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Ground-based observation of aerosol optical properties in Lanzhou, China

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Abstract

Aerosol optical properties from August 2006 to July 2007 were obtained from ground-based and sky radiance measurements in Semi-Arid Climate and Environment Observatory of Lanzhou University (SACOL), China. High aerosol optical thickness (AOT) associated with low Ångström exponent (α) was mainly observed in spring, which was consistent with the seasonal dust production from Hexi Corridor. The maximum monthly average value of AOT 0.56 occurred in March of 2007, which was two times larger than the minimum value of 0.28 in October of 2006. Approximately 60% of the AOT ranged between 0.3 and 0.5, and nearly 93% of α value varied from 0.1 to 0.8, which occurred in spring. The significant correlation between aerosol properties and water vapor content was not observed. The aerosol volume size distribution can be characterized by the bimodal logarithm normal structure: fine mode ($r < 0.6$ μm) and coarse mode ($r > 0.6$ μm). Aerosols in spring of SACOL were dominated by large particles with the volume concentration ratio of coarse to fine modes being 7.85. The average values of asymmetry factor (g) in the wavelength range 440–1020 nm were found to be 0.71, 0.67, 0.67 and 0.69 in spring, summer, autumn and winter, respectively.

Key words: aerosol; optical property; Lanzhou City

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Introduction

As one of the important components of the earth atmosphere system, aerosol plays an extremely important role both in the global climate change and biogeochemical cycle (Zhang *et al*., 1997). Aerosol can influence the earth radiative budget directly by scattering and absorbing solar radiation and indirectly by influencing cloud properties and lifetime. However, the effect of aerosols on the global climate change has drawn much attention in recent years due to considerable uncertain climate forcing (IPCC, 2001).

Ground-based remote sensing of aerosols is ideal for reliably and continuously derive detailed aerosol properties in key locations around the world. Validating aerosol products obtained from various satellite sensors may need ground-based measurements of variety of optical aerosol characteristics with different data quality requirements. Many aerosol ground-based observation networks have been established to understand the optical properties of aerosol and indirectly evaluate their effect on climate. The Global Atmosphere Watch (GAW) of World Meteorological Organization (WMO), a coordinated network of observing stations, has already provided information on changes of the chemical composition and physical properties of the background atmosphere from all parts of the world (WMO, 2001). The Aerosol Robotic Network (AERONET), an automatic robotic sun and sky scanning measurement program, has grown rapidly through international federation since 1993 to over 100 sites worldwide so far. The program provides the satellite remote sensing, aerosol, land and ocean communities' quality-assured aerosol optical properties to assess and validate satellite retrievals (Holben *et al*., 2001). The Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia) field campaign was conducted primarily in South Korea, Japan, China and adjacent oceanic regions to characterize the properties of Asian aerosols (Huebert *et al*., 2003). A sun and sky radiometer network based in East-Asia (SKYNET) was also established and conducted similar measurements as AERONET (Takamura *et al*., 2002).

Asian dust rising from the dust storms that occur in the arid regions of China and Mongolia at high altitudes (1–2 km or more) is easily delivered into the free troposphere and transported over thousands of kilometers during the spring by the westerlies (Iwasaka *et al*., 1988; Husar *et al*., 1997). It is estimated that nearly 800 Tg of mineral aerosols are emitted into the atmosphere each year, among which 50% is deposited over the source and adjacent regions and the remainder is transported to the remote Pacific Ocean (Zhang, 2001). Despite Asian dust has a significant effect on the atmospheric radiation budget and much attention has been paid to this issue, the information on Chinese dust properties and their spatial and temporal

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variation is still limited.

The objective of this study was to characterize the dust aerosol and water vapor content of the atmosphere using continuous measurements in a Chinese semi-arid region based on the 12-month AERONET data. A long-term record of aerosol observations should provide a valuable data to enrich the knowledge of aerosol properties in Northwest China.

1 Measurement

Lanzhou, the capital of Gansu Province, is located in the geometric centre of land territory of China with mountains surrounding in the north and the south, and Yellow River passing through from east to west. Lanzhou is defined as "semi-arid continental monsoon climate" and dry with plenty of direct sunshine. It has four distinct seasons each year: winter (December, January, and February), spring (March–May), summer (June–August), and autumn (September–November). The annual average precipitation is 327 mm and concentrates in summer. The annual average temperature is 10.3°C with huge annual and daily difference. Lanzhou is frequently affected by dust storms in spring due to that it locates at the downwind of Hexi Corridor, which is one of dust activity centers in China.

