*）を，$Ep=ET-Tr$として求めた。併せてサンプリングにより土壌水分の推移を測定した。

潅漑後は蒸発散が蒸散を上回り，作物生産に関与しない地面蒸発が活発であった。移流による顕熱供給の影響で蒸発散が純放射を上回る場合も認められた。

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，土壌中に有効水分が存在し，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。更に一回の潅漑量が多く，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，これらの損失を生じさせない一回当たり潅漑量，および潅漑間隔を示した。

キーワード：新疆，蒸発，蒸散，蒸発散

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