Original Research Article

Impact of solar radiation intensity on temperature, relative humidity, wind speed and direction in Lubigi *Cyperus papyrus* L. wetland surface

Abstract

Response to the position of the sun, the length of the day and solar radiation changes can be complex and perhaps even counter – intuitive. Assessment of diurnal solar radiation intensity measured as photosynthetically active radiation (PAR) on relative humidity (RH), temperature, wind speed and direction in *Cyperus papyrus* (papyrus) wetland surface canopy was done during the months of September, 2010 (wet month) and June, 2011 (dry month) when the sun is at the equator and Tropics of Cancer respectively.

Significantly strong correlation existed between PAR with RH, temperature and wind speed during September and June. The significant difference in PAR intensity during the months coincided with temperature and wind speed at noon (11.00 - 1200 hours) and sun rise (07.00 - 08.00 hours) respectively. Significant difference in PAR in the evening (19.00 hour) was followed by significant temperature difference between 21.00 to 21.00 hours of the months. Therefore, the influence of the sun's position on the ecophysiology and development of papyrus requires assessment.

Keywords: Papyrus, relative humidity, solar radiation, temperature, wetlands

Introduction

The area bounded by the Tropic of Cancer on the north and Tropic of Capricorn on the south is known as the tropics and does not experience significant seasonal variations because the sun is always high in the sky [1]. However, the position of the sun, the length of the day and solar radiation change occur [2]. This directly affect the annual changes of extraterrestrial radiation in the tropics with position of the sun in the north and south of the equator with varied energy budget [3]. [4] also related shift in energy budget to position of and intensity of convection clouds and large scale tropical circulation. Heat energy storage in the Lake Victoria basin during daytime was reported considerably as larger sink in open water as compared to wetland ecosystems [5]. At regional and ecosystem levels, [6] argued that the daily response to such changes can be complex and perhaps even counter – intuitive. The radiation absorption by water vapour (attenuation of radiation) also plays an important role in the physics of the atmosphere and the absorbed energy changes partly into heat and produces a change of temperature in the free atmosphere [7]. An additional part of the energy is transformed into longer wave radiations emitted into the environment. In Lake Victoria region, extraterrestrial radiation is low and high during the months of June and September respectively [2].

The diurnal cycle of convective activity and cloudiness over Lake Victoria basin was described by [8]. [9] argued that two wet seasons in Lake Victoria basin appear to have fundamental dynamic differences. For this reason, [8] said; diurnal cycles of cloudiness during different seasons are expected to be quite different. However, cloudiness cycles was reported to cause restricted and intense sunshine between 11.00 - 16.30 hours [10], and high night cloudiness impact on evaporation through net radiation [11].

This study aimed at assessing the variation of solar radiation in the *Cyperus papyrus* wetland surface in Lake Victoria basin during the months of June and September when the sun is at Tropic of Cancer on 21st June and directly overhead at noon on the equinoxes near 21st of September respectively and the influence on temperature, relative humidity (RH), and wind speed and direction. It is important in the understanding of the atmospheric changes that occur as a result of wetland ecosystems presence. The study hypothesized that the solar radiation intensity has no significant effect on the diurnal weather changes in the *C. papyrus* wetland canopy.

Materials and Methods

Study area

The study was conducted in Lubigi wetland, Kampala District. This wetland is one of largest remaining permanent water logged wetland in Lake Victoria basin. It is located at an altitude of 1,158 - 1,173 m above sea level and covering geographical co-ordinates of 0^0 17′ N to 0^0 22′ N and 31^0 30′ E to 31^0 34′ E (Figure 1). Early rain season in the area starts from March to May and second rain from August to December.

Experiment and data collection

Data was collected during the entire month of September, 2010 and June, 2011 which was characterized by dry and wet period respectively. A data Hog 2 logger installed in monotypic stand of *C. papyrus* located at 0^0 24´ N and 32^0 31´ E at an average of 1,166 m above sea level was used for weather data recording. The logger was calibrated for relative humidity (RH), air temperature, wind speed and direction, and photosynthetically active radiation (PAR). RH/Temperature probe calibration for relative humidity and air temperature was at standard factory specifications at nominal points of 1% and 75.45 RH, and 27 degrees Celsius. Pyranometer calibration was directly against a calibrated reference World Meteorological Office, First Class Pyranometer under natural daylight conditions with uncertainty +5%. However, the actual calibration was based on an estimated confidence of not less than 95% (typically +3%). RH/Temperature, wind sensors and pyranometer were connected to the logger at different specified calibrated channels. None of the channel was calibrated for rainfall data recording. Changes in air temperature, RH, wind speed and direction, and solar radiation in form of photosynthetically active radiation (PAR) were averaged on thirty (30) minutes. Data were collected for wet period of September, 2010 and dry period of June 2011. Average values were determined for 30 days samples of both day and night time phenomena. June, 2011 and September, 2010 were selected because of the dry and wet spell and characteristic difference in sun's position from equator [2].