Solar direct and sky radiance measurements presented in this article were made from August 2006 to July 2007 in Semi-Arid Climate and Environment Observatory of Lanzhou University, (SACOL) (35.94°N, 104.14°E). The sun/sky radiometer was installed on the top of Cuiying Mountain at 1965.8 m above sea level in Yuzhong Campus of Lanzhou University, and is not influenced by anthropogenic activity. SACOL is located at the southeast and approximately 47 km away from the center of Lanzhou City. The topography around the site was characterized by the Loess Plateau consisting of plain, ridge and mound, etc. The soil material was mainly quaternary aeolian loess with the main soil type being sierozem.

All of measurements reported in this article were performed with sun/sky autonomous radiometers, which are a part of the AERONET. Sun and sky measurements were performed in seven spectral bands (340, 380, 440, 500, 670, 870 and 1020 nm). Data sets used in this study were the level 2 data fully cloud-screened, calibrated and verified by the method of Smimov *et al.* (2000). Detailed description of the instruments and data acquisition procedure were described by Holben *et al.* (1998, 2001). The uncertainty in aerosol optical thickness was less than ± 0.01 for $\lambda > 440$ nm and less than ± 0.02 for shorter wavelength, was ± 10% for water vapor, and was less than ± 5% in the sky radiance measurements.

2 Results and discussion

2.1 Aerosol optical thickness, Ångström exponent and water vapor content

The aerosol optical thickness is representative of the airborne aerosol loading in the atmospheric column, and is important for the identification of aerosol source region and aerosol evolution. Figure 1 shows the monthly average aerosol optical thickness (AOT), Ångström exponent (α) and water vapor content during 2006–2007 in SACOL, with the standard deviation. It can be easily found that AOT showed a distinct seasonal variation in this arid area with high values mainly occurred in spring. The obvious seasonal variation of AOT was also observed in other western stations such as Germu, Dunhuang and Waliguan (Zhang *et al.*, 2002; Xia *et al.*, 2004a; Qiu and Yang, 2000). The seasonal average AOT in spring of SACOL measured in this study (0.47) is higher than the largest average value (0.42) measured by Huang *et al.* (2008).

