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EDDY COVARIANCE MEASUREMENT OF CO_2 CONCENTRATION AND TURBULENT FLUX ABOVE COWPEA (VIGNA UNGUICULATA [L.] WALP) AT AN AGRICULTURAL SITE IN ILE-IFE, NIGERIA

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ABSTRACT

This study investigated Net Ecosystem Exchange (NEE) over a leguminous plant, cowpea (Vigna unguiculata [L.] Walp) at an agricultural site in Ile-Ife, Nigeria, monitored during two transition seasons: dry-to-wet (March - June) and wet-to-dry (August - November) in 2015. Measurements of carbon dioxide (CO_2) concentration and turbulent flux were made by eddy-covariance (EC) technique alongside Photosynthetically Active Radiation (PAR) and net radiation. Physiological parameters (e.g., Leaf Area Index, plant height and surface albedo) were observed throughout the growth stages of the plant from emergence to senescence. High levels of CO_2 mass concentrations, 850.0 mgm^{-3} - 1200.0 mgm^{-3}, were found during the nighttime periods which are adduced to increased soil and plant respirations. In the late afternoons, around 1500 hrs LT, pronounced minima with values of about 650.0 mgm^{-3} were recorded. The drop in the observed value of CO_2 concentration during the daytime is largely due to photosynthetic activity which increases as PAR values increase. The intensity of PAR (maximum value recorded was about 1800 Wm^{-2}) is a dominant factor responsible for the depletion of CO_2, from emergence to senescence. Based on the net production of CO_2 at the study site, it can be concluded there was an uptake of carbon by the cowpea, irrespective of the developmental stage of its growth.

Keywords: Cowpea (Vigna unguiculata [L.] Walp), developmental stages, CO_2 concentration and flux, Net Ecosystem Exchange, seasonal transitions.

INTRODUCTION

Plants utilize carbon dioxide (CO_2) for photosynthesis in the daytime in order to manufacture their food. The rate at which this is achieved by plants is largely dependent on the fraction of the Photosynthetically Active Radiation (PAR) reaching their surfaces (Kelly et al., 2002). Variation of CO_2 over different plants in an ecosystem exchange depending on the time of the day, is significant in determining the efficiency of PAR as it is being converted for CO_2 utilization.

The available CO_2 fluxes differ for different ecosystems because of different plant coverage and different photosynthetic strengths. Therefore, the daytime concentration of CO_2 available for a plant in a field may depend on the rates of net photosynthesis and net soil respiration, CO_2 in the surrounding air, and the rate of turbulent transport of CO_2 from the surroundings (Brown and Rosenberg, 1970; Merbold et al., 2011; Jacobs et al., 2003). These factors regulate the available CO_2 concentration and fluxes at nighttime except that respiration prevails.

Studies have shown that plants differ from each other with respect to their contribution to the CO_2 exchange, and based on year-round CO_2 exchange measurements, legume fields (such as soybean, cowpea etc.) have been observed to act as net sources for atmospheric CO_2 (Baker and Griffis, 2005; Gebremedhin et al., 2012; Gilmanov et al., 2010, 2013; 2014). Therefore, mass quantification of the CO_2 exchange in a tropical area like Nigeria as observed for both daytime and nighttime conditions, and the environmental parameters leading to its variation will be of benefit to researchers. Particularly, this will help agronomists in the determination of efficiency for conversion of PAR by cowpea (Vigna unguiculata) for CO_2 utilization (Zhangye et al., 2015).

Cowpea (Vigna unguiculata [L.] Walp) is an ancient economically important leguminous plant widely grown and consumed in West Africa. It is a C_3-pathway carbon fixing plant. It has been observed to respond to increased CO_2 with increased photosynthesis and growth than other plants (Rogers et al. 2006, 2009). Cowpea is known for its high protein content (Afiukwa et al., 2013; Ogbonnaya et al., 2003; Asante et al., 2006). It maintains soil fertility through its excellent capacity to fix atmospheric nitrogen and thus, does not require very fertile land for growth (Abayomi et al., 2001; Abayomi and Abidoye, 2009; Lobato et al., 2008; Peksen and Artik, 2004).

In this study, eddy covariance measurements of CO_2 (its concentration and fluxes) have been made above cowpea at an agricultural site in Ile-Ife, Nigeria covering two weather transitions: (i) dry-to-wet (March - June), and (ii) wet-to-dry (August - November) in the region. The aim was to determine whether the net ecosystem exchange (NEE) for carbon dioxide over cowpea results in a net source or sink of carbon irrespective of the season during the developmental stages of its growth. In addition, efforts were made to determine the efficiency of conversion of PAR by cowpea with regards to the magnitudes of CO_2 concentration and fluxes at the study site.