Statistical analysis

Minitab version 13 was used for statistical data analysis [12]. Regression analysis was used to test for statistical relationship between variables. Non parametric test of Mann-Whitney was used for diurnal differences between weather variables during September, 2010 and June, 2011. All statistical values were considered significant at less than 0.05.

Results

The daily and hourly variability of air temperature in wetland canopy surface during the months of September, 2010 and June, 2011 is shown in Table 1.

Observed temperature values were not significantly different during dry and wet months except for values between 11.00 - 12.00 hours and 20.00 - 21.00 hours that were significantly lower for September month. Temperature inversion occurred between 8.00 - 10.00 hours and 19.00 - 21.00 hours in the morning and evening respectively. The inversion preceded significant temperature difference between the months. Slightly stable thermal atmosphere was formed throughout the night during dry and wet months. The dry month exhibited longer thermal equilibrium.

The variation of the daily and hourly changes in relative humidity (RH) in the surface of *C. papyrus* during September (wet) and June (dry) months is presented in Table 2.

Significantly low RH compared to the rest of the hours was recorded between 11.00 – 19.00 hours and 09.00 – 22.00 hours during the dry and wet season respectively ($p < 0.05$). RH was very distinct during the months with significantly higher values in the dry month. A highly significant difference was observed between 20.00 - 10.00 hours ($p < 0.05$). A lag in RH inversion compared to temperature occurred in morning hours but for evening hours both temperature and RH inversion started at the same time (Tables 1 and 2). Maximum relative humidity of 100% dominated most hours during dry spell.

The daily and hourly change in wind direction in surface of wetland canopy during September and June is presented in Table 3.

Southern wind dominated night hours (19.00 - 03.00) during both dry and wet months. However, dry month experienced more of southerly wind and was significantly higher between 07.00 - 08.00 hours and at 10.00 hours compared to the wet month. Wind generally oscillated between eastern and southern direction. Wind oscillation was significantly different between hours of each season except for 20.00 hour of the wet season ($p > 0.05$).

The daily and hourly variability of wind speed over wetland canopy is shown in Table 4.

Diurnal variation of wind speed occurs with dry month exhibiting significantly lower speed during night hours (01.00 - 10.00). Similar high wind speed was observed in dry and wet months during half of days' hours (11.30 - 21.00). Maximum wind speed was observed at about 15.00 - 17.00 hours in the dry month of June. A shorter period of high wind speed was exhibited around 15.00 - 16.00 hours during the wet month.

Photosynthetically active radiation (PAR) intensity was used to indicate changes in general solar radiation in surface of *C. papyrus* wetland canopy. Table 5 shows daily hourly changes of PAR during the months.

Solar radiation picked up in the morning (7.00 hour). Similar pattern was observed for both dry and wet months. Maximum values were reached around 12.00 hour in both dry and wet months. Significantly higher values in the wet month occurred between 07.00 - 08.00 hours, 12.00 - 15.00 hours and in the evening hour (19.00).

The relation between daily hourly solar radiation (PAR) with corresponding temperature, relative humidity (RH) and wind speed and direction for months of June (dry) and September (wet) is represented in Table 6.

All the weather variables changes could be accounted for the PAR variation. PAR influence on wind direction was experienced in each hour of the day except for 20.00 - 21.00 hours of both months of June and September which exhibited minimum values above 12.4 degrees (Table 3). PAR effect on wind speed was not significant since the values were below the F-values for dry (40.8 m s^{-1}) and wet (55.9 m s^{-1}) respectively. However, PAR effect on wind speed was higher during September (55.9%) compared to 40.8% of June. Temperature change was not significantly related to PAR variation since all values were below the F-values of the months of June (68.5 ^{0}C) and September (76.7 ^{0}C) respectively. Significant difference in RH occurred above 64.5% and 83.9% during June and September respectively. The effect of PAR on RH was shorter for dry season of June (11.00 - 19.00 hours) compared to wet season of September (09.00 - 22.00 hours) (Table 2).

