Investigation for Photosynthetically Active Radiation Regime in the Mongolian Grain Farm Region

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Abstract

This article discusses common features of photosynthetically active radiation (PAR) in the Mongolian grain farm region during the period of 1986 to 1996. The quantitative characteristics of solar radiation, such as direct, diffuse and global radiation are evaluated in the study through the long term trend.

The mean pattern of seasonal variation of PAR shows that the yearly minimum global (direct + diffuse) PAR is 68.9 ± 7.6 MJ/(m² month) in December while the maximum is 307.5 ± 10.3 MJ/(m² month) in May. The yearly summation is 2.22 ± 0.07 GJ/(m² yr) and is very stable compared with monthly variations.

Key words: Solar radiation, PAR, Mongolian grain farm region, Mongolian grassland.

1. Introduction

Solar radiation is one of the primary factors affecting plant growth and metabolism. Plants utilize atmospheric gases to create organic substances through the photosynthetic process. This report uses the term Photosynthetically Active Radiation (PAR), where the wavelength is within the spectral range of 380–710 nm. To determine the major characteristics of photosynthetic productivity, monthly and yearly amounts of PAR were determined for the grain farm region of Mongolia. Additionally, the phenomenon of PAR flux was investigated. As the Mongolian harvest is especially sensitive to the variation of PAR amounts, this study is important for Mongolian agriculture.

Mongolian agriculture is strongly dominated by the geographical location and its climate. Spring and summer seasons have a long daytime and sunshine, while winter has a short day time but almost all clear days due to high pressure systems. The study is complicated by the fact that the physiological

diversities of plants are determined by the Mongolian climate and weather patterns. It is imperative to gather data on these physiological plant processes, yet data on this point has been insufficient.

In this study, we used investigative data at the Ughtaal Solar Station (48° 3' N, 105° 25' E, 1160 m above the mean sea level), which is located in the central agricultural zone of Mongolia. The average features of Ughtaal include a yearly mean temperature of -1.4°C and 249 mm a year in precipitation, computed from the last 30 years of meteorological data. Land is covered with snow for 157 to 161 days a year. The vegetation period is limited to 92 to 128 days a year.

Data were collected at the station for every hour in the daytime during 1986–1996. In order to measure the PAR received at the earth's surface, a thermo-electric actinometer (AT-50) was mounted. This instrument has two filters (BS-8, KS-19), which can selectively pass only PAR (Batsukh *et al.*, 1982). The direct radiation in the full wavelength and the direct PAR can be obtained by the filter operation, manually. We simultaneously measured diffuse radiation using a thermo-electric pyranometer (M-80M)

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with a black and white type sensor. With this instrument, the global and diffuse radiation can be observed with and without a shadow disk for direct solar flux (Tugjsuren, 1996).

2. Direct Photosynthetic Active Radiation (SPAR)

The PAR portion of daily-integrated radiation depends on the spectral content of two kinds of radiation, direct and diffuse radiation. The global radiation can be expressed by the summation of both types of radiation. Maximum energy in the spectrum of direct solar radiation is center around 480–550 nm at the highest solar elevation angle, and moves to longer wavelengths as solar altitude decreases, due to scattering by atmospheric particles.

The portion of SPAR in direct solar radiation flux changes depending on not only solar altitude, but also absorption gases, and aerosol amount in the cloud-free atmosphere as well as cloud amount in the cloudy atmosphere. For PAR flux changes, conversion coefficients from the whole solar radiation spectrum at the surface to the PAR may be evaluated in limited use. The first estimate of conversion coefficient C_s from the direct radiation in the whole spectrum to the corresponding SPAR is derived from the theoretical spectral distribution of radiation. C_d and C_q can be defined as conversion coefficients for diffuse and global solar radiation in a similar way. These coefficients have also been determined experimentally by many researchers for different climatic-geographical areas (e.g., Batsukh, 1989; Batsukh *et al.*, 1988).