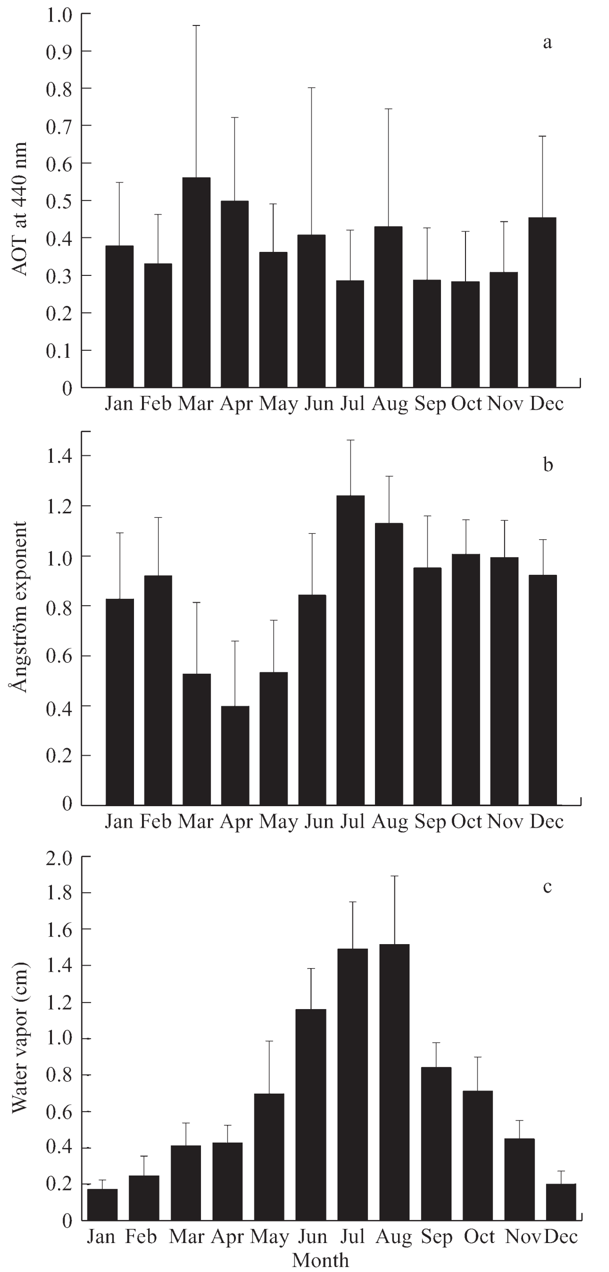

Fig. 1 Monthly average of aerosol optical thickness (AOT) at 440 nm (a), Ångström exponent (440–870 nm) (b), and water vapor content (c) during 2006–2007 in Semi-Arid Climate and Environment Observatory of Lanzhou University (SACOL).

The maximum monthly average value of AOT (0.56) occurred in March of 2007, which was two times of the minimum (0.28) in October of 2006. The appearance of high values of AOT in spring of SACOL was related to the contribution of dust particles emitted from Hexi Corridor by the long-range transport (Wang *et al*., 1999; Tao *et al*., 2007). The average AOT in winter of SACOL (0.39) was lower than the measurement of Zhao *et al*. (2005) in which the average AOT in the urban area of Lanzhou reached 0.74 in December, 1999. The occurrence of high value in urban region was related to the anthropogenic pollution and meteorological conditions. In general, the annual average AOT was 0.38 and seasonal means were 0.47, 0.37, 0.29 and 0.39 for spring, summer, autumn and winter, respectively.

Ångström exponent (α) was a measure of the wavelength dependence of aerosol optical thickness and a good indicator of aerosol size distribution. As shown in Fig. 1b, the monthly average values of α were always greater than 0.8 in summer, autumn and winter. These results indicated that the greater contribution of fine particles to extinction in summer, autumn and winter of SACOL. The values of α were commonly less than 0.53 during March to May. The seasonal average of α in spring for SACOL measured in this study (0.48) was lower than the measurement (0.53) of 2006–2008 (Huang *et al*., 2008). The result indicated that the aerosol particles were mainly dominated by coarse particles and related to the dust events in spring. The high values of both α and AOT occurred in August indicated that there was an increase in the contribution of fine particles during the high temperature period (Lyamani *et al*., 2006).

A notable seasonal variation of water vapor content is given in Fig. 1c. The highest values of water vapor content occurred in summer, which was consistent with the description of the climate in Lanzhou. The value of AOT and α had little correlation with water vapor content (relation coefficient less than 0.3). The appearance of low value of relation coefficient was in a good agreement with the measurements in Dunhuang (Xia *et al*., 2004a). This phenomenon was due partly to the very weak humidification capability of dust aerosol, as compared with urban or smoke aerosols. Additionally, the distinctly difference in seasonal variation of AOT, α and water vapor content also prevented the occurrence of a close relation between AOT, α and water vapor content.

Figures 2 and 3 report the frequency distribution of AOT and α in the four seasons over SACOL. The AOT distributions (Fig. 2) commonly showed a unimodal structure with a value of 0.4 in spring and 0.2 in other three seasons. The frequency distributions of AOT were about 34%, 72%, 64% and 49% in ranges of 0.1–0.3 in spring, summer, autumn and winter, respectively. Especially in spring, about 60% of AOT occurred in ranges of 0.3–0.5. The distributions of α (Fig. 3) were unimodal structure centered at 1.0 in autumn and winter, and bimodal structure centered at 0.2 and 0.7 in spring, and trimodal structure centered at 0.8, 1.1 and 1.4 in summer. The frequency