Discussion

The daily photosynthetically active radiation (PAR) pattern was similar to that reported by [13], and [14] in wetlands canopy in the Naivasha and Kirinya wetlands respectively. PAR picked up in the morning (7.00 hour) and similar pattern was observed for both June (dry month) and September (wet month) with significantly higher values during wet month between 07.00 - 08.00 hours, 12.00 - 15.00 hours and 19.00 hour. The lower solar radiation intensity in the dry month of June is attributed to the sun's position at the Tropic of Cancer as a result of the axial tilt of the earth at the equator [2]. The radiation intensity is usually determined by angle between direction of sun's rays to normal surface of atmosphere, and such angles change at different latitudes, during the day and in different seasons. However, the effect of cloudiness cycles cannot be ruled out since this was reported to cause restricted and intense sunshine between 11.00 - 16.30 hours [10].

Significant difference in PAR in the evening (19.00 hour) was followed by significant temperature difference between 21.00 to 21.00 hours of the months. Data based on regression analysis indicates that the significant difference is not directly caused by the PAR intensity but attributed to the elevated RH change during the months of June and September (Table 2). Attenuation of radiation by RH plays an important role in the atmosphere [7]. The absorbed energy changes partly into heat and produces a change of temperature in the free atmosphere. An additional part of the energy is transformed into longer wave radiations emitted into the environment in the absence of solar radiation which affects the duration of thermal equilibrium particularly in the night. The increased thermal air equilibrium during night hours of June is attributable to the low net radiation. The effect of high night cloudiness impacting on evaporation through net radiation cannot be ruled out [11]. The shorter thermal equilibrium duration during the wet month of September is attributed to the high PAR that caused evaporative cooling of the air due to net radiation of the in the night. The significant difference in PAR intensity during the months also coincided with temperature change at noon (11.00 - 1200 hours) which reflect a direct effect on PAR on temperature as exhibited by the relatively similar variance of temperature response to PAR approximated at 76.7% and 74.6% for wet and dry season respectively.

General wind oscillation was easterly and southerly wind and significant diurnal difference occurred during 07.00 - 08.00 hours and 10.00 hours of the months. At the equatorial regions, air is heated more strongly than at other latitudes, causing it to become lighter and less dense [15]. Wind oscillation in Lubigi wetland is attributed to the warm air rising to high altitudes and flowing southward towards the poles where air near the surface is cooler during both June and September months. This movement ceases at about 30° S, where air begins to cool and sink and a return flow of this cooler air takes place in the lowest layers of the atmosphere [15]. The dominance of southern wind during dry month (June) compared to wet month (September) implies higher cooling rate due to reduced PAR in June.

Wind speed during dry spell of June was lower than the value (15 m s^{-1}) reported for dry season in Lake Victoria eco-region [16]. The lower altitude at which the meteorological unit was installed could have contributed to the recorded speed. The significant difference in PAR intensity during the months coincided with the significant wind speed difference at the sun rise (07.00 - 08.00 hours); an indication that early morning heating makes the air lighter and therefore flow faster as observed during the day. The non-significant difference in diurnal wind speed between September (wet month) and June (dry month) during more than half of the days' hours (11.30 - 21.00 hours) indicates relatively similar air weight and turbulence at the papyrus wetland canopy.

The study indicates significant PAR influence in papyrus canopy surface on wind speed and temperature at sun rise (07.00 - 08.00 hours) and noon (11.00 - 12.00 hours) respectively. These changes attributed to the sun's position in the different months makes is important in the ecophysiology and development of papyrus. [17] and [14] reported water flux in papyrus canopy and photosynthesis increasing to a threshold as PAR and air-temperature increased. The intensity of the threshold during the months could be related to the sun's position.

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Table 1: Daily and hourly temperature (^{o}C) changes in papyrus wetland canopy surface during the months of June and September. NS and S represent non significant and significant differences between hourly means of dry and wet months.

Time (hours)	Dry period-June			Wet period-September			p-value
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	
01.00	17.76	15.44	20.70	17.48	14.57	20.15	NS
02.00	17.48	15.80	19.53	17.32	14.70	20.40	NS
03.00	17.38	15.57	19.15	17.06	14.67	19.36	NS
04.00	17.31	15.65	19.84	17.03	15.51	19.58	NS
05.00	17.20	15.35	19.92	16.82	15.49	19.18	NS
06.00	17.18	15.13	19.36	16.92	15.68	19.10	NS
07.00	17.00	14.88	18.88	17.07	15.75	19.21	NS
08.00	17.32	14.73	19.48	17.59	16.03	19.47	NS
09.00	19.20	16.98	22.02	19.33	17.56	23.43	NS
10.00	21.86	17.33	25.05	21.47	18.83	25.36	NS
11.00	23.87	17.71	26.71	23.17	20.47	26.61	S
12.00	25.05	18.37	27.86	24.58	20.71	27.51	S
13.00	25.63	18.80	28.57	25.28	19.15	28.27	NS
14.00	25.27	15.47	28.89	25.60	18.29	28.39	NS
15.00	24.67	16.34	28.75	25.55	18.33	28.86	NS
16.00	24.48	16.59	28.22	24.83	18.52	28.15	NS
17.00	24.30	16.65	27.93	23.89	16.95	28.13	NS
18.00	24.07	16.73	27.13	23.44	17.65	28.15	NS
19.00	22.81	16.86	25.72	22.22	17.86	27.09	NS
20.00	20.82	16.87	23.87	20.15	17.34	22.65	S
21.00	19.52	16.65	22.52	19.02	16.92	21.11	S
22.00	18.74	16.74	21.21	18.39	16.32	20.90	NS
23.00	18.29	16.55	20.60	18.09	15.47	20.72	NS
00.00	17.95	16.19	20.38	17.88	15.10	20.35	NS