While C_s is dependent on solar elevation angle in general, as pointed out by Tooming (1977), an effective conversion coefficient C_{sef} can be defined as the ratio of the daily and/or monthly means of SPAR to those in the whole wavelength by actinometric measurements:

$$C_{sef} = \frac{\sum S_{ph}}{\sum S},$$

where S and S_{ph} are daily- or monthly-integrated direct solar radiation and SPAR, respectively. In a similar manner, effective conversion coefficients of diffuse and global radiation are defined by the following formulas;

$$C_{qef} = \frac{\sum Q_{ph}}{\sum Q},$$

$$C_{def} = \frac{\sum D_{ph}}{\sum D},$$

Fig. 1. The monthly variation of effective conversion coefficients, C_{sef} , C_{def} , and C_{qef} , which are ratios of direct, diffuse and global PAR to the corresponding solar radiation flux in the whole wavelength, respectively.

$$\begin{aligned}\sum Q_{ph} &= \sum D_{ph} + \sum S_{ph}, \\ \sum Q &= \sum D + \sum S.\end{aligned}$$

In these equations, variables D and Q denote diffuse and global solar radiation, and the suffix ph means the spectrum region for active photosynthetic radiation. Researchers have found methods for determination of coefficients C_s , C_d , C_{def} , C_q , C_{qef} (Tooming, 1977; Batsukh, 1989; Batsukh *et al.*, 1982). For example, Efimova (1977) determined average values of $C_s=0.43$, $C_d=0.57$ theoretically. Tooming (1977) and our investigation can provide these values of C_{sef} , C_{def} and C_{qef} , which are estimated from experimental data.

Figure 1 shows the seasonal trends of these coefficients derived from Ugtaal data during the period of 1986–1996. The conversion coefficient, C_{sef} , of direct solar radiation has a relatively large variation of 0.30–0.41 in the mean seasonal trend. This is reflected by the fact that the direct solar radiation is more sensitive to the solar and atmospheric condition compared with other coefficients.

From our investigations, it was shown that yearly input of SPAR at territory Ugtaal under normal conditions ranges from 926.4 to 1,149.8 MJ/(m²yr), as seen in Table 1. Despite the relatively constant amount of solar energy received at the earth's surface annually, its quantitative amounts for a monthly mean are significantly changeable.

Table 1. Monthly integrated Direct Photosynthetically Active Radiation (SPAR; MJ/(m² month)) during the period of 1986–1996 at Ugtaal in Mongolia. “Sum” means the summation of monthly amount for a year, and “average” and “Std dev” are the average and standard deviation during the period for month and “Sum”.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Sum
1986						127.4	142.6	133.2	107.3	72.0	43.6	27.4	(653.5)
1987	30.6	60.5	101.9	107.6	127.1	134.6	127.8	111.2	108.4	70.6	39.6	23.8	1,043.7
1988	29.9	59.0	99.7	106.2	131.0	137.2	142.6	133.9	108.0	71.3	42.1	23.0	1,083.9
1989	39.2	58.3	90.0	128.9	128.5	155.5	114.1	126.7	99.0	70.9	44.1	30.0	10,85.2
1990	43.9	57.9	85.1	144.7	151.5	135.7	137.0	84.6	115.6	95.4	54.4	44.0	1,149.8
1991	47.3	73.1	94.7	139.7	162.4	127.4	136.4	119.2	61.9	81.4	38.2	16.9	1,098.6
1992	39.4	57.1	69.2	98.6	123.3	164.6	136.7	82.9	64.6	71.1	21.3	25.3	954.1
1993	20.0	47.3	89.1	128.3	138.3	106.7	72.4	92.2	74.4	89.6	49.6	18.5	926.4
1994	41.0	66.3	98.0	128.6	162.7	112.7	110.1	112.2	98.8	90.5	49.9	20.5	1,091.2
1995	42.9	67.1	99.0	130.3	159.5	127.0	114.2	113.2	97.4	90.1	48.8	21.1	1,110.6
1996	40.1	66.7	100.1	138.4	160.4	134.5	115.1	111.4	109.1	88.2	49.0	22.2	1,135.2
Average	37.4	61.3	92.7	125.1	144.5	133.0	122.6	111.0	95.0	81.0	43.7	24.8	1,067.9
Std dev	8.2	7.2	10.0	15.7	16.4	16.5	20.7	17.8	19.0	10.0	8.9	7.4	73.5

A specific feature of seasonal variation of SPAR has mean values of 24.8 MJ/(m² month) in December as a minimum and 144.5 MJ/(m² month) in May as a maximum during the period of 1986–1996. The maximum values are 162.7–164.6 MJ/(m² month) observed in May or June. The minimum value of SPAR is 16.9 MJ/(m² month) in December. From winter to summer, SPAR increases relatively fast, especially from February to April. Generally, due to the solar elevation increasing towards the summer solstice, SPAR should increase until June, but the peak SPAR has been in May due to the climatic conditions in Mongolia. A sharp decrease of SPAR is also shown in September to November.