MATERIALS AND METHOD

The study site was inside the Teaching and Research Farm of Obafemi Awolowo University (TRF-OAU), Ile-Ife (7.52°N; 4.52°E; 296 m). It is located in a low wind area, and about 7 km from the main campus (Jegede et al., 1997). It has a dimension approximated 1500 m by 300 m. It is open and level terrain with different varieties of arable crops like maize, cassava, water melon and fruits. It is a dense canopy area with a few scattered trees. The soil is characterized by loamy-clay from the top (0-10 cm) to the bottom. There are also offices and facility buildings for the use of staff members available at the site. The study area is approximated 60 m by 45 m. Three separate short masts (1.5 m, 1.6 m and 2.2 m tall, respectively) were installed at the site as shown in the Fig. 2. The eddy covariance system mounted on a 2.2 m tall mast comprised: an ultrasonic anemometer (model CSAT3), an open-path Li-COR infra-red gas analyzer (model LI- 7500) and a temperature–humidity sensor (model HMP60, Vaisala) which were placed at 2.0 m above the ground surface, sampled the turbulent parameters (see Table 1). Wind speed was measured along the three orthogonal dimensions by the CSAT3 ultrasonic anemometer while CO_2 flux and water vapor density were sampled by the LI 7500 infra-red gas analyzer. The HMP60 recorded air temperature and relative humidity at the site.

Separately on a 1.6 m tall mast were mounted slow response sensors; cup anemometer (model A100L2), pyranometer (model Kipp & Zonen) and HMP45C. All the sensors were placed at 1.5 m above the surface. A precision infrared radiometer (SI-111) for leaf surface temperature, net radiometer (NR-Lite) for net radiation and LICOR quantum sensor (LI190SB) for PAR were integrated for the measurement. Other sensors were mounted at 1.45 m on the 1.5 m tall mast. The turbulent parameters were sampled at 10Hz and averaged at 30 mins interval. Acquired Data were stored by CR1000 datalogger and later transferred to a computer (HP-Laptop) for analysis. The environmental variables; mean wind speed, solar radiation, air and soil temperatures, soil moisture, relative humidity, soil heat flux, leaf surface temperature and PAR were sampled at 10 s and averaged at 2 mins interval. After elimination of spurious data values using quality control and quality assurance (QA/QC) technique following the procedure by Foken and Wichura (1996), the flux data were reduced to 30 minutes averages, analyzed and then used to study the variation of CO_2 concentration and mass flux above the planted cowpea.

Figure 1: Plan view of the study site at the T & R Farm, Obafemi Awolowo University, Ile-Ife, Nigeria. Insert is map of Nigeria showing OAU campus (google earth, 2015).

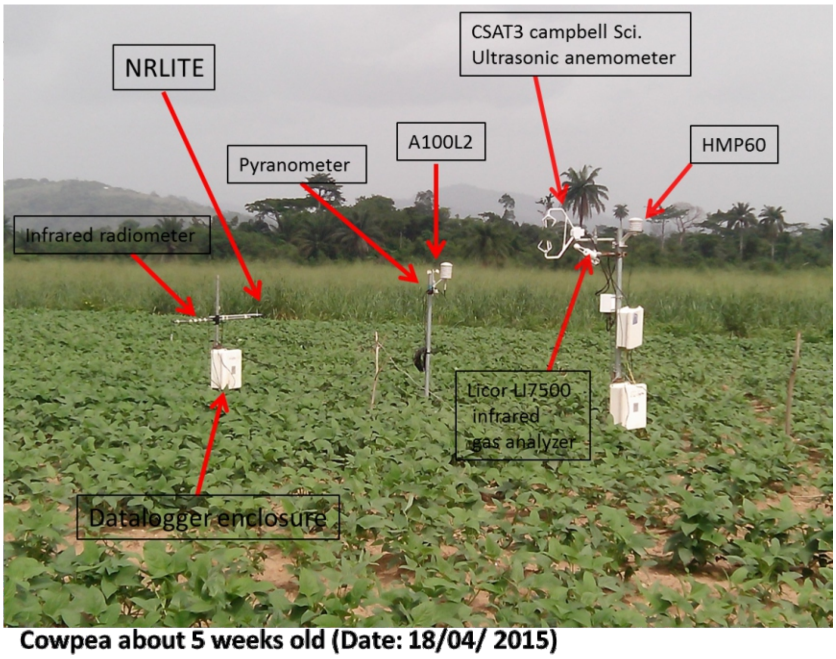

Figure 2: Positioning of masts and sensors at the Study Site, T & R Farm, OAU, Ile-Ife, Nigeria. Cowpea about 5weeks old (Date: 18/04/2015)