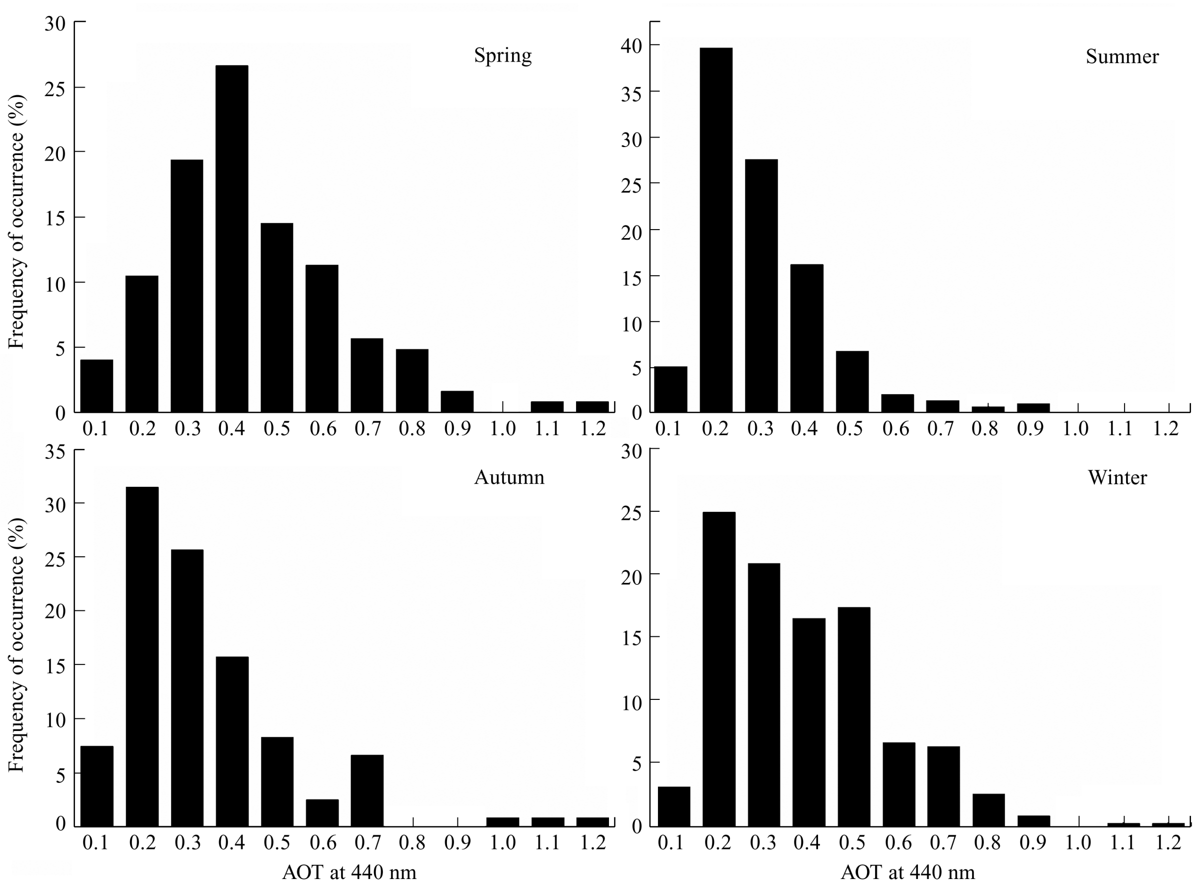

Fig. 2 Frequency distributions of AOT (440 nm) for each season in SACOL.