3. Diffuse Photosynthetically Active Radiation (DPAR)

The atmosphere is non-transparent due to many kinds of suspended material, which consists of molecules, different types of aerosols and other bigger particles, such as cloud particles, rain droplets or snow/ice particles. Downward diffuse radiation at the surface depends basically on these atmospheric constituents and surface albedo in some cases.

The DPAR flux under whole atmospheric conditions shows 163.5 MJ/(m² month) in May as the mean maximum and 41.1 MJ/(m² month) in January as the mean minimum during 1986–1996. The peak value is 182.0 MJ/(m² month) in May, while 31.1 MJ/(m² month) in January is a minimum level, as shown in Table 2.

It may be said that natural aerosols increase in

spring and autumn in Mongolia, with relation to dust and sand storms, while strong cloud developments are dominant in summer. The cloud particles consisting of water droplets or ice crystals, are effective scatterers of solar radiation. Specifically, strong scattering and small absorption by clouds are sometimes connected with upper-level or well-developed clouds. Middle layer clouds can also affect this process. Naturally, the measured flux of diffuse radiation must depend on cloud amount and its inhomogeneity. Transition of stratus to nimbostratus cloud may cause an increase in ratio of diffuse radiation.

Comparatively, high value of the surface albedo can be observed in winter due to snow cover. Multiple scattering between the surface and the atmosphere is enhanced for high surface albedo, causing an increase in diffuse radiation. This effect may appear in DPAR observed from November to March in territory Ugtaal. In this region, a heavy sand-storm, like a yellow-sand event in the far-east Asia happens sometimes from March to May, so that the DPAR may increase as shown in Fig. 2.

4. Global Photosynthetically Active Radiation (QPAR)

Global solar radiation is one of the most essential factors for vegetation. Results of the investigation show that a mean value of integrated solar radiation over all wavelengths at Ugtaal for 11 years (1986–1996), is 4.4–4.7 GJ/m² for the whole year, and 2.3–2.7 GJ/(m² yr) for the vegetation period (May–Sep-

Table 2. Same as Table 1 except for Diffuse Photosynthetically Active Radiation (DPAR; MJ/(m² month)).

Month	1	2	3	4	5	6	7	8	9	10	11	12	Sum
1986						158.4	151.9	137.5	96.5	74.9	50.0	42.1	(711.3)
1987	45.0	59.8	106.2	136.8	172.1	159.1	151.9	132.1	95.0	75.2	48.9	39.2	1,221.3
1988	46.1	62.3	120.2	133.9	172.4	160.2	153.7	136.1	95.0	75.2	49.3	45.0	1,249.4
1989	38.9	49.3	96.8	111.6	162.4	141.8	149.0	117.4	89.3	59.8	46.3	40.2	1,102.8
1990	37.1	54.0	88.4	96.5	169.9	147.2	125.3	125.6	82.8	61.2	50.0	46.7	1,084.7
1991	35.9	50.4	108.7	126.4	153.0	156.2	128.5	114.1	93.9	70.2	48.2	48.2	1,133.7
1992	51.9	67.8	121.4	161.7	182.0	147.6	139.4	132.4	93.9	73.5	61.1	43.2	1,275.9
1993	50.5	70.9	117.1	130.8	163.6	146.6	142.5	108.9	90.7	55.4	49.1	44.9	1,171.0
1994	34.4	41.9	94.5	106.3	157.3	139.4	148.8	130.2	90.5	60.1	50.5	46.4	1,100.3
1995	31.1	44.1	91.1	110.0	150.5	127.1	137.2	109.1	90.7	59.8	50.7	46.3	1,047.7
1996	40.0	51.2	100.2	111.2	151.4	138.5	142.4	132.6	91.2	60.0	49.9	43.0	1,111.6
Average	41.1	55.2	104.5	122.5	163.5	147.5	142.8	125.1	91.8	65.9	50.4	44.1	1,149.8
Std dev	7.0	9.7	12.2	19.1	10.6	10.4	9.6	10.8	3.8	7.8	3.8	2.8	76.3

Fig. 2. Yearly-averaged QPAR and DPAR (MJ/(m² month)) for each month during the period of 1986–1996 at Ugtaal in Mongolia.

tember).

There are wide and integrated data archives on geographical distribution of daily, seasonal and yearly global radiation in China and Russia surrounding the Mongolian territory. This approach can fill up a white map of Mongolia with the complementary data.