RESULTS AND DISCUSSION

Diurnal Variation of CO_2 Concentration and Flux with PAR

Variation of mass concentration of CO_2 above cowpea was compared with PAR as shown in the Figs. 3(a) and (b), for Phase 1 (dry - wet, March – June) and Phase 2 (wet – dry, August – November) of the measurements respectively. Maximum CO_2 concentration was observed during the nighttime, about 1200 mgm^{-3} which occurred between 0300 and 0600 hr (LT) while minimum concentration value approximately 650 mgm^{-3} around 1500 h (LT) occurred during the daytime. The mean diurnal concentrations showed higher levels of

CO_2, about 950 mgm^{-3} for dry months and 700 mgm^{-3} for wet months. The diurnal range value for wet season was lower, about 100 mgm^{-3} than 250 mgm^{-3} recorded for dry months. Therefore, there was a net source of CO_2 in the dry months and net sink in the wet months.

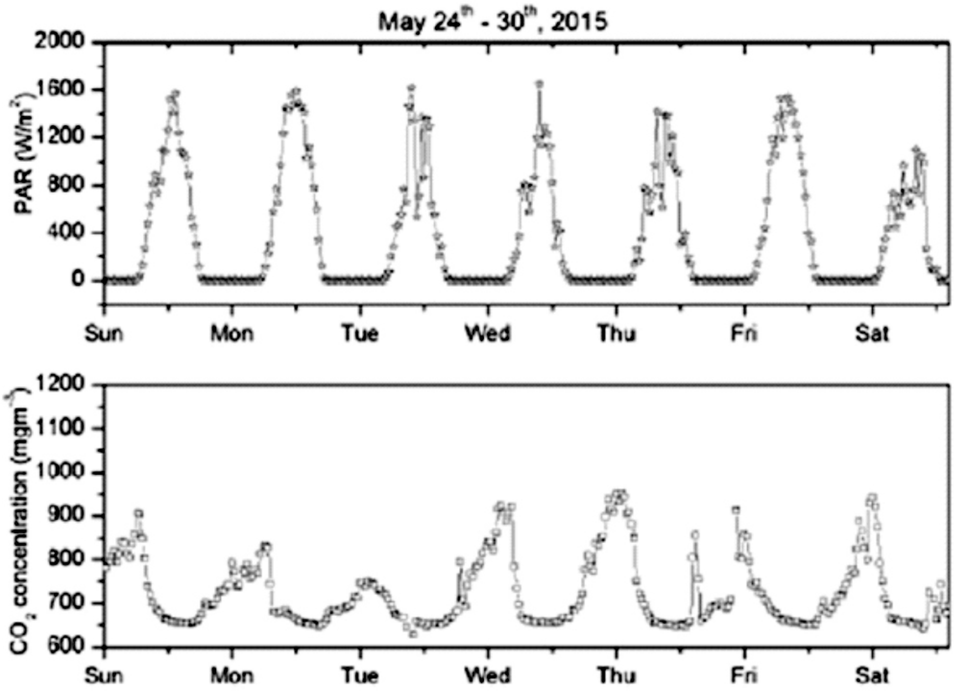

Figure 3(a): Diurnal Variation of PAR and CO_2 concentration (Phase I: May 2015)

