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The influence of edaphic fertility on the dynamics of herbaceous net primary productivity in savanna ecosystem of Kebbi Central, Nigeria

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Abstract

Net Primary Productivity (NPP) is the rate at which biomass accumulate per unit area per time, minus amount of organic materials used for autotrophic respiration. This study aimed at determines the influence of edaphic fertility on herbaceous NPP. Soil samples were collected using soil auger at 0-15cm depth, and chemical parameters were analysed using standard methods. NPP was determined in 400 (1m x 1m) randomly selected quadrats, by clipping aboveground biomass of central 20cmx20cm quadrats and digging 40cm depth for collecting belowground biomass using hands and forceps. Fresh biomasses were oven dried at 65°C for 2days. Soil chemical properties were statistically significantly ($P<0.05$) higher in Site A, with pH (7.31±1.57), N (0.16±0.05%), P (12.33±0.93), Na (0.13±0.10), Mg (0.85±0.21), Ca (6.33±0.31), CEC (7.35±0.61), OC and OM had 0.45±0.02% and 0.77±0.01% respectively, but highest value of K (0.17±0.01) was recorded in Site D. ANPP shows a gradual increase from 15.00±2.5gm^{-2}/month in June to 154.03±11.23gm^{-2}/month in September, while BNPP ranges from 7.34±1.22gm^{-2}/month in June to 62.81±6.39gm^{-2}/month in October and the results was significant between the months ($p<0.05$). Between the Sites NPP varies significantly ($P= 0.0198$) and increase in the following trends; C<D<B<A with 138.8±10.01gm^{-2}/month), 142.73±13.55gm^{-2}/month, 148.5±8.51gm^{-2}/month, 189.54±14.67gm^{-2}/month respectively while BNPP was not statistically significant between the study Sites ($P= 0.282$). NPP is higher in edaphic fertile and neutral to slightly basic soil (pH= 7.31±1.57) than strongly acidic or basic soil. Further research on NPP of the most dominant species and the effect of climatic variables on NPP should be conducted.

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Introduction

Green plants absorbed light energy and atmospheric carbon dioxide to synthesised carbohydrate in the presence of water. Biomasses available above and below ground are the nutrients and energy sources that support secondary production on the earth (Haberl *et al.,* 2007). Net Primary Productivity (NPP) is the rate at which plants convert carbon dioxide and water into energy-rich carbon compounds per unit space and time. NPP is equal to the change in both aboveground and belowground plants biomass plus any loss over a particular period due death and subsequent decomposition of plant materials (Scurlock *et al.,* 2002; Li *et al.,* 2015), where NPP = $NPP_{aboveground}$ + $NPP_{belowground}$; $NPP_{aboveground}$ = $NPP_{standing\ biomas}$ + NPP_{litter}, while $NPP_{belowground}$ = roots biomass both dead and live biomass (Clark *et al.,* 2001). NPP are usually expressed as grams of oven dried biomass per unit area and time. E.g.$gm^{-2}yr^{-1}$, $month^{-1}$, $week^{-1}$, or day^{-1} or ($kcalm^{-1}$) yr^{-1} (Nag, 2015). NPP represents the net carbon retained by ecosystems after assimilation through photosynthesis and losses due to autotrophic respiration (Clark *et al.,* 2001; Li *et al.,* 2015).

It plays an important role in soil and water conservation, preventing wind erosion, sand fixation and air purification (Zhao *et al.,* 2014). Terrestrial NPP has attracted much attention among the scientific community because it is an incoming energy to the biosphere, and a measure of net carbon dioxide (CO_2) assimilation and serve as bases for assessing the status of ecological processes (Pan and Li, 2015).

However, NPP is a key component of energy and mass transformation in ecosystems (Clark *et al.,* 2001), an important indicator of ecosystem health and services (Running *et al.,* 2004), and a critical component of the global carbon cycle that provides linkage between terrestrial biota and atmosphere (Zhao and Running, 2004; Beer *et al.,* 2010; Piao *et al.,* 2011). Understanding terrestrial NPP variation is essential for understanding terrestrial carbon cycle, biosphere-atmosphere interaction and response of ecosystem function to climate change and CO_2 fertilization (Scurlock *et al.,* 2002).

Soil supports plant growth and acts as a reservoir of water and nutrients, medium for producing the food and fiber that maintained ecosystems functions on which all life ultimately depends (Voroney *et al.,* 2015; Salisu and Rabiu, 2019).

Soils directly and indirectly affect plants productivity and diversity, since primary producers required nitrogen and phosphorus, which are available as nitrate, ammonia and phosphorus (Ramirez *et al.,* 2007).

Herbaceous vegetation dominates Savanna ecosystem, provide forage for herbivores and soil carbon sequestrations, which regulates global terrestrial carbon cycle, and greenhouse gases like CO_2, CH_4 that exert influences on climate systems, as well as energy and water exchange (IPCC, 2001; Salisu and Rabiu, 2019; Xu, *et al.,* 2020).

Savanna contributes ecosystem functions to many of the world's major watersheds areas that provide a functional unit of the landscape (Scurlock and Hall, 2000). Herbaceous biomass are extremely important for livestock production by agro-pastoralist and nomadic herders that depend almost entirely on it (Dong *et al.,* 2011). Increased of human and livestock population, savanna ecosystem received threats due to excessive livestock grazing, seasonal burning, expansion of farm land, construction of houses, industries, roads, markets, schools etc. Adequate savanna management may influence the regional and possibly global energy, biodiversity, water and carbon balances (Santos *et al.,* 2003).

Herbaceous vegetation are expected to undergo major changes in the future due to increasing temperature, CO_2 concentration, rainfall patterns and subsequently changed variability in fire regimes and human activities (IPCC, 2007). This study aimed at determine the influence of edaphic fertility on Herbaceous NPP in savanna ecosystem, based on the following objectives; 1) To determine some soil chemical parameters; and 2) To determine monthly variation of NPP using destructive methods.

Materials and methods

Study area

Kebbi state located in the North-western Nigeria, between latitude 12.45° N and longitude 4.2° E. It covers a geographical land area of 36,800 km², borders with nation of Niger Republic to the west and Benin Republic to the South-east and locally bordered Nigerian states; Niger, Sokoto, Zamfara to the South, North and East respectively. The state marked by a single rainy season last from May to October with mean annual rainfall of about 720mm and long dry season last for the remaining period of the year (Baba *et al.,* 2014). The mean temperature range is 26°C during harmattan season (November to February) and 38°C-40°C during the month of April to June (Girma, 2008). Its vegetation is Northern Guinea Savanna in the South and South-East and Sudan Savanna in the North, covers with short grasses and small trees. Although, the state face desertification but still being altered in many areas by cultivation, grazing, cutting of fuel woods, excavation of soil, bush fire and so on.

The study was conducted in four Sites including Aleiro located between longitude 4.4388° E and Latitude 12.3562° N, Kalgo 4.2000° E and Latitude 12.3342° N, Argungu 4.5