

Full Length Research Paper

Response of *Cyperus papyrus* productivity to changes in relative humidity, temperature and photosynthetically active radiation

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Ecosystem development is related to climatic conditions. To assess the effect of seasonal changes in climate factors on papyrus ecosystem development, community biomass was estimated non-destructively and climate factors recorded in the wetland. Absolute aerial biomass and productivity were not significantly different between wet and dry seasons. Although there was significant vapour pressure deficit change over the seasons, the impact on net primary productivity was not significant, but exhibited positive association during dry season. Primary productivity was positively related to photosynthetically active radiation during both dry and wet seasons. Except for the dry season that accounted for 26.1% of primary productivity, that of the wet season was independent (0%) of measured weather variables.

Key words: *Cyperus papyrus*, photosynthetically active radiation, productivity, relative humidity, temperature, wetlands.

INTRODUCTION

Although photosynthesis is fundamental to plant growth and estimated as net biomass accumulation, other environmental factors modify its magnitude (Hall and Long, 1993; Page et al., 2011). The understanding of how environmental changes influence plant growth is critical for the assessment of potential impacts of climate

change on ecosystems.

Weather variability measured as changes in rainfall, temperature, solar radiation, humidity and wind characteristics interact with plant and influence processes such as photosynthesis, respiration, transpiration and translocation (Beadle, 1993; Jones, 1993). Changes in

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weather variables (rainfall pattern, wind speed, temperature and evaporation rate) during the year in Lake Victoria basin in East Africa region has been reported (Hughes and Hughes, 1992; Spigel and Coulter, 1996; Yin et al., 2000; Oyugi, 2010).

Knowledge of the effects of such changes are necessary for improving the accuracy of global climate carbon models within the region, and also provide support to the program of improving wetland management and policy for climate change mitigation and carbon accounting. The new policy to reduce greenhouse gas emission through reforestation in developing countries have highlighted the prospects of conserving tropical wetlands by negotiating carbon offset and trading agreements (Murdiyarto et al., 2010). This study investigated the contribution made by tropical papyrus wetlands to carbon stock.

The influence of weather variability on *Cyperus papyrus* ecosystem productivity is yet unclear. However, modeling results of micro-climate and light interception on *C. papyrus* bracteole (leaf) photosynthesis was done (Jones, 1988; Humphries and Long, 1995). Model prediction and productivity measurements suggest that increasing temperatures may result in substantial decrease in carbon sequestration and inputs to stored carbon in the underlying papyrus peat deposits (Humphries and Long, 1995; Saunders et al., 2007).

Saunders et al. (2007) estimated the carbon sequestration of tropical papyrus wetlands from measurement of net ecosystem exchange by eddy covariance. Maximum rates of CO₂ assimilation were associated with peaks in both air temperature and photosynthetically active radiation (PAR) flux with lesser vapour pressure deficit (VPD) effect. The study involved analysis of diurnal CO₂ flux produced from the wetland as a result of decomposition, respiratory growth and maintenance respiration.

Temperature influence and other weather factors that directly or indirectly influence papyrus productivity measured as absolute biomass change has not been fully investigated. The standing biomass is important because individual dying shoots in papyrus wetlands are replaced through recruitment. This takes care of the population dynamics within wetland systems, and provides empirical data for biomass quantification that can be used to upscale to larger wetland area using accurate papyrus area estimation by satellite imagery (Maclean et al., 2006).

In this study, it is hypothesized that weather factors drive pattern of papyrus development. Although the quality and quantity of stream inflows into and out of wetlands, macrophyte harvesting and characteristics human settlement around the wetland would have influence through nutrients input into the wetland systems that would ultimately influence productivity and its variability, they were considered as integral constant factor in this model.

MATERIALS AND METHODS

Study area

The study was conducted in Lubigi wetland, a monotypic *C. papyrus* wetland in Kampala District, Uganda. The wetland covers total area of 2.96 km² (Namakambo, 2000). Daily average temperature of the area ranges between 17 to 27°C during the year. This is a typical tropical wetland conditions, characterized with wet and dry climate. Rainy seasons are from September to December and March to May of each year. Erratic changes have been observed in the onset and end of the different seasons in the recent past.

