Hydrometeorological conditions of grassland vegetation in Central Mongolia and their impact for leaf area growth

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Abstract

The long-term observation of surface heat and water budget and hydro-meteorological elements has been carried out over a grassland site at Arvaikheer (46.23 N, 102.82 E) in central Mongolia as the framework of the GAME-AAN (GEWEX Asian Monsoon Experiment-Asian Automatic Weather Station Network). The purpose of this study is to clarify the relationship between vegetation and climate using long-term data (1982-2000) of satellite-derived LAI and climatic data observed at Arvaikheer. Furthermore, we aimed to reveal physical process by comparing soil moisture, and heat and water budgets in 1999 and 2000 as a case study of good and poor vegetation growth. Significant positive correlations with 99% confidence levels were found for July precipitation (P) and the LAI in July LAI (0.538), August (0.826) and September (0.564). Composite analysis for five highest (H5) and lowest (L5) LAI years showed the significant positive anomalies of P in July and LAI in July and August for H5. In June and July 1999, soil moisture and P values were higher than values in 2000; this pattern was reversed in August and September. The mean LAI during the 1999 growing season (1.0) was about twice that of 2000 (0.6). In 1999, the ratio of evapotranspiration (ET) to P (ET/P) and change of stored soil moisture (ΔW) to P (ΔW /P) were 0.79 and 0.15, respectively. In 2000, ET/P and ΔW /P were 0.94 and 0.0, respectively. These results suggest that the P and ΔW before July had the most influent on grass growth in central Mongolia.

Keyword: Mongolia, Grassland, Leaf area index, Soil moisture, Rainfall, Evapotranspiration

1. Introduction

Few studies have examined the relationship between vegetation and climate in Mongolia. Kondoh and Kaihotsu (2003) found that Mongolian grasslands showed a clear relationship between total summer precipitation and the NDVI amplitude. Ni (2003) noted that grasses showed a positive relationship to precipitation and aridity index (mean annual precipitation divided by mean air temperature plus 10 degrees) in north-east China and south-east Mongolia. Suzuki et al. (2003) pointed out that the Mongolia showed 11 weeks later start of green-up than Kazakh, while Mongolia and Kazakh located in almost same latitude. They suggested that Kazakh had more soil moisture from snowmelt than its in Mongolia. However, neither study clarified physical or physiological processes together with inter-summer variation of precipitation and vegetation.

The long-term observation of surface heat and water budget in association with hydro-meteorological elements has been carried out over a grassland site at Arvaikheer (46.23 N, 102.82 E) in central Mongolia as the framework of the GAME-AAN (GEWEX Asian Monsoon Experiment-Asian Automatic Weather Station Network; Sugita et al. 2003). The purpose of this study is to clarify the relationship between vegetation and seasonal and interannual variability of rainfall using long-term data (1982-2000) of satellite-derived LAI and climate variables observed at Arvaikheer (Miyazaki et al., 2004). Furthermore, we aimed to reveal physical process by comparing surface climate, soil moisture, and heat and water budgets of in 1999 and 2000 as a case study of good and poor vegetation growth.

2. Data and methods

Long-term observations of hydro-meteorological elements and surface flux have been conducted by using Automatic Weather Station (AWS) at the site in Arvaikheer in central Mongolia since 17 September 1997. Annual mean air temperature and annual precipitation (P) are $0.4^{\circ}C$ and 245 mm, respectively. All the vegetation at this site is C_3-type grasses, mainly in the Gramineae (e.g., *Stipa Gobica*), Compositae (e.g., *Artemisia adamsii*), and Cyperaceae (e.g., *Carex duriuscula*) families. The soil consists of brown humus and sand from the surface to 20 cm, brown soil with rock from 20-70 cm, and brown silt below 70 cm. Winds prevail from the north-west and homogeneous grasslands extend more than 5 km around the site. Surface flux was observed at 7.8 m height by Portable Automated Mesonet III (PAM III: Miltzer et al. 1995) Automatic Weather Station (AWS) developed by the National Center for Atmospheric Research (NCAR) in the United States. The observational height of surface flux to ensure sufficient fetch, since surface fluxes are considered 100-times greater than the measuring height (780 m; Horst and Weil, 1994).