Table 2: Daily and hourly relative humidity (%) changes in surface of *C. papyrus* wetland canopy during the months of September and June. NS and S represent non significant and significant differences between hourly means in wet and dry months.

Time (hours)	Dry period-June			Wet period-September			p – value
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	
01.00	99.48	88.50	100	95.68	86.43	97.77	S
02.00	99.59	87.68	100	95.65	85.68	97.82	S
03.00	99.84	95.05	100	95.78	83.23	97.66	S
04.00	99.83	94.71	100	96.11	90.75	97.88	S
05.00	99.53	90.21	100	96.42	91.43	97.97	S
06.00	99.63	94.10	100	96.33	91.23	97.93	S
07.00	99.65	95.92	100	96.03	90.34	97.88	S
08.00	99.50	92.19	100	95.72	89.59	97.82	S
09.00	98.54	86.20	100	92.18	75.81	97.88	S
10.00	90.35	76.05	100	82.67	64.05	93.00	S
11.00	80.92	63.19	100	74.83	60.36	87.34	S
12.00	74.94	57.84	100	68.73	58.11	86.13	S
13.00	71.45	53.60	98.64	66.15	53.49	93.89	S
14.00	72.72	50.21	99.65	65.48	53.18	95.39	S
15.00	74.40	50.86	100	66.20	50.86	91.98	S
16.00	74.93	54.91	100	68.25	55.21	92.66	S
17.00	76.81	59.75	100	71.90	53.60	97.22	S
18.00	77.64	60.09	99.26	74.01	49.40	97.55	S
19.00	83.37	63.68	99.60	78.96	57.42	97.49	S
20.00	92.87	80.21	99.93	87.71	75.32	97.55	S
21.00	97.01	84.78	100	91.73	80.87	97.66	S
22.00	98.56	90.53	100	93.62	83.14	97.77	S
23.00	99.15	90.34	100	94.25	86.43	97.82	S
00.00	99.59	95.53	100	94.51	84.37	97.71	S

Table 3: Daily and hourly wind direction (degrees) changes in surface of papyrus wetland canopy during the months of September and June. NS and S represent non significant and significant differences between means of dry and wet months.

Time (hours)	Dry period-June			Wet period-September			p-value
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	
01.00	199.1	0	340	213.1	5	340	NS
02.00	181.8	0	345	186.3	0	355	NS
03.00	184.5	0	345	180.5	0	355	NS
04.00	165.8	0	350	177.2	0	350	NS
05.00	163.9	0	325	161.7	0	355	NS
06.00	173.2	0	355	157.9	0	355	NS
07.00	185.6	0	355	129.2	0	280	S
08.00	210.1	0	350	140.0	0	335	S
09.00	160.8	0	355	111.5	0	315	NS
10.00	158.7	0	345	103.9	0	330	S
11.00	157.6	0	355	159.5	0	355	NS
12.00	160.9	0	350	163.6	0	340	NS
13.00	175.3	0	355	155.8	0	335	NS
14.00	170.8	0	305	153.3	0	330	NS
15.00	171.7	0	340	155.5	0	315	NS
16.00	172.2	0	325	173.0	0	340	NS
17.00	168.4	0	290	166.4	0	315	NS
18.00	175.8	0	220	173.8	0	350	NS
19.00	182.3	0	290	191.1	0	350	NS
20.00	209.7	25	345	198.8	25	335	NS
21.00	219.0	5	350	208.6	5	355	NS
22.00	204.6	0	340	216.1	0	355	NS
23.00	194.3	0	330	215.1	0	355	NS
00.00	187.2	0	355	211.5	5	350	NS

Table 4: Daily and hourly wind speed (m s^{-1}) in surface of papyrus wetland canopy during the month of June and September. NS and S represent non significant and significant differences between means of dry and wet months.