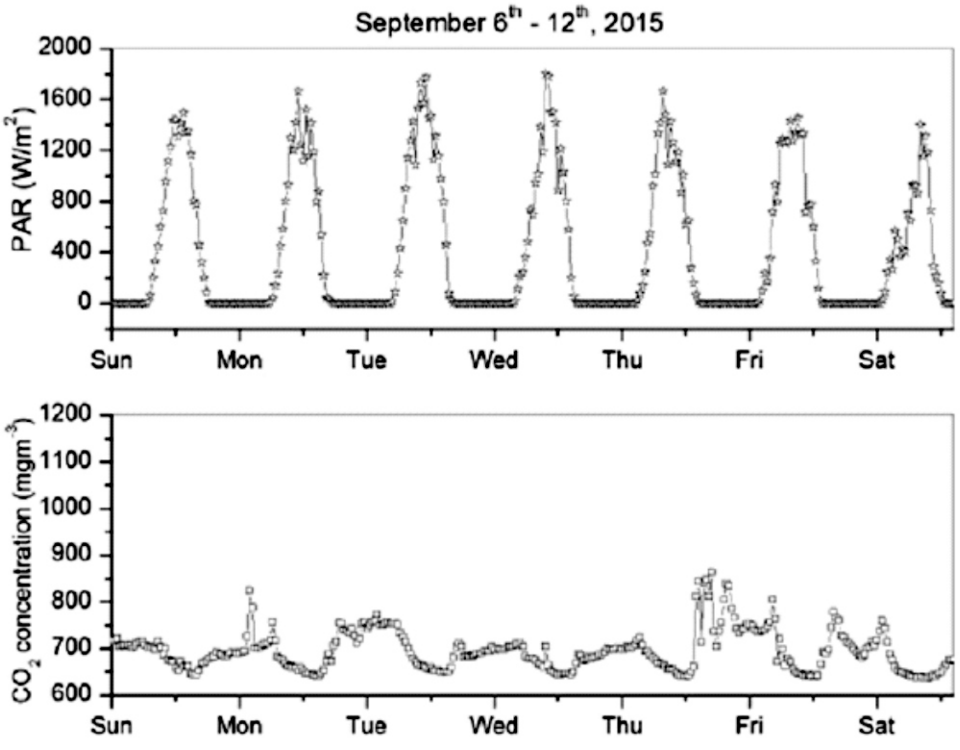

Figure 3(b): Diurnal Variation of PAR and CO_2 concentration (Phase 2: September 2015)

For the measured fluxes of CO_2 as shown in the Figs. 3(c) and (d), similar diurnal patterns were observed for daytime and nighttime scenarios. The diurnal range value for dry period was observed to be 1.26 mgm^{-2}.s^{-1}, which was found to be higher than 1.07 mgm^{-2}.s^{-1}as recorded for the wet period. High levels of PAR (> 1600 Wm^{-2}) during the daytime resulted in remarkable drops in the CO_2 concentration and fluxes (< -0.5 mgm^{-2}.s^{-1}) at the surface.