Due to a difference of daytime duration of 1.6–1.9 times between winter and summer for all Mongolian areas, monthly QPAR increases around 3–4 times. For example, according to our data in Ugtaal, daytime duration increases from 260 h in December to 481 h in July. In connection with such an increase of daytime duration, an incoming QPAR changes in Ugtaal from 68.9 MJ/(m² month) in average in December to 307.5 MJ/(m² month) in average in May,

as shown in Table 3.

A rapid increase of monthly QPAR is also seen from February to May in Fig. 2, while a steep decrease starts from August. The maximal QPAR in average usually appears in May, but there are exceptional cases (See the data, 1989 and 1992) where the maximal month moves from May to June. The main reason for the shift of maximum QPAR may be the variation of cloudiness.

Table 3 shows that the annual variation of yearly-integrated QPAR is quite stable (2.22 ± 0.06 GJ/(m² yr)) compared with the SPAR (1.07 ± 0.07 GJ/(m² yr)). However, the monthly variation of SPAR for each year has a wide range from 11% in May to 30% in December. The stable input is very favorable for plant growth.

After Mt. Pinatubo's eruption (June 15, 1991), the volcanic dust extended from the tropical region to the polar region for several months. This effect to the PAR should be checked carefully, because the El Nino happened in the same period of April 1991–September 1992. Pinatubo's effect might be possibly overlaid and/or mixed with the El Nino effect, but the global modification of cloud pattern due to the change of the atmospheric circulation system is not clear. Pinatubo's effect in Mongolia may be mainly due to an increase in the stratospheric aerosols, while the El Nino can modify the cloud pattern through an increase or decrease in the circulation system. The basic difference between them, i.e., aerosol or cloud effect, may appear in the difference in the trend of SPAR and QPAR. Figure 3a shows the large fluctuation during the period of 1991–1993 for the monthly data. Since the SPAR is attenuated directly

Table 3. Same as Table 1 except for Global Photosynthetically Active Radiation (QPAR; MJ/(m² month)).

Month	1	2	3	4	5	6	7	8	9	10	11	12	Sum
1986						285.8	294.5	270.7	203.8	146.9	93.6	69.5	(1,364.8)
1987	75.6	120.2	208.1	244.4	299.2	293.8	279.7	243.4	203.4	145.8	88.6	63.0	2,265.2
1988	75.9	121.3	219.9	240.1	303.5	297.4	296.3	270.0	203.0	146.5	91.4	68.0	2,333.3
1989	78.1	107.6	186.8	240.5	287.3	297.4	263.2	244.1	188.3	130.7	90.4	70.2	2,184.6
1990	81.0	111.9	173.5	241.2	321.4	282.9	262.3	210.2	198.4	156.6	104.4	90.7	2,234.5
1991	83.2	123.5	203.4	266.0	315.4	283.7	264.9	233.3	155.9	151.6	86.4	65.2	2,232.5
1992	82.8	124.9	190.6	260.3	305.3	312.2	276.1	215.3	158.5	144.6	82.4	68.5	2,221.5
1993	70.5	118.2	206.2	259.1	301.9	253.3	214.9	201.1	165.1	145.0	98.7	63.4	2,097.4
1994	75.4	108.2	192.5	234.8	320.0	251.1	258.9	242.4	189.3	150.6	100.4	66.9	2,190.5
1995	74.0	111.2	190.1	240.3	310.0	254.1	254.1	222.3	188.1	149.9	99.5	67.4	2,158.3
1996	80.1	117.9	200.3	249.6	311.3	273.0	257.5	244.0	200.3	148.2	98.9	65.2	2,246.8
Average	77.7	116.5	197.1	247.6	307.5	280.4	265.7	236.1	186.7	146.9	94.1	68.9	2,216.5
Std dev	4.1	6.3	13.1	10.6	10.3	20.4	22.2	22.6	18.4	6.4	6.8	7.6	64.0

by aerosols and cloud, the fluctuations in the period must be affected by an increase of these suspended particles. If the cloud amount and its optical thickness are increasing over the usual level, the amount of QPAR should be decreasing except for optically thin cloud cases. In the case of aerosol, its effect is a little different from clouds, because the increase in DPAR can compensate for the decrease in SPAR.