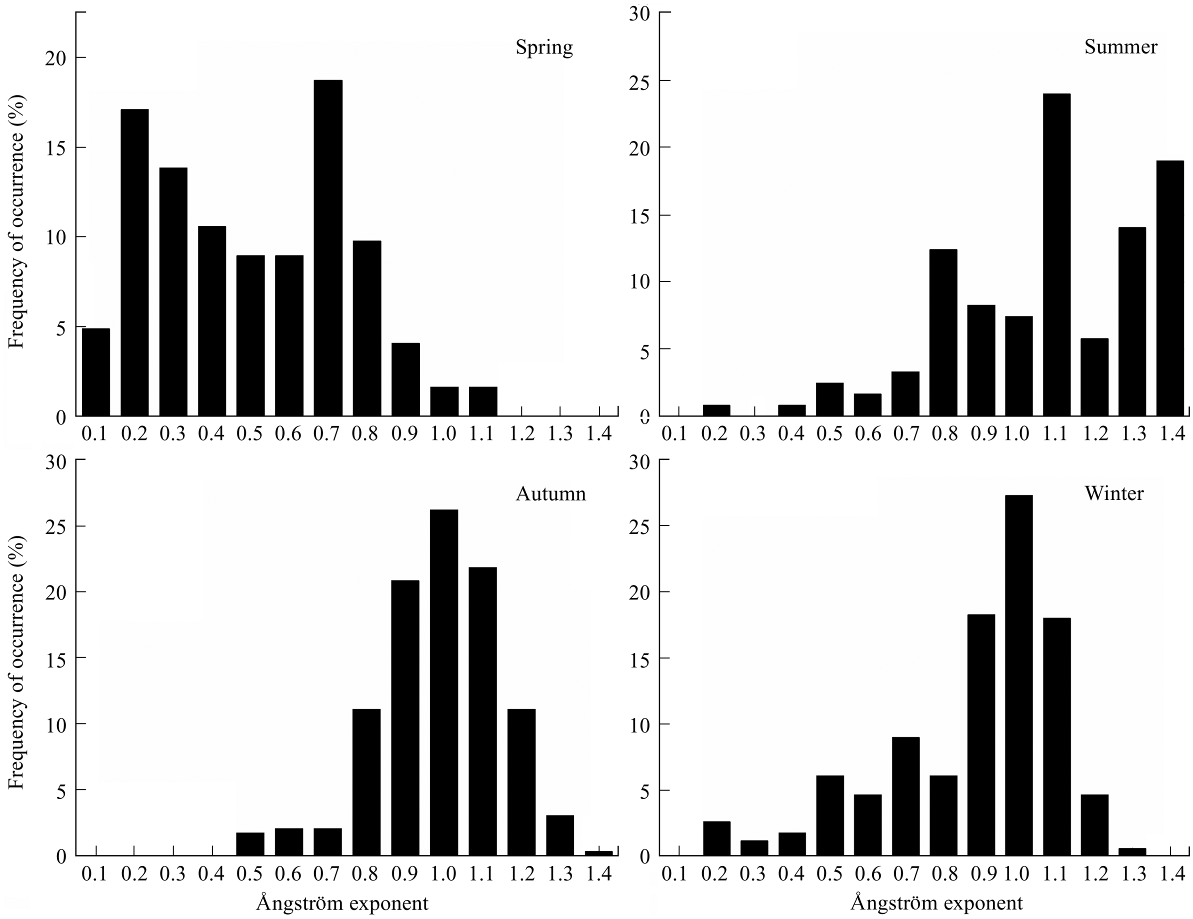

Fig. 3 Frequency distributions of Ångström exponent (α) (440–870 nm) for each season in SACOL.

distributions of α were 52.1%, 79.9% and 69.6% fluctuated from 0.8 to 1.1 in summer, autumn and winter; and nearly 93% of α varied from 0.1 to 0.8 occurred in spring.

2.2 Aerosol volume size distribution

The seasonal average volume size distributions of aerosols during 2006–2007 over SACOL are reported in Fig. 4. The aerosol volume size distributions were commonly in a bimodal logarithm normal structure: fine mode (r < 0.6 μm) and coarse mode (r > 0.6 μm). The fine modes showed the maxima peak at radius 0.11–0.15 μm in spring, autumn and summer, and radius 0.19 μm in winter. The coarse modes showed the maxima peak at radius 2.2–2.9 μm in spring and summer, and 3.8 μm in autumn and winter. The size distribution showed a distinct difference in dominant mode for the different seasons. The coarse modes were obviously dominant in spring and winter, especially in spring due to the presence of dust particles with relative big size. The volume concentration ratio of coarse to fine modes was 7.85, which ratio was evidently lower than that in Bahrain-Persian Gulf (about 10), Dunhuang (about 30) and western part of Africa and the Arabian Peninsula (about 50) (Dubovik *et al*., 2002; Xia *et al*., 2004b).