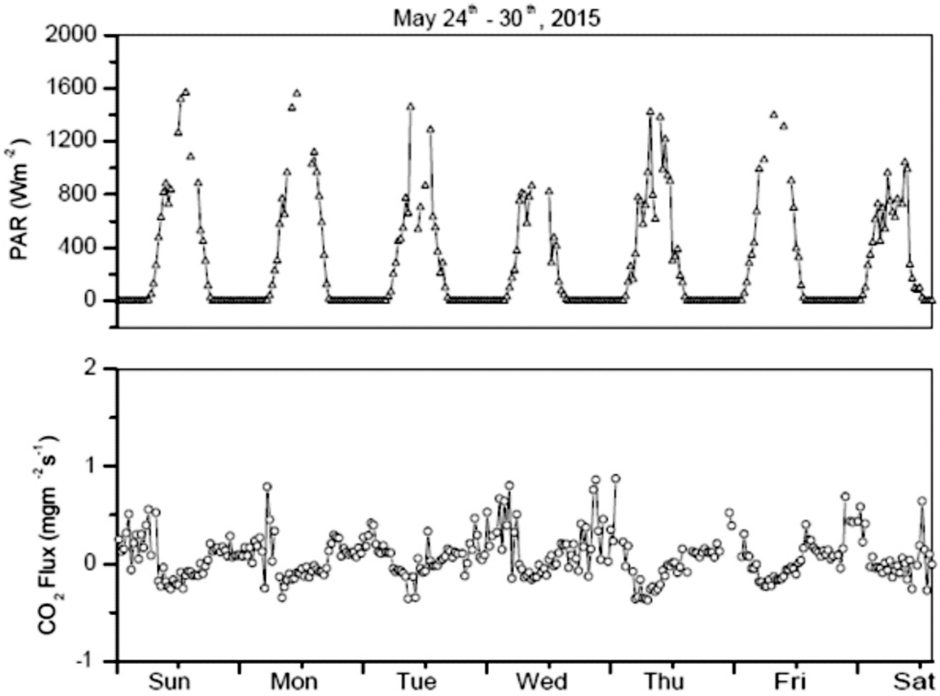

Figure 3(c): Diurnal Variation of PAR and CO_2 flux (Phase I: May 2015

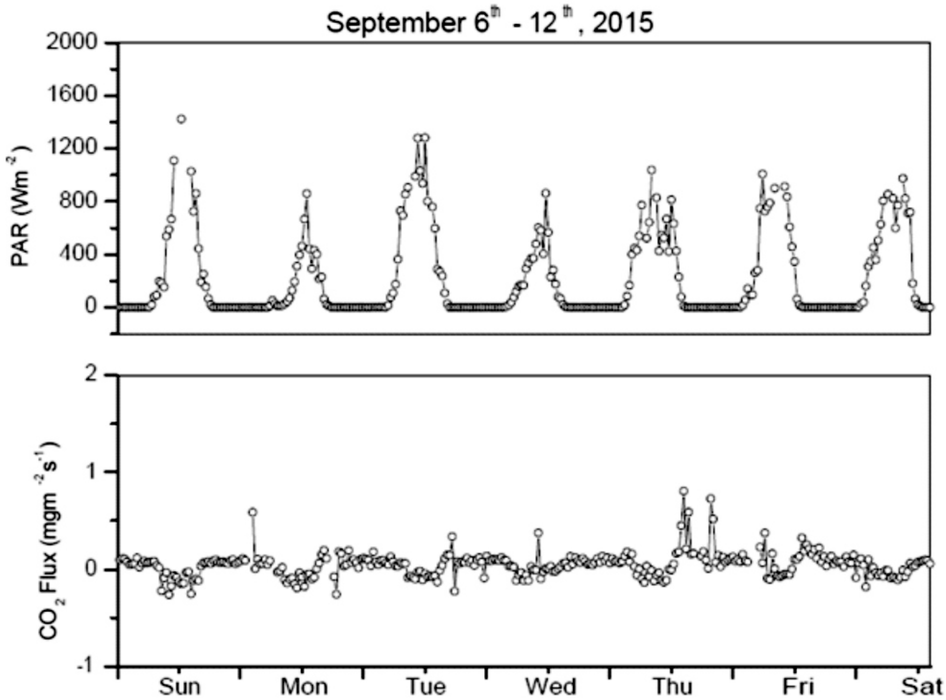

Figure 3(d): Diurnal Variation of PAR and CO_2 flux (Phase I: May 2015)

Diurnal Variation of Meteorological Variables above Growing Cowpea

Figures 4(a) and (b) show the diurnal variation of mean meteorological variables: air temperature, relative humidity and radiative fluxes as observed for phases 1and 2 during the measurement periods. Temperature difference was found to be 15°C for dry period (phase I) and 11°C for wet period (phase 2). The relative humidity difference was 51% for dry period and 40% for wet period. The large differences in both temperature and humidity values at the site were adduced to much of the heating being used as sensible heat (dry air) in the dry period and latent heat in the wet period respectively. The amount of global radiation was greater, about 900 Wm^{-2} in the dry period than in the wet period which was about 800 Wm^{-2}. This is due to increase in solar radiation heating of the earth surface in the dry period than in the wet period. The soil temperature and heat flux also showed similar diurnal variation with the CO_2 flux (see Fig. 5). The mass flux of CO_2 was observed to have dropped with increasing values of both soil temperature and soil heat flux, particularly in the daytime due to prominent photosynthetic activities at this period.