Figure 3 b shows no remarkable decrease in QPAR during this period except for September, compared with Fig. 3 a. This tendency of QPAR might suggest that the fluctuation of SPAR is caused by an increase in aerosol. Pinatubo's effect over Japan after several months was estimated at about 0.15–0.20 in optical thickness at $0.53\mu\text{m}$ (Takamura *et al.*, 1994). This is in accordance with the attenuation of SPAR. However, as an optically thin cloud such as cirrus has a similar effect, it is difficult to separate both effects completely only from these parameters.

The start and end time of the vegetation period is a quite important parameter for agriculture. The vegetation in Mongolia becomes active when the mean air temperature exceeds 5 degrees. The decisive factor for active vegetation is not only a latitudinal location but also altitude, with a decrease by 6.5 K in average temperature for each km increase in altitude. The QPAR is basically independent of altitude, but the growth process of plants is strongly controlled by QPAR and environmental temperature as well as water.

The geographical conditions of Mongolia show a continental climate type due to location and elevation (more than 80% of territory is located at 1,000 m or higher). Therefore, the duration of vegetation

Fig. 3. Long term trend of monthly SPAR (a) and QPAR data (b). The SPAR is more sensitive to atmospheric conditions such as aerosol or cloud loading, than the QPAR.

Fig. 4. Comparison of QPAR between Ugtaal and the neighboring Asian region. Both places are at the same latitude, but have different altitudes.

period is relatively shorter than that in neighboring countries, where the mean altitude is much lower than the Mongolian territories.

For comparison, Figure 4 represents monthly trends of QPAR at territory of Ugtaal and Asian territory of the former USSR (now in Russia), placed at almost the same latitude, but about 800 m in altitude. The yearly integration of QPAR in Ugtaal ($2,217 \text{ MJ}/(\text{m}^2 \text{ yr})$) is almost the same as that of Asian territory ($2,271 \text{ MJ}/(\text{m}^2 \text{ yr})$), but the difference in vegetation period is larger. It should be noted that the QPAR is one of the most important factors for vegetation, and also the altitude of land should be considered for vegetation activities. Plant growth is very sensitive to differences in temperature due to altitude, especially where the mean temperature is below freezing.

5. Summary

(1) The mean yearly input of direct PAR (SPAR) at the territory of Ugtaal is $1,067.9 \text{ MJ}/(\text{m}^2 \text{ yr})$ with a variation of 926.4 to $1,149.8 \text{ MJ}/(\text{m}^2 \text{ yr})$ through the observation period of 1986–1996. One of the specific features of seasonal trends of SPAR shows that the maximal and minimal input during

the observation period are in May as 144.5 ± 16.4 and in December as $24.8 \pm 7.4 \text{ MJ}/(\text{m}^2 \text{ month})$, respectively.

(2) The maximal peak of diffuse PAR (DPAR) shows $163.5 \pm 10.5 \text{ MJ}/(\text{m}^2 \text{ month})$ in May during the period. This may be due to sand storms in this season. The minimal DPAR is $41.2 \pm 7.0 \text{ MJ}/(\text{m}^2 \text{ month})$ in January in the same period.

(3) Monthly input of global PAR (QPAR) at the territory of Ugtaal varies from $68.9 \pm 7.6 \text{ MJ}/(\text{m}^2 \text{ month})$ in December to $307.5 \pm 10.3 \text{ MJ}/(\text{m}^2 \text{ month})$ in May. Yearly input of QPAR is $2.2 \text{ GJ}/(\text{m}^2 \text{ yr})$ and very stable within a standard deviation of 2.9% during the period.

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モンゴル穀物生産地域における光合成有効放射量の計測

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要 約

モンゴルの穀物生産地域で、1986年から1996年までの11年間にわたって、光合成有効放射量(PAR)の測定が行われた。この期間の、直達、散乱、全天日射量(直達+散乱)の月積算量の解析が行われ、この地域における光合成有効放射量の季節的、経年的な特徴が明らかにされた。

その結果、この観測期間の平均として、全天日射量の

月平均の最小は12月で $68.9 \pm 7.6 \text{ MJ}/(\text{m}^2 \text{ month})$ 、最大は5月で $307.5 \pm 10.3 \text{ MJ}/(\text{m}^2 \text{ month})$ である。年間の積算量は、 $2.22 \pm 0.07 \text{ GJ}/(\text{m}^2 \text{ yr})$ であり、月平均の経年的変動に比べて、年積算量は経年的にかなり安定していることがわかった。

キーワード: 日射量, 光合成有効放射量, モンゴル穀物生産地域, モンゴル草原