2.3 Asymmetry factor (g)

The asymmetry parameter represents an estimation of the asymmetry distribution of the dispersed radiation. The

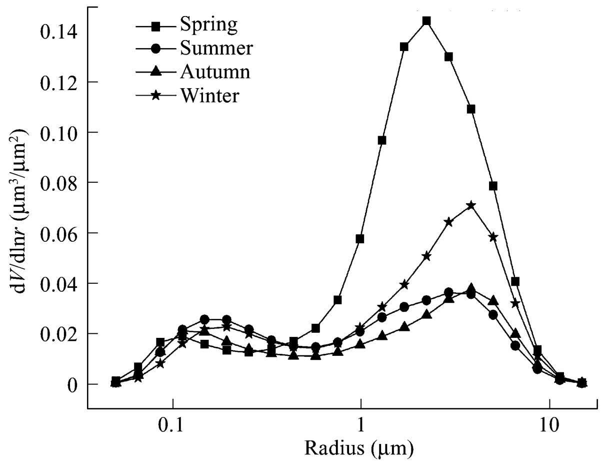

Fig. 4 Seasonal average aerosol volume size distributions derived from the sky radiance as a function of particle radius for SACOL during 2006–2007.

seasonal average values of g at 440, 675, 870 and 1020 nm for SACOL during 2006–2007 are presented in Fig. 5. The average values of g commonly showed a decreasing trend with wavelengths in summer, autumn and winter. Except the decrease at 440–870 nm, the average values of g showed an increasing trend at 870–1020 nm in spring. This result was similar to the measurements at Beijing, Gwangju, Shirahama and Noto in the dusty days (Yu *et*

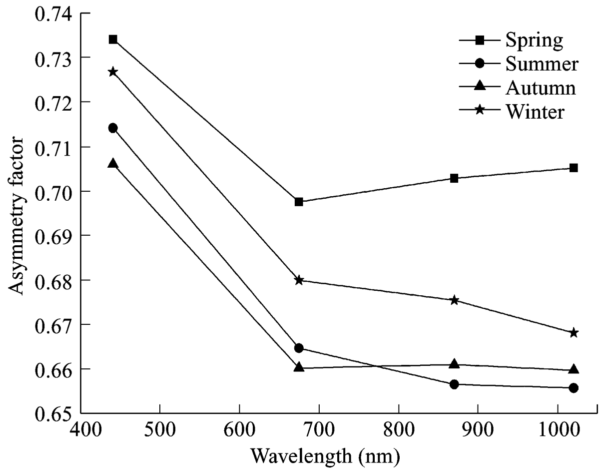

Fig. 5 Seasonal average asymmetry factor at 440, 675, 870 and 1020 nm for SACOL during 2006–2007.

al., 2006). The average values *g* in spring and winter were larger than summer and autumn. The yearly average value of *g* at 440 nm was up to 0.72, which was larger than the measurement of Andrada *et al*. (2008), who presented that the average value of *g* for Cordoba reached 0.67 during 1999–2006 at the same wavelength. In the view of climate, the averages of asymmetry factor in the wavelength range of 440–1020 nm were 0.71, 0.67, 0.67 and 0.69 in spring, summer, autumn and winter, respectively.

3 Conclusions

The aerosol optical thickness (AOT), Ångström exponent (α), water vapor content, volume size distributions and asymmetry factor (*g*) in Semi-Arid Climate and Environment Observatory of Lanzhou University (SACOL) were presented using the data of solar direct and sky radiance measurements from August 2006 to July 2007.

The AOT over SACOL showed a distinct seasonal variation with the maximum in spring and the minimum in autumn and was mainly influenced by weather conditions and dust events. The magnitude of α was found to be relatively high throughout the year, and the highest values were shown in summer and the smallest in spring. Approximately 60% of AOT ranged between 0.3 and 0.5, and 93% of α values varied from 0.1 to 0.8 occurred in spring. The significant correlation between aerosol properties and water vapor content was not observed.

The aerosol volume size distribution can be characterized by the bimodal logarithm normal structure: fine mode ($r < 0.6$ μm) and coarse mode ($r > 0.6$ μm). Aerosols over SACOL in spring were dominated by coarse particles due to the presence of dust events, with the volume concentration ratio of coarse to fine mode being 7.85. The asymmetry factor in spring was higher than other three seasons. The variation of *g* value with wavelengths had regional characteristics. The values of *g* obtained in spring were higher than those reported for other urban/industry, which suggested the possible contribution of large particles and indicated that the particles were predominant in forward scattering in this semi-arid region.

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