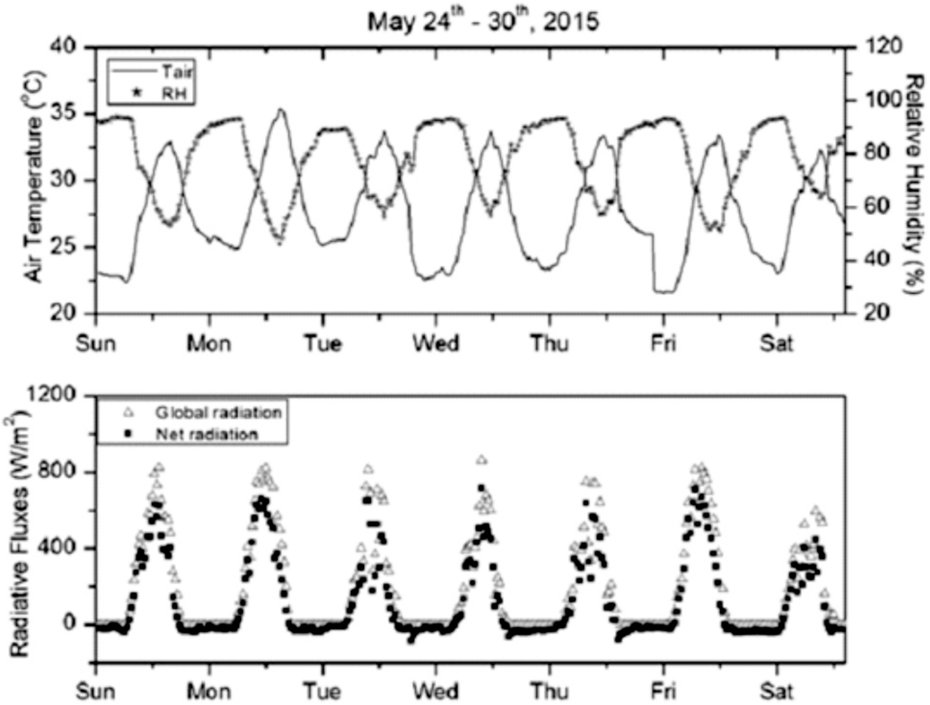

Figure 4(a): Diurnal Variation of Surface Meteorological parameters above the growing cowpea at the T & R Farm, OAU, Ile-Ife for May 24th – 30th, 2015

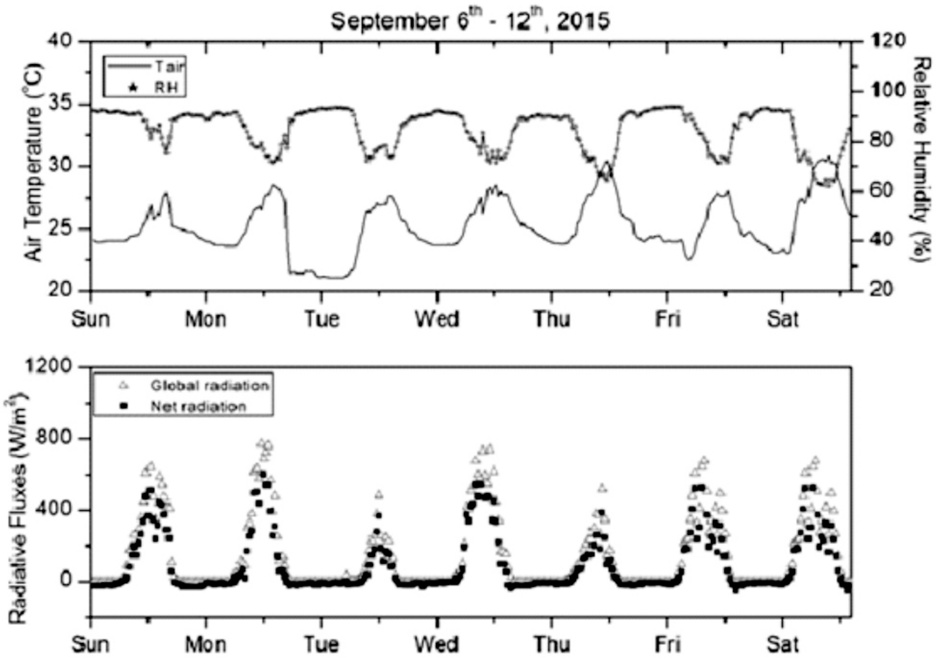

Figure 4(b): Diurnal Variation of Surface Meteorological parameters above the growing cowpea at the T & R Farm, OAU, Ile-Ife for September 6th – 12th, 2015