Mongolia's Institute of Meteorology and Hydrology (IMH) provided daily P data from 1999 to 2000 at Arvaikheer. The IMH also provided long-term 10-day mean air temperature and 10-day P data from 1982 to 2000. In addition to station data provided by IMH, we used summarized global data on daily mean air temperature, daily mean dew point temperature, and daily precipitation amounts and snow depths. These data were obtained from the Global Climate Observing System (GCOS) Surface Network (GSN), produced by the National Climate Data Center (NCDC), and are available via the NCDC web server (http://www.ncdc.noaa.gov/).

In this study, we used a global LAI dataset derived from global composites of maximum NDVI values. The data are part of the National Oceanic and Atmospheric Administration (NOAA) Pathfinder Advanced Very High Resolution Radiometer (AVHRR) Land dataset (PAL) Ver. 3. The global composites were created using an algorithm that incorporates results from a three-dimensional radiative transfer model and a six-biome classification scheme, as described in Myneni et al. (1997). The data contain monthly LAI values at a 16 x 16 km spatial resolution from July 1981 to May 2001 and are available online at http://cybele.bu.edu. We used the data from the grid near Arvaikheer (46.175-46.325 N, 102.66-102.86 E).

3. Results and Discussion

3.1 Relationship between local climate and LAI

The monthly mean air temperature (T) at Arvaikheer exceeds $5^{\circ}C$ in May and the monthly mean T drops lower than $5^{\circ}C$ in October. It is common that the monthly mean T with 5 degrees is the threshold for vegetation activity. Moreover, most precipitation (about 90% of annual precipitation) and growth of vegetation at Arvaikheer occurs from May to September. Therefore, we define the vegetation growing season (GS) as May to September.

To clarify the seasonal variation of T, P and LAI at the site, we present the time series of monthly T, P and LAI averaged from 1982 to 2000 with standard deviations (SD) (figures are not shown). The seasonal maximum of both T ($16.1^{\circ}C$) and P (77.0 mm) appeared in July, while the seasonal minimum of both T ($8.9^{\circ}C$) and P (14.7 mm) appeared in September. P had large SD from June to August with more than 30mm, while T had small SD from June to August with less than 1.5 degrees. LAI increased from May (0.4) to June (1.2) rapidly then became nearly constant until September with slight maximum in August (1.3). From 1982 to 2000, T during GS had significant increasing trend (0.1 degree/year) with 99% confidence level. In same period, P and LAI during GS had no significant trend.

To evaluate the relation between climate and vegetation, it is useful to calculate correlation between T, P and LAI. No significant correlation showed for T and LAI. Table 1 shows statistical correlations between P and the LAI from 1982 to 2000. Nineteen data points were used for this analysis. Thus, the degree of freedom for correlation analysis was 17, and the lower limits for significant correlation were 0.529 and 0.456 at 99% and 95% confidence levels, respectively. Positive significant correlations at 99% confidence levels were found for P in July and the LAI in July (0.538), August (0.826) and September (0.564). Positive significant correlations at 95% confidence levels were found for P in May and the LAI in June, and for P in June and the LAI in June. No correlation showed for P in August and the LAI in August or September, or for P in September and the LAI in September, implying that after August, P has less effect on grass growth.

Table 1. Correlation matrix of P and the LAI. The bold values are significant correlation coefficient. *: the 95% significance level. **: the 99% significance level.

	LAI				
P-month	5	6	7	8	9
5	0.245	**0.482***	0.074	0.069	0.086
6	--------	**0.458***	0.445	0.050	0.053
7	-------	-------	**0.538****	**0.826****	**0.564****
8	-------	-------	------	-0.141	-0.065
9	-------	-------	------	-------	-0.009

To reveal the actual phenomena guiding relationships between P and the LAI, we created the composites of years with the five highest (H5; in the years of 1984, 1985, 1990, 1997, and 1998) and five lowest (L5; in the years of 1982, 1986, 1988, 1995, and 2000) for mean LAI value during GS. We present the anomalies of P and LAI for comparing H5 and L5 composite in Fig. 1 (a) and (b). P of H5 in July had significant (larger than SD) positive anomaly with 45.4 mm while P of L5 had nearly significant negative anomaly with 44.4 mm. The LAI of H5 in July and August had the significant positive anomaly with 0.7 and 0.6, while the LAI of L5 from July to September had the almost significant negative anomaly with 0.5. In other months, no significant difference showed for P and the LAI. These results support findings of large, significant positive correlations for P in July and the LAI from July to September. This suggests that plenty of July rainfall is the most important factor for grass growth.