Time (hours)	Dry period-June			Wet period –September			p-value
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	
01.00	0.53	0	2.29	0.65	0.15	1.84	S
02.00	0.46	0	1.39	0.78	0	3.19	S
03.00	0.44	0	1.39	0.80	0	2.87	S
04.00	0.51	0	1.74	0.91	0.15	3.93	S
05.00	0.55	0	2.04	0.85	0.20	3.43	S
06.00	0.63	0	2.19	0.80	0.20	2.09	S
07.00	0.57	0	2.19	0.86	0.15	2.54	S
08.00	0.47	0	1.69	0.76	0.15	2.34	S
09.00	0.51	0	2.14	1.00	0.20	2.09	S
10.00	1.27	0.20	4.43	1.53	0.45	3.33	S
11.00	1.56	0.40	3.73	1.83	0.90	4.08	NS
12.00	1.77	0.65	4.23	1.91	0.70	4.08	NS
13.00	1.92	0.85	4.33	2.15	0.80	5.52	NS
14.00	2.17	0.70	4.73	2.23	0.50	4.28	NS
15.00	2.45	0.50	5.23	2.53	0.85	4.28	NS
16.00	2.42	0.20	4.73	2.60	0.60	5.57	NS
17.00	2.43	0.30	5.03	2.29	0.50	4.38	NS
18.00	1.95	0.15	4.38	2.08	0.40	4.63	NS
19.00	1.50	0.20	3.83	1.41	0.25	2.84	NS
20.00	0.78	0.15	1.89	0.80	0.20	2.04	NS
21.00	0.64	0.10	2.29	0.61	0.25	1.30	NS
22.00	0.71	0	3.58	0.71	0.30	1.34	NS
23.00	0.45	0	1.59	0.71	0.30	1.59	S
00.00	0.45	0	1.20	0.62	0.15	1.64	NS

Table 5: Daily and hourly PAR in surface of papyrus wetland canopy during June and September. NS and S represent non significant and significant differences between means of dry and wet months.

	Dry period-June			Wet period-September			
Time (hours)	Mean	Minimum	Maximum	Mean	Minimum	Maximum	p-value
01.00	0	0	0	0	0	0	
02.00	0	0	0	0	0	0	
03.00	0	0	0	0	0	0	
04.00	0	0	0	0	0	0	
05.00	0	0	0	0	0	0	
06.00	0	0	0	0	0	0	
07.00	0.84	0	8.42	4.07	0	18.95	S
08.00	96.42	12.63	292.63	140.55	5.26	493.68	S
09.00	380.79	8.42	787.37	427.54	136.84	954.74	NS
10.00	781.51	47.37	1267.37	802.22	137.90	1408.42	NS
11.00	1071.39	149.47	1612.63	1151.03	345.26	1863.16	NS
12.00	1234.82	254.74	1816.84	1482.83	440	2255.79	S
13.00	1065.84	158.95	1682.11	1421.97	53.68	2193.68	S
14.00	1037.42	17.90	1917.9	1483.37	127.37	2291.58	S
15.00	887.99	22.11	1720	1288.42	186.32	2093.68	S
16.00	817.96	35.79	1450.53	858.71	13.68	1746.32	NS
17.00	601.07	40	1317.9	620.05	24.21	1245.26	NS
18.00	339.23	32.63	675.79	367.13	27.37	841.05	NS
19.00	84.65	1.05	234.74	66.53	1.05	241.05	S
20.00	0.3	0	0.3	0	0	0	
21.00	0	0	0	0	0	0	
22.00	0	0	0	0	0	0	
23.00	0	0	0	0	0	0	
00.00	0	0	0	0	0	0	

Table 6: Regression analysis results of PAR with temperature, RH, and wind speed and direction during the dry and wet month of June and September respectively.

Variable (s)	June (dry month)	September (wet month)
RH	r^2 = 73.4%, F = 64.52, p = 0.000	r^2 = 78.3%, F = 83.88, p = 0.000
Temperature	r^2 = 74.6%, F = 68.45, p = 0.000	r^2 = 76.7%, F = 76.69, p = 0.000
Wind speed	r^2 = 63.4%, F = 40.82, p = 0.000	r^2 = 70.5%, F = 55.94, p = 0.000
Wind direction	r^2 = 33.2%, F = 12.44, p = 0.002	r^2 = 15.1%, F = 5.08, p = 0.035

Figure 1: Lubigi *C. papyrus* wetland in Lake Victoria basin and location of meteorological unit.