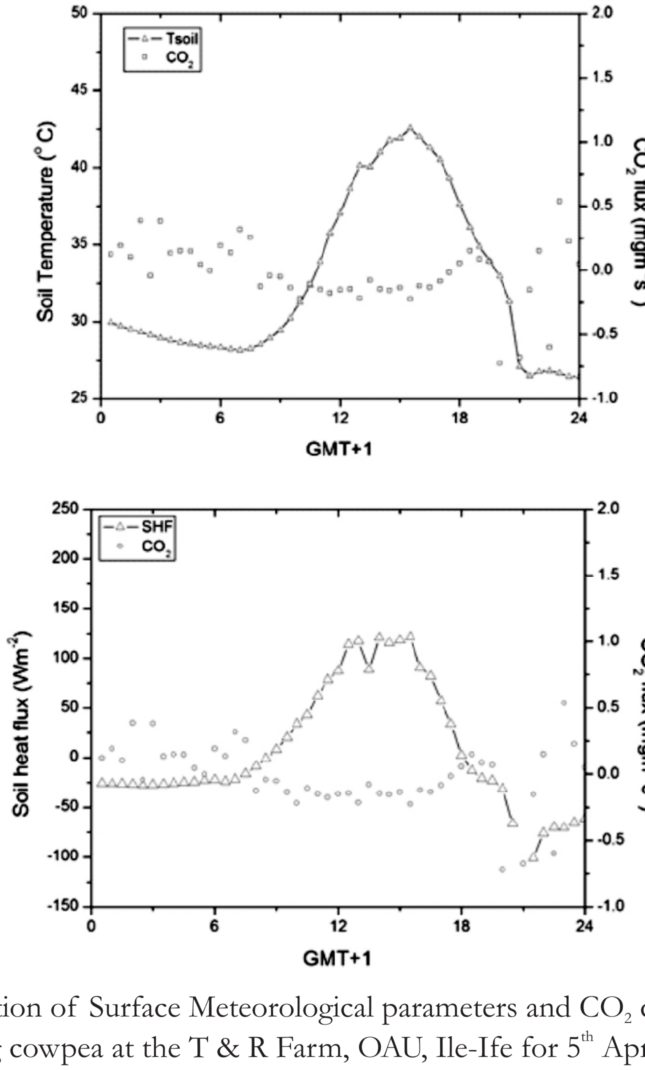

Figure 5: Diurnal Variation of Surface Meteorological parameters and CO_2 concentration above the growing cowpea at the T & R Farm, OAU, Ile-Ife for 5th April, 2015.

Effects of Turbulence on CO_2 Flux

Figure 6 shows scattered plots of CO_2 flux against sensible heat flux (Hs) and friction velocity (u*) as observed for 5th of April, 2015. For daytime condition, as shown in the Fig. 6(a), the value of Hs increased from about 20.0 Wm^{-2} to about 200.0 Wm^{-2} as surface became warmer, indicating increase in turbulence intensity at the surface which then aided CO_2 flux to be more scattered in the negative direction (from 0 – 0.25 $mgm^{-2}s^{-1}$). CO_2 fluxes were plotted against u*, as shown in the Fig. 6(b). The scattered plot shows that CO_2 fluxes increased with turbulence intensity as indicated by the value of u*. Most fluxes were noticed to have fallen within the positive range of values of CO_2 flux from 0.0 to 0.4 $mgm^{-2}s^{-1}$ for increased values of u*.

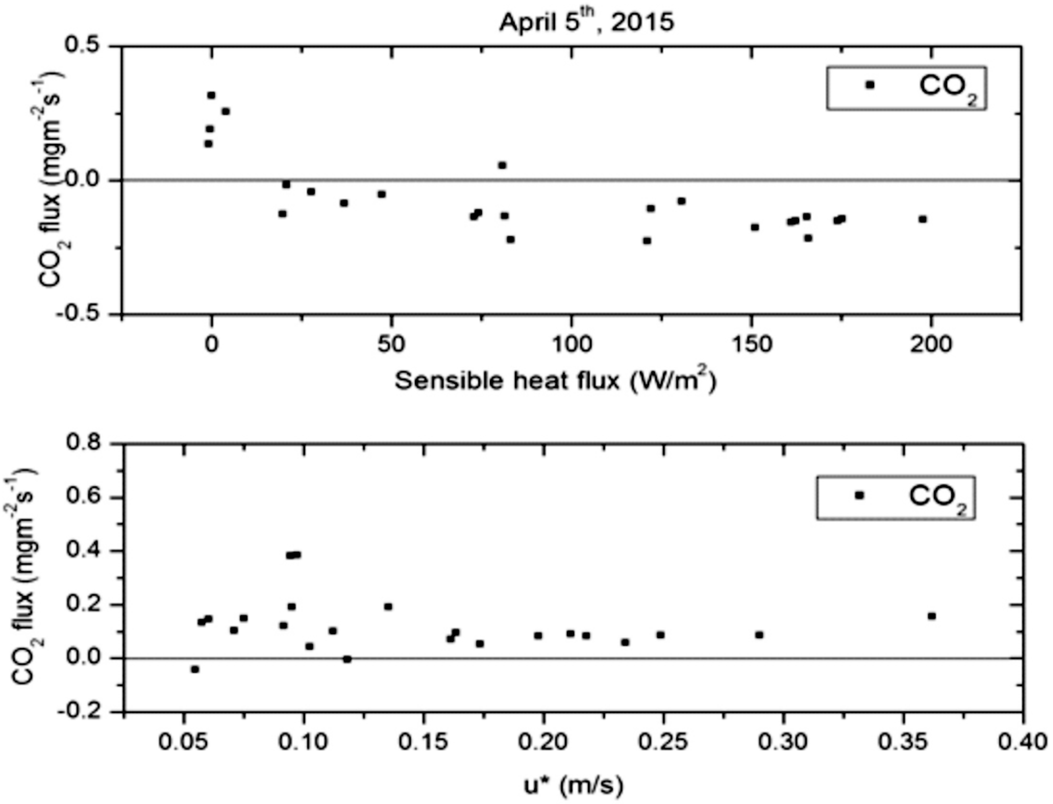

Figure 6: Carbon dioxide (CO_2) flux plotted against (a) sensible heat flux for daytime condition and (b) friction velocity for the nighttime condition at the T & R Farm, OAU, Ile-Ife on 5th April, 2015

