CHARACTERISTICS OF DIURNAL PATTERN OF GLOBAL PHOTOSYNTHETICALLY-ACTIVE RADIATION AT ILORIN, NIGERIA

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(Submitted: 30 August, 2006; Accepted: 5 October, 2006)

Abstract

A two year data (September 1992 August 1994) on photosynhetically-active radiation (PAR) measured at Ilorin (Lat.: 8°32′N. Long.: 4°34′E) using LI-190SA quantum sensor are analysed both on daily and monthly mean diurnal bases. This was done with the aim of characterizing the diurnal pattern of this radiation at this location. The typical climatic days chosen were clear, cloudy, partly cloudy and Harmattan days, as defined by clearness index. The result shows that the pattern, whether on daily or monthly basis, varies greatly depending on the atmospheric conditions. The amplitude of variation of the monthly mean diurnal flux could be divided into two distinct groups: the larger ones are associated with months when the atmosphere has less cloud and the Harmattan dust spell is either just setting in or clearing off (February, March, April, October and November) while the smaller amplitudes are associated with cloudy and turbid months (May-September, December and January). The month with highest flux at maximum was March while the lowest was in August. The diurnal pattern shows that crops at Ilorin have a high potential for PAR utilization anytime of the year except, probably, in the months of July and August, provided other necessary conditions for plant growth are favourable.

Keywords: *Diurnal pattern, photosynthetically-active radiation, Ilorin*

Introduction

For a number of applications, it is essential to determine the photosynthetically-active radiation (PAR) available at a given moment above plant canopies. Crop growth modeling requires accurate photosynthesis estimation and thus, intercepted light is a fundamental parameter in any photosynthesis algorithm. Incident PAR is required to estimate intercepted light for the purpose of modeling photosynthesis of single plant leaves or complex plant communities (Papaionnou, 1993). PAR is also one of the important components of microclimate critical for forest regeneration (Chen *et al.*, 1993). Therefore knowledge of the temporal and spatial fluctuations of global PAR or its components incident over the surface of the Earth is of fundamental importance.

Although daily total irradiation or its mean is important, it is not always the most appropriate figure to characterize the potential utility of PAR. Hourly values or shorter intervals and hence the diurnal patterns of PAR allow us to derive very precise information about efficiency of photosynthetic systems. Hence detailed study of daily and hourly PAR under local climatic conditions have been carried out at various places (eg. Stanhill and Fuchs, 1977; Stigter and Musabilha, 1982; Howell *et al*, 1983: Nathan, 1984; Nagaraja Rao, 1984; Karalis, 1989; Slomka, 1989: Papaioannou *et al*, 1993). However, the portion of PAR in the solar spectrum is not routinely measured in Nigeria as no such data have yet been reported for any location in Nigeria.

In this paper, the diurnal pattern for typical climatic days and monthly mean of hourly irradiance are presented and analysed. The effects of the changing seasons on the pattern are discussed. This is with the aim of completely characterizing global PAR (diurnally) at this location so as to enable workers and researchers in this sector know its potential. The findings and conclusions here will also be useful at other places with similar agro-climatic conditions. The seasonal variation (in terms of daily and monthly mean of daily values) of this radiation is described in Udo and Aro (1998). Similar analyses had been done for global solar radiation (Udo and Aro, 2000) and downward infrared radiation (Udo,

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2004), which were the other radiation components measured at this location.

2. Materials and Methods

The instrument used in measuring global PAR was LI-190SA quantum sensor (Model-Licor). It measures PAR in the 400-700nm waveband. The recording instrument was a data logger (CR10, Campbell Scientific Ltd. Logan, UT, USA) complete with a storage module. The signals were later conditioned with the instrument factor into the unit of $\mu Em^{-2}s^{-1}$ (this unit is based on the fact that photosynthetic efficiency of green plants is proportional to the number of photons absorbed in the spectral range 400-700nm, and not to their energy). Although the data were recorded at 3 minutes interval, hourly averages were calculated for all data. The data were recorded for a period of two years (September, 1992-August, 1994) and were therefore grouped into two annual sets data (January-December, 1993, and September-December, 1992 plus January August, 1994). Since the data are analysed on daily or monthly basis, the method of dividing the data is not important. The instrument was calibrated at the beginning and end of data taking. Details concerning the instrument and other instruments mounted on the same radiation station are given elsewhere (Udo and Aro, 1998; Udo, 2002). The analysis is based on data taken between 7.00 and 19.00 hours, local standard time (LST). It is conservatively estimated that measured values of the hourly photon flux are accurate to within ± 5%.