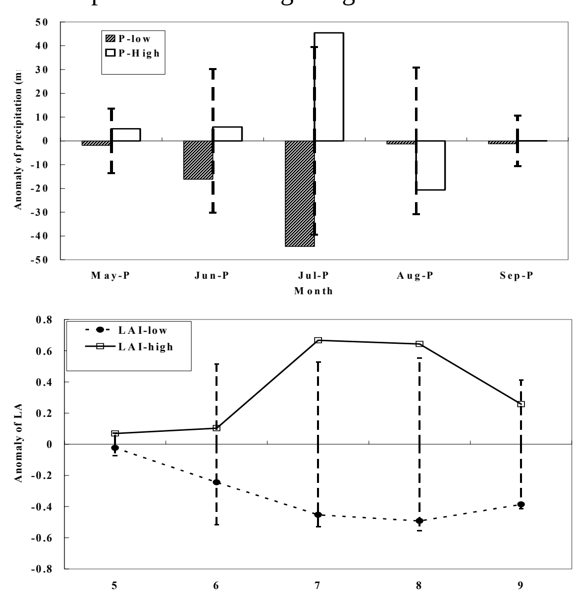

Fig. 1 Comparison of (a) P (b) LAI by composites of the five years with the highest LAI values and five years with the lowest LAI values, which was chosen from mean LAI value during growing season. Error bars show the standard deviation over 19 years (1982-200).

3.2 Comparison of summer climate and vegetation in 1999 and 2000

Annual P in both years (150 mm) was about 60% of that in normal years (240 mm) while seasonal variability in P differed in these years. We used these two years in a case study to examine results from the previous section further. From May to July, 1999 had a higher P frequency (43.5% of total days) than 2000 (33% of total days; Figure was not shown). In 1999, P values exceeding 3 mm/day occurred on 13 days from May to July; only 7 days in the same period in 2000 exceeded 3 mm. From August to September, both 1999 and 2000 showed the same frequency of P. In 1999, no day had a P value greater than 10 mm/day; four such days were observed in 2000.

The surface condition is the most important parameter controlling heat and water budgets. Soil moisture is a useful parameter for expressing the surface condition.

Figure 2 shows the time series of 5-day mean θ at depths from 5 to 20 cm, on average, during the growing season. In both 1999 and 2000, θ responded to P very well. The θ in 1999 was higher than in 2000 in June and July, and lower than in May and August. Erdenetsetseg (1997) showed the soil moisture regime at typical sites with long-term observation. The temporal variation of θ in 1999 resembled with the long-term mean soil water content in steppe region, while the temporal variation of θ in 2000 was similar to that in desert region shown in Erdenetstseg (1997). The frequency of P in 1999 was about 1.5 times of its in 2000. This also affected the different intra-seasonal variation of θ between in 1999 and 2000.

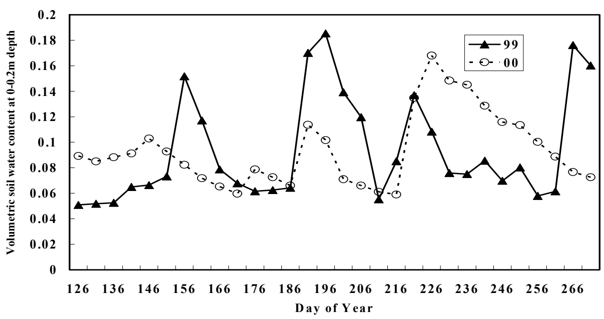

Fig. 2 Comparison of 5-day mean volumetric soil water content averaged from 5- to 20-cm depths from May to September in 1999 and 2000.