Table 1 shows the list of deployed instrumentation to the study site (sensors with their years of acquisition in brackets) and Table 2 shows plant albedo values as observed at the site during the measurement period. Depending upon age of planted cowpea, the albedo values ranged between 0.19 and 0.27. Production of CO_2 is also found to be correlated with LAI.

Table 1: Measurements at the study site during the observation period March – November, 2015
*The year of acquisition is enclosed in the brackets

s/n	Parameters	Name of Instrument	Model, Manufacturer and Year of acquisition/production*
1	Wind speed (turbulent)	3-dimensional ultrasonic anemometer	Campbell Scientific, Inc. USA CSAT3 (2008)
2	Carbondioxide concentration and water vapor density	Infrared gas analyzer	Li-COR Inc.; USA LI 7500 (2010)
3	Air temperature and relative humidity	Temperature and Humidity probe	VAISALA, USA HMP45 (2008)
4	Surface temperature	Precision infrared radiometer	Apogee Instruments, USA SI-111. (2009)
5	Photosynthetically active radiation (PAR)	LI-COR Quantum sensor	Campbell Scientific, Inc. USA LI190SB (2008)
6	Global radiation	Pyranometer	Kipp and Zonen, Holland CMR1 (2004)
7	Wind speed (mean)	Cup anemometer	Vector Instr., UK A100L2
8	Soil heat flux	Soil heat flux plate	Hukseflux, Inc. USA HFP01 (2009)
9	Soil moisture content	Water-content reflectometer	Campbell Scientific, Inc. USA CS616 (2006)

Table 2: Weekly averages of micrometeorological parameters observed at the study site, T & R Farm, OAU between March 10th and June 8th, 2015 covering different stages of cowpea growth and development.

Week	Average Albedo ( )	Plant height, H (m)	Leaf Area Index LAI (m^2m^{-2})	Air Temp. (°C)		Relative Humidity (%)		Net radiation (Wm^{-2})		Photosynthetically Active Radiation PAR (Wm^{-2})	Conc. of Carbon dioxide (CO_2) (mgm^{-3})	
				Min	Max	Min	Max	Min	Max	Max	Min	Max
1 – 2	0.21	0.20	0.47	25.7	35.5	40.6	92.0	-38.3	467.9	1494.3	659.4	703.1
3	0.24	0.32	1.84	21.6	36.0	42.8	93.6	-76.3	714.0	1800.9	640.6	1059.3
4	0.23	0.45	2.41	22.9	35.5	30.4	92.4	-45.4	645.1	1635.2	640.0	846.2
5	0.27	0.53	2.74	25.0	36.7	35.2	92.0	-63.8	620.0	1711.1	642.1	727.7
6	0.24	0.58	4.15	21.3	35.5	58.0	81.9	-43.8	746.3	1848.3	645.6	899.2
7	0.24	0.61	5.43	23.6	34.1	53.6	93.4	-58.0	667.4	1690.3	642.7	972.2
8	0.26	0.63	5.14	23.4	35.8	48.1	93.7	-61.9	749.4	1844.6	647.9	1046.4
9	0.26	0.64	5.36	22.8	34.9	49.9	93.7	-45.2	644.0	1586.7	625.4	1087.5
10	0.22	0.67	5.36	21.5	35.4	46.3	93.9	-85.7	716.4	1647.7	530.7	1195.1
11	0.25	0.67	5.02	21.5	33.0	59.7	93.5	-55.6	876.8	1422.2	639.8	988.6
12	0.19	0.67	4.13	23.7	31.8	61.7	98.7	-40.0	791.2	1357.7	637.7	987.9

CONCLUSIONS

The results showed that CO_2 flux varied considerably with micrometeorological variables for the different stages of development of cowpea. PAR is the dominant factor which controls photosynthesis with limited solar radiation at the surface. The daytime CO_2 assimilation increases rapidly with PAR. The study further concluded that since there was a net uptake (nighttime release more than daytime usage) of CO_2 by the plant at the study site, then it is a net source of carbon due to its carbon-fixation strategy as it stores more CO_2 during nighttime than in the daytime.

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