3. Brief Geography of the Site

Ilorin, is about the mid point of Nigeria with coordinates: Latitude: 8°32′N; Longitude: 4°34′E; Altitude: 375m. The prevailing winds in Nigeria and hence Ilorin are the South-Westerly (SW) and North-Easterly (NE) trade winds. The SW wind blows from Atlantic Ocean and brings rain to West African coast, including Nigeria from about April to October this is the rainy season period. The NE wind, blows across the country between November and March bringing the Harmattan dust with it this is the dry season period. Dry season at Ilorin is made up of two distinct groups: (i) the Harmattan period (mainly months December and January) when the cold and dust laden North-Easterly trade wind from the Sahara desert keeps the atmosphere over Ilorin and its environs heavily overcast for days, with characteristic hazy and cloud free weather conditions, (ii) the cloud and dust-free period (November, February and March) of mainly high irradiation and clear weather conditions.
Details of the geography of the site are found elsewhere (Udo and Aro, 1999). Information given above is however enough to enable us explain the diurnal pattern of PAR at this location.

4. Results and Discussion

4.1 Typical climatic days

The diurnal patterns for typical climatic days are presented in Fig.1. The selected days were: 18/05/93 (clear day, K_T = 0.68), 20/09/92 (cloudy day K_T = 0.12), 13/09/92 (partly cloudy day, K_T = 0.36) and 9/12/92 (Harmattan day, K_T = 0.37). The indicated K_T values are those of clearness indices. Clearness index is the ratio of daily global solar radiation to daily extraterrestrial radiation: it gives the percentage depletion by the sky of the incoming global radiation and therefore indicates both the level of availability of solar radiation and changes in the atmospheric conditions in a given locality. The figure shows that (i) on a typical clear day, the daily photon irradiation (area under the curve) can be as high as $53.5Em^{-2}$ against 9.4 Em^{-2} (only 17.6% of the clear day value) obtained on a typical cloudy day. A typical partly cloudy and Harmattan days values of 28.4 and $23.4Em^{-2}$ are 50.1 and 43.7% respectively of the clear day value. (ii) The diurnal patterns vary from the smooth nature, half-sinusoidal with definite maximum point of occurrence on a clear day to shapeless, uneven curves with no definite maximum point of occurrence on especially partially cloudy day. If the day is uniformly cloudy or with Harmattan dust throughout, the pattern is expected to be same as that of a clear day, although with a reduced maximum.
The occurrence of clear days and very cloudy days at Ilorin is very rare (Udo, 1997). For the two year period, only 11 days were K_T 0.65 and only 23 days were K_T values found to be between 0.12 and 0.24. These values for cloudy days are much higher than the generally accepted values (0.05) for overcast sky conditions. This indicates that inspite of the generally cloudy conditions in Ilorin, the skies are hardly overcast the whole day. The highest observed instantaneous (hourly) photon flux was $2112.7\mu Em^{-2}s^{-1}$ on April 11, 1993 at 15:00 hrs, LST. This value is expected to be higher if the data were analysed on a shorter time interval. The very high instantaneous intensity is due to reflection and refraction of sunlight by cloud particles in the air (Othman *et al*, 1993). This explanation is

likely because the occurrence of this type of radiation climate is always on partly cloudy day.

4.2 Monthly mean diurnal pattern

Figure 2 shows the monthly mean diurnal pattern for each month of the two year period and the average. The maximum for each month was at 13:00 hrs, LST (about solar noon) as expected except in the months of June (1993 and 1994) and September and October (1992) where the maximum occurred at 14:00 hrs. The seeming anomaly in these months are probably due to convective cloudiness which normally occurs about solar noon and disappears in the afternoon. A similar explanation was given by Kasten (1983) in Germany, although his was for global solar

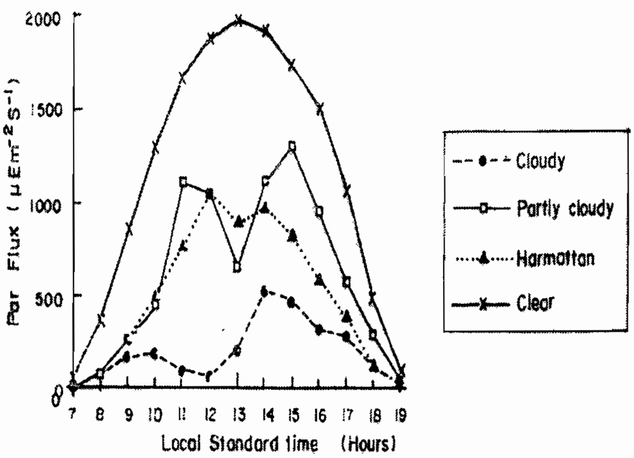

Fig. 1: Diurnal pattern of PAR for typical climatic days

radiation; after all, PAR is a component of global solar radiation.