The mean LAI during the 1999 GS (1.0) was about twice that in 2000 (0.6). The annual maximum LAI value reached 1.6 in June 1999 and 0.7 in June 2000. The uncertainty in the LAI estimate may be order of 0.5 LAI (Myneni et al. 1997). Therefore, the difference of annual maximum LAI is significant. The LAI peak in June 1999 likely related to the θ in root zone deeper than 10cm in June. In May and June 1999, the frequency of P was about twice of its in May and June 2000. The days with P more than 5 mm/day were four times in middle and late May 1999 while there was no day with P more than 5 mm/day in May and June 2000. In June and July 1999, θ values were higher than in 2000, while θ values in August and September 2000 were higher than in 1999. P in June and July 2000 were significant smaller than the average P from 1982 to 2000. It implies that the small P caused low θ in June and July 2000. These results point out that higher θ in early 1999 GS may have an impact on the LAI, since the 1999 LAI was significantly greater than the 2000 LAI.

Figure 3 shows a time series of 5-day mean sensible heat flux (H) and latent heat flux (LE) during the GS. From May to June, H was the dominant component of the surface heat budget with about 15 to 20 MJm^{-2}/day in both years; during this same period, H reached its annual maximum of 20.2 MJm^{-2}/day and 22.3 MJm^{-2}/day in early June 1999 and mid-June 2000, respectively. In 1999, LE exceeded H in three periods (mid-June, early August, and late September), in response to soil moisture increases after heavy rainfall. In 2000, LE surpassed H in mid-June and early August during high soil moisture conditions. In 1999, LE reached its annual maximum in mid-July at about 14.7 MJm^{-2}/day that was about 60% of Rn, while LE in 2000 attained an annual maximum in early August at about 12.4 MJm^{-2}/day that was about 50% of Rn. This result is different from the results of Japanese grassland (Saigusa et al. 1998) which the ratio of LE to Rn was same between wet and dry year. This difference may imply that the Mongolian grassland is more sensitive for the difference of climate than the Japanese grassland where there is enough precipitation for the grass growth.

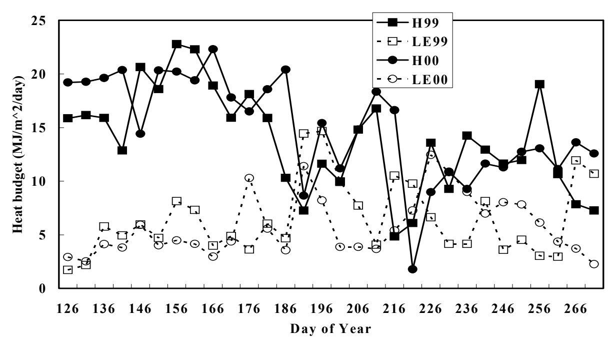

Fig.3 Comparison of 5-day mean sensible heat flux and latent heat flux values from May to September in 1999 and 2000.

Figures 4 (a) and (b) show the time series of 5-day cumulative values for each component (P, ET, and ΔW) of the water budget during the 1999 and 2000 growing seasons, respectively. Change in observed soil water content was used to calculate ΔW . The cumulative P before July was 96.7 mm and 60.7 mm in 1999 and 2000, respectively. The rain gauge using in Mongolia is Tretyakov type with wind shield and measured at 2m. The average catch ratios range from 81 to 97% for rain (Yang et al. 1995), which corresponds from 4.5 to 28.5mm when annual precipitation was 150mm. Therefore, the difference of cumulative P (36 mm) before July was significant. In 1999, cumulative ΔW gradually increased in May and abruptly increased from 4.7 to 20.7 mm following an increase in cumulative P; cumulative ΔW remained nearly zero until the end of July 2000. In mid-July 1999, cumulative ΔW reached an annual maximum of 27.1 mm when θ reached its annual maximum (cf., Fig. 2). In mid-August 2000, cumulative ΔW reached an annual maximum of 14.9 mm when θ was at its annual maximum (cf., Fig. 2). In 1999, averaged ET/P and ΔW /P during the GS were 0.79 and 0.15, respectively. In 2000, averaged ET/P and ΔW /P during the GS were 0.94 and 0, respectively. The water budget was thus not completely closed. The remaining water, however, is only about 5% of P, which is less than the uncertainty in evaluating evaporation and measuring P. Results suggest that about 15% of precipitation was stored in the soil layer, and approximately 80% evaporated in 1999, which resembled results from the mean value of the classical estimation of evaporation near Arvaikheer (Tuvedendorzh and Myagmarzhav, 1985), and Selenge river basin in Mongolia (Ma et al. 2003). In contrast, almost all P evaporated and little to no water was stored in the soil in 2000, which is similar to the highest value of Selenge river basin (Ma et al. 2003) and the characteristics of whole Mongolia (Natsagdorj, 2000).