Site selection for the metallic tower in the study area

The selection of the site for mounting the metallic tower was in the monotypic stand of papyrus plants located about 170 m from the wetland edge. The bottom sediment of the location was approximately 4.5 m deep. The tower was used for the attachment of meteorological unit (Figure 1). The meteorological unit was located at approximate 1,165 m above sea level at 0°24' N and 32°31' E. Further anchorage of the tower in the papyrus mat was done by forcing longer pieces of timber across the width of rectangular frame that rested on the papyrus mat. This gave the tower structural firmness on the papyrus mat in order to support additional weight. A ladder walk way (transect) was constructed in the wetland using eucalyptus poles to allow easy movement into and out of the wetland (Figure 2).

Papyrus biomass and primary productivity assessment

Biomass and primary productivity assessments were done in quadrats (3 x 3 m²), and limited to the aerial growth of the monotypic stand of papyrus. The assumption was that growth in papyrus wetlands only occur as turnover rate of the aerial shoots for fully developed rhizome structures. Eight replicate quadrats located along the access transect at distance of 100 m were used for the investigation. Each quadrat was 2 m away from the center line of the transect. All live culms within the quadrats were identified and culms girth measured during each visit. The assessment covered eleven months (October, 2010 to August, 2011) at intervals of three (3) weeks. Live culms whose girth were measured included those with un-opened umbels, partially open and fully open green umbels without signs of senescence (< 40% of the umbel brown and no clear evidence of senescence). The regression equation $\text{Log}(y) = 2.832\text{Log}(x) - 0.5241$ of biomass (y) against culm sizes (girth) (x) was used (Figure 3) to estimate *C. papyrus* biomass after measurements of culm-girth of different papyrus population, and life cycle within the quadrats. Productivity was computed from biomass difference between sampling intervals divided by number of days in each interval. Biomass and productivity values were reported per unit area.

Weather factors in the surface of *C. papyrus* wetland canopy

Temperature and relative humidity (RH) in the surface of *C. papyrus* wetland canopy were monitored using inbuilt sensors in the Skye Data Hog 2 logger, type SDL 5260 and changes in photosynthetically active radiation (PAR) was recorded using SKP 215/S/D/I 36961 pyranometer. These were used as indicators of critical weather factors. All weather variables (values) were averaged on 30 min interval from October, 2010 to August 2011. The stored weather data was regularly downloaded to a lap top



Figure 1. Mounted metallic tower in Lubigi wetland. On top are Data Hog 2 logger, anemometer and pyranometer. The pyranometer and anemometer are obscured by papyrus umbel structures.



Figure 2. Constructed access transects into Lubigi wetland.

computer using Skye software after every two weeks interval. The vapour pressure deficit (VPD) in papyrus canopy was calculated based on formula of FAO (1998). Minimum and maximum values of temperature and RH were used in the calculations to avoid lower estimation of mean saturation vapour pressure. A standard value for the atmospheric pressure (kPa) and psychrometric constant (kPa °C⁻¹) as a function of altitude was used.

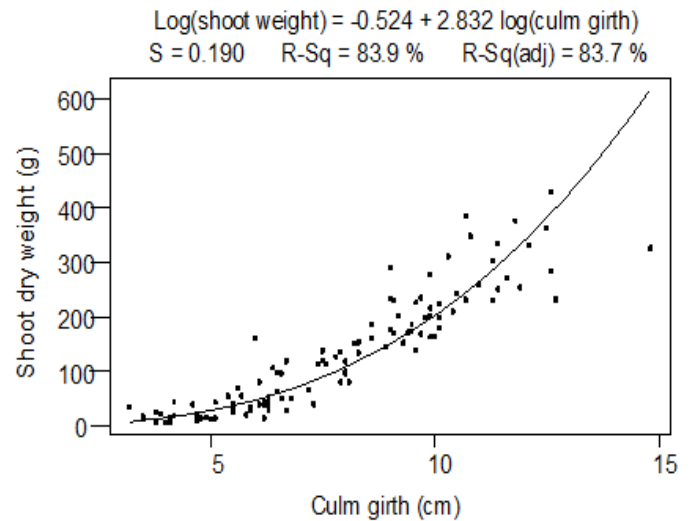


Figure 3. Relationship between culm-girth and dry weight of aerial shoots of *C. papyrus* in Lubigi wetland (n = 120) (Adopted from Opio et al., 2014).

Mean saturated vapour pressure (e_s) of the air

Saturated vapour pressure is related to air temperature and was calculated from the air temperature;

$$e_s = \{e^0 T_{max} + e^0 T_{min}\} / 2$$

Where T = Daily air temperature (°C).

$$e^0(T) = 0.6108 \exp\{17.27T / (T + 237.3)\}$$

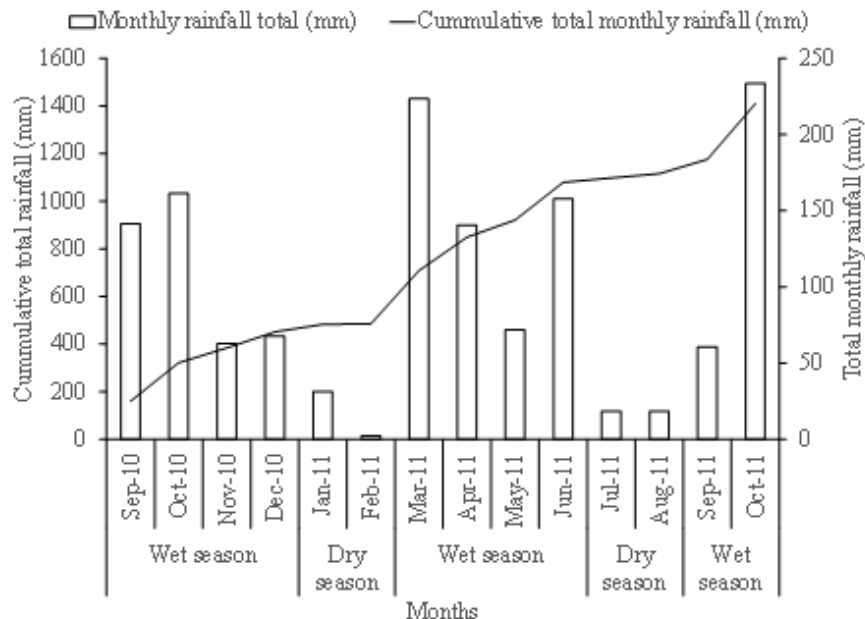


Figure 4. Total monthly rainfall and cumulative total rainfall distribution in Lubigi area.

$exp^{(0)} = 2.7183$ (base of natural logarithm) raised to the power $\{ \}$.
 $e^0(T)$ = Saturated vapour pressure at the air temperature $T(kPaC^{-1})$.

Actual vapour pressure (e_a) derived from relative humidity data of the air

Relative humidity (RH) was expressed as the degree of saturation of the air as a ratio of the actual (e_a) to the saturated vapour pressure $e^0(T)$ at the same temperature (T). It constituted the ratio between the actual amount of water, the ambient air had and that it could hold at the same temperature. Although the actual vapour pressure was considered relatively constant throughout the day, the relative humidity was considered a maximum near sunrise and minimum around early afternoon. Therefore, the calculation of vapour pressure was based on the mean RH data.

$$e_a = (RH_{mean}) / 100 \{ e^0(T_{max}) + e^0(T_{min}) \} / 2$$

Where

e_a = Actual vapour pressure (kPa)

RH_{mean} = Average relative humidity, defined as the average between RH_{max} and RH_{min}

RH_{max} = Maximum relative humidity (%).

RH_{min} = Minimum relative humidity (%).

$e^0(T_{max})$ = Saturated vapour pressure at daily maximum temperature (kPa).

$e^0(T_{min})$ = Saturated vapour pressure at daily minimum temperature (kPa).

Vapour pressure deficit ($e_s - e_a$) of the air (VPD) was the difference between the saturated (e_s) and actual vapour pressure (e_a) of the air. Total monthly rainfall data was also obtained from Makerere University weather station located about 2 km from Lubigi wetland. Cumulative monthly total rainfall was plotted to generate the seasonal characteristics. Ogallo (1989)

observed that during rainfall periods, much of the rainfall volume is accumulated and therefore the curve reaches its maximum curvature. Therefore, onset of the rainy seasons is determined from the curves as the first points of the maximum curvature.

Data analysis

Statistical analysis was done using Minitab software, Release 13 for windows. Non-parametric Kruskal-Wallis test was used to assess differences of biomass, productivity and weather values between dry and wet season. Multiple regression analysis was done to assess the relationship between independent variables (RH, temperature, PAR) and the dependent variable (productivity). Homogeneity of variance in data sets during the multiple regression analysis was automatically tested by Durbin - Watson statistics to ensure uniformity. All statistical values were considered significant at less than 0.05.

RESULTS

Monthly total and cumulative total rainfall distribution

The monthly total rainfall and cumulative distribution showed longer wet season compared to the dry seasons (Figure 4). The percentage rainfall in the dry season was below 50% of the minimal monthly rainfall during the wet season.

Papyrus aerial standing biomass and primary productivity (NPP) in Lubigi wetland

Biomass range was 1.80 to 6.69 kg m⁻² and 3.43 to 6.76

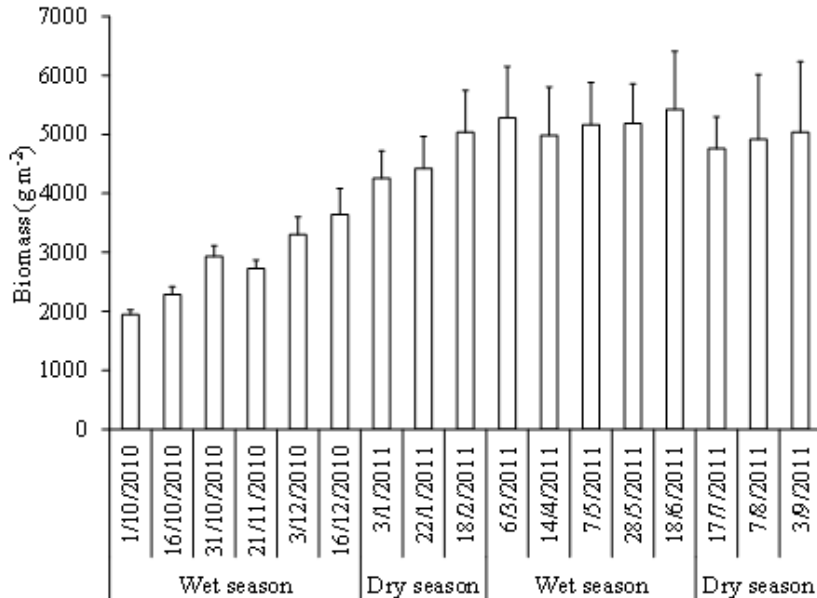


Figure 5. Mean aerial biomass of *C. papyrus* in Lubigi wetland. Error bars are standard error of means (n = 8).

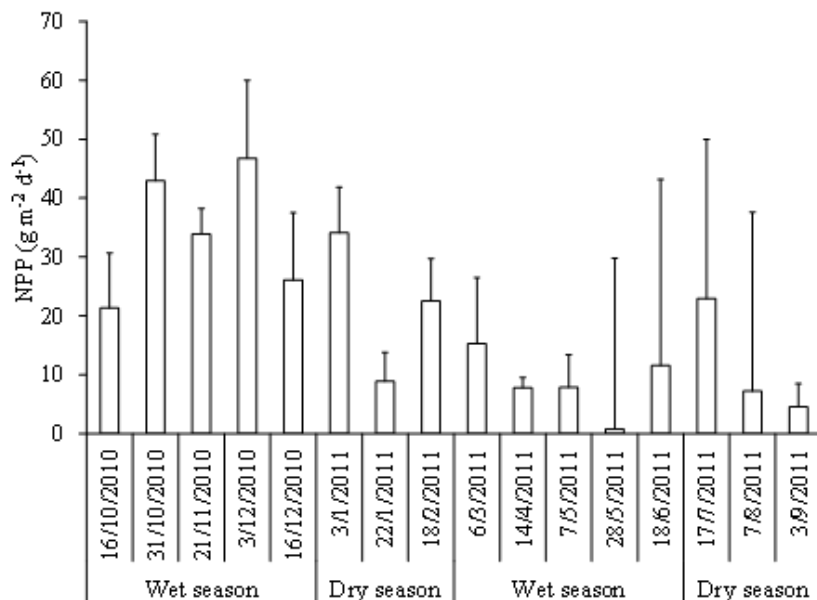


Figure 6. Mean primary productivity (NPP) of papyrus in Lubigi wetland. Error bars are standard errors of means (n = 8).

kg m⁻² during wet and dry season respectively (Figure 5). Kruskal-Wallis test of seasonal biomass differences was not significant (H = 31.15, DF = 15, p = 0.983). The increased trend of papyrus biomass up to February 2011 indicated a recovering ecosystem which is attributed to the effect of past massive papyrus harvesting. During the establishment of the quadrats, the papyrus culms appeared well established. NPP were not significantly

different between the seasons with mean values of 28.96±3.99 g m⁻² d⁻¹ and 25.99±6.35 g m⁻² d⁻¹ during wet and dry seasons respectively. NPP changes coincided with the months of biomass changes. The high variability during May, 2011 and August, 2011 (Figure 6) is attributed to some of the experimental quadrats that were covered by a climber, *Ipomoea purpurea*. The climber emerged in the wetland during the investigation period.

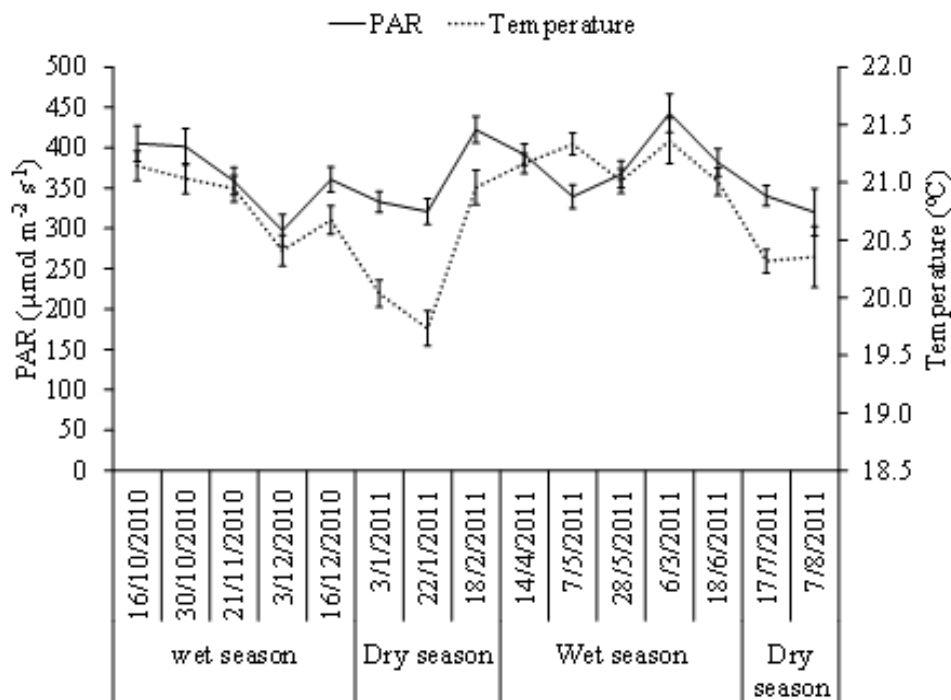


Figure 7. Mean temperature and photosynthetically active radiation (PAR) in papyrus surface canopy during the days of the year. Error bars are standard error of means.

The variability could also be related to the effect of the strong flow regime that disturbed the quadrats. Kruskal-Wallis test of NPP during the days of the year was not significant ($H = 22.37$, $DF = 15$, $p = 0.099$) except for the wet season from October, 2010 to December, 2010, and the dry months of February, 2011 and July, 2011 that were above the critical value (H) of $22.37 \text{ g m}^{-2} \text{ d}^{-1}$ which corresponded to the significance level.

Weather changes in *Cyperus papyrus* surface canopy

Temperature pattern was similar to PAR (Figure 7), and had higher range during wet season (12.7 to 30.6°C) compared to the dry season (11.2 to 31.1°C). Temperature changes were not significantly different since all values were below the critical value (H) ($H = 61.18$, $DF = 1$, $p = 0.00$) that corresponded to the significance level. Diurnal PAR range was 0 to $2332.6 \text{ μmol m}^{-2} \text{ s}^{-1}$ and 0 to $2031.6 \text{ μmol m}^{-2} \text{ s}^{-1}$ during wet and dry season respectively. Highest PAR coincided with the months of September and March. Although mean PAR was higher during the dry season, comparison of means indicated non-significant difference between seasons ($H = 0.54$, $DF = 1$, $p = 0.464$). VPD decreased to minimum values in the dry season, and increased to maximum values during the wet season (Figure 8). Seasonal comparison of VPD indicated significant difference during the days of the year ($p = 0.037$).

Relationship of aerial papyrus productivity with VPD, temperature and PAR

The overall relationship between weather variables and productivity was not significant during both dry and wet seasons ($p = 0.409$ and $p = 0.882$ respectively) (Table 1). The seasonal regression models for the relationships were:

$$\text{NPP (dry season)} = 0.34\text{PAR} + 1.24\text{VPD} - 1.39\text{Temperature} + 17.2$$

$$\text{NPP (wet season)} = 0.01\text{PAR} - 3.3\text{VPD} - 1.75\text{Temperature} + 69.7$$

Overall, weather variables explained productivity variance by 26.1% during the dry season, and that of the wet season was independent of the weather variables (0%).

DISCUSSION

The estimated NPP in Lubigi wetland were within the range reported by many authors (Thompson et al., 1979; Muthuri et al., 1989; Jones and Muthuri, 1997; Boar, 2006; Bakari et al., 2007). The non-significant difference in seasonal NPP conforms to the study by Muthuri et al. (1989) in Naviasha wetland, Kenya. However, NPP values were slightly higher than $22.1 \text{ g m}^{-2} \text{ d}^{-1}$ (Saunders et al., 2007) and $21 \text{ g m}^{-2} \text{ d}^{-1}$ (Muthuri et al., 1989). The

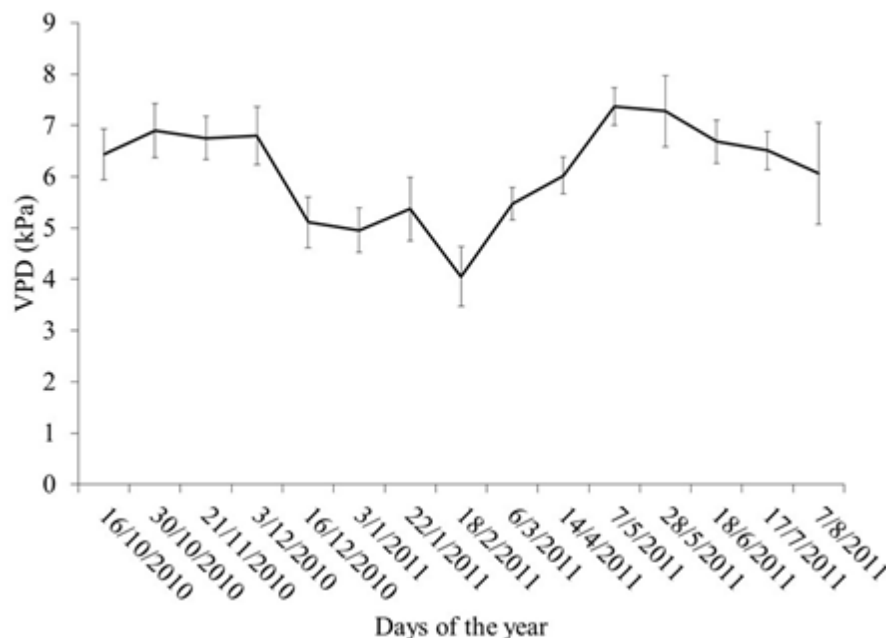


Figure 8. Mean vapour pressure deficit (VPD) in papyrus canopy during the days of the year. Error bars are standard errors of the means.

Table 1. Relationships between *Cyperus papyrus* aerial productivity with temperature, photosynthetically active radiation (PAR) and vapour pressure deficit (VPD) during the dry and wet seasons.

Variable	Productivity in dry season		Productivity in wet season	
	Regression coefficient	p-value	Regression coefficient	p-value
Temperature (°C)	-1.39	0.600	-1.75	0.869
PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	0.34	0.312	0.01	0.791
VPD (kPa)	1.24	0.405	-3.30	0.473

variability of 3.40 to 64.42 $\text{g m}^{-2} \text{d}^{-1}$ and 3.12 to 74.65 $\text{g m}^{-2} \text{d}^{-1}$ during wet and dry seasons respectively were broader compared to 24.7 to 34.1 $\text{g m}^{-2} \text{d}^{-1}$ range (Muthuri et al., 1989). Productivity differences in papyrus wetlands are attributed to structural differences which affect the amount of carbon that can be assimilated by the plant community (Jones, 1988). Beadle (1993) reported older or more complex community normally exhibit decreased productivity.

Mitsch and Jørgensen (1989) reported development of plants as a function of initial conditions and the strength of the conditions on the plants. The effects of dead biomass accumulation, high senescence and culm production contribution to the lowering of NPP have been investigated in plant (Leoni et al., 2009). Therefore, natural regeneration capacity in papyrus wetlands contributes to structural changes with effect on growth (Bakari et al., 2007). This is because papyrus wetlands exhibit establishment, growth and mortality concurrently (Muthuri et al., 1989), which imply a balanced trade-off of

resources characteristic of tropical environment. However, environmental factors have been reported to affect magnitude of growth, shift carbon allocation, change productivity and shift mode of reproduction (Hunt, 1982; Beadle, 1993; Fennessy et al., 1994; Jones, 1993). Coletti et al. (2012) indicated that short term and long term vegetation responses may also be counter-intuitive due to adaptability in water uptake strategy of the vegetation community partially decoupling biomass from water availability. Lowest ratios of measured transpiration and photosynthesis in plants in the middle of dry season at a time when stomata responded strongly during optimum of photosynthesis at high temperatures were reported (Schulze et al., 1975). Therefore, the feedback mechanism in carbon sequestration involves synergy of processes, where an initial process triggers changes in a second process that in turn influences the initial process. A positive feedback intensifies the original process, and a negative feedback reduces it.

In papyrus dominated wetlands, changes in seasonal

growth were thought to occur independent of relatively constant weather parameters (Saunders et al., 2007). In this study, although the variation of VPD was significant over the period; the relationship with productivity was not significant. High NPP was associated with increased PAR during both seasons. Increasing VPD reduced NPP during the wet season but was associated with the rising NPP during the dry season. Overall, impact variance of weather variables on NPP was zero during the wet season; imply productivity change is caused by other environmental factors. These include nutrient concentrations that were reported to increase papyrus growth (Kansiime et al., 2003; Mugisha et al., 2007; Kanyiginya et al., 2010).

The 26% productivity variance could be explained by weather variables during the dry season although the association was not significant. Efficiency of photosynthesis increases to a maximum with temperature rise and then decline (Saunders et al., 2007, 2012). While the rate of respiration continue to increase more or less up to the point that a plant dies (Turrall et al., 2011). Therefore, temperature effect is related to the influence of physiological changes (Pospišil et al., 2000). Related study of carbon dioxide flux model prediction and growth measurements suggest that increasing temperatures may result in substantial decrease in carbon sequestration and inputs to stored carbon in the underlying papyrus peat deposits (Humphries and Long, 1995). In this study, temperature was also negatively associated with productivity during both dry and wet seasons.

Conclusion

NPP was not significantly different between wet and dry season, and was not significantly influenced by the changes in temperature, VPD and PAR.

Conflict of Interests

The authors have not declared any conflict of interests.

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