Figure 2 shows that, generally, in the months of February, March, April, October and November when the atmosphere has less cloud activity and the Harmattan dust spell is either just setting in or clearing off, the amplitudes of variation are larger. Hence the amplitude variation observed from month to month could be divided into two distinct groups: the smaller amplitudes could be associated with the variations during the cloudy and turbid months (May-September and, December and January) while the larger ones are associated with less turbid and cloudy months. Here, therefore, lies the seasonal effect on the distribution of PAR at Ilorin. Additionally, the effect of clouds are observed to have even out, leaving the variations as smooth half-sinusoidal curves. On the average, the highest maximum flux was in March while the lowest was in August.

Figure 2 also shows that at Ilorin, on the average, crops have high potential for PAR utilization at anytime of the day and for any month as the fluxes are generally greater than 200μEm^{-2}s^{-1} except in the early morning (7:00-8:00 hrs) and late evening (18:00-19:00 hrs) times. Hence, crops can be grown at nay time of the year provided other conditions like soil moisture content and temperature are favourable, except, probably in the moths of July and August.

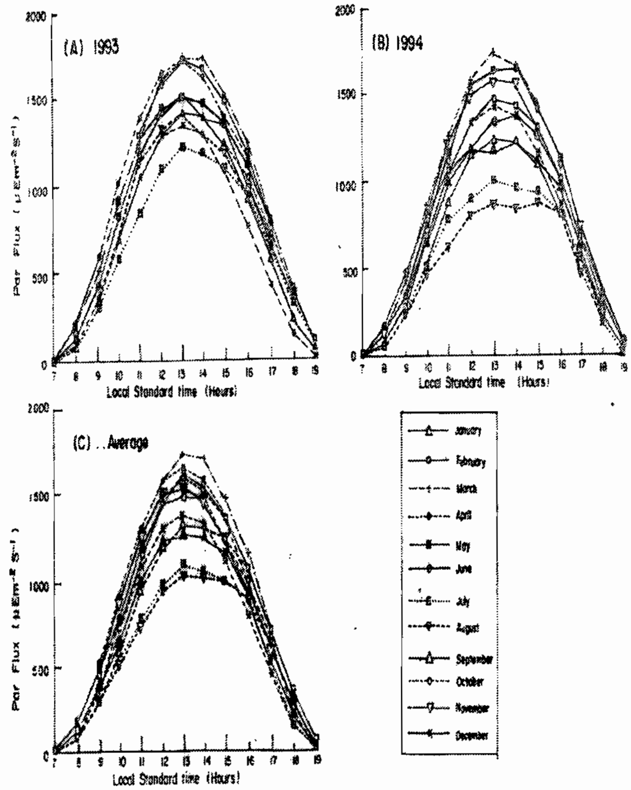

Fig. 2: Monthly mean diurnal pattern of PAR

5. Conclusion

The diurnal variation of PAR at Ilorin shows that it varies from time to time depending on the atmospheric conditions. The difference between the pattern on different climatic days is remarkable. For example, the pattern varies from the smooth nature, half-sinusoidal with definite maximum of occurrence on a clear day to shapeless, uneven curves with no definite maximum point of occurrence on especially partly cloudy day.

The amplitude of variation of the monthly mean diurnal flux could be divided into two distinct groups: the smaller amplitudes being associated with cloudy and turbid months while the largest ones are associated with less cloudy and turbid months.

Due to reflection and refraction from cloud tops, abnormally high photon flux is not unexpected at Ilorin especially on partly cloudy days.

The diurnal pattern of PAR whether on daily or monthly mean basis shows that Ilorin has a high potential for PAR utilization and hence crops can be grown at any time of the year provided other necessary conditions are favourable.

Acknowledgements
The authors are grateful to Prof. R. T. Pinker, Dr. F. Miskolezi (both of the Department of Meteorology, University of Maryland, USA) and Mr. M. Isiomon (Department of Physics, University of Ilorin, Nigeria) for their invaluable contributions especially in facilitating the measurement of these data.
The analysis was carried out using computing facilities at both the Department of Applied Physics and Electronics, and Manufacturing Engineering, University of Dundee, Scotland and Department of Physics, University of Ilorin, Nigeria.

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