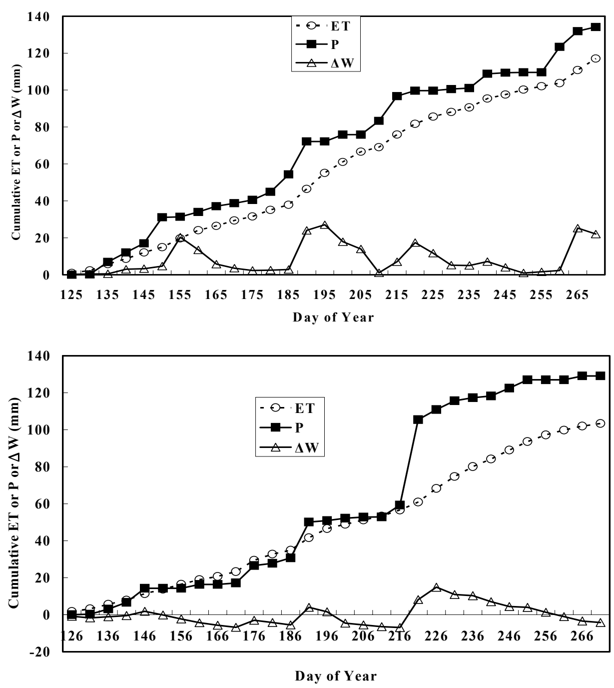

Fig.4 Time series of 5-day cumulative precipitation, evapotranspiration, and stored moisture values from May to September in (a) 1999 and (b) 2000.

4. Summary and remarks

In this study, we investigated the impacts of seasonal and interannual variability on vegetation as well as soil moisture and evapotranspiration over a grassland at Arvaikheer, central Mongolia. Correlations were determined for 19 years (1982-2000) of monthly mean LAI and climate data. The largest and significant correlation was found for P in July with LAI in July, which continued until September. Furthermore, significant correlation showed for P in May and LAI in June, P in June and LAI in June. In the composite analysis of H5 and L5, the significant positive anomalies of P (45.4 mm) in July and LAI in July (0.6) and August (0.6) were found, which was corresponded to the correlation analysis. It implies that the P in July had the largest impact for grass growth.

To study the physical processes of grass growth, we conducted a case study using energy and water budget data with hydro-meteorological elements from 1999 and 2000. In both 1999 and 2000, total precipitation during GS was almost same about 130 mm. However, the intra-seasonal distribution of rainfall was different. P in 1999 before July was about 70% of total P during GS while P in 2000 before July was about 40%. These intra-seasonal distribution of P caused the difference of the intra-seasonal variation of surface θ. The θ in upper 20cm in June and July 1999 was higher than in 2000. The LAI from June to September in 1999 was always larger than in 2000. These differences of surface conditions were closely related with the average ET between 1999 (1.3mm/day) and 2000 (0.7mm/day). In 1999, averaged ET/P and ΔW /P during the growing season were 0.79 and 0.15, respectively. In contrast, ET/P and ΔW /P during the growing season were 0.94 and 0, respectively. There was almost no stored water in the soil in 2000 because of low P frequency and the small P amounts in June and July 2000.

The results of this study suggest that grass growth in central Mongolia is influenced by P and ΔW before July. High amounts of P, provided after August, did not contribute to grass growth. Although this study focused on one site, it is the first study to examine physical processes related to seasonal rainfall variation and its impact on grass growth in central Mongolia. To generalize our results, we are conducting further analyses using LAI data and data from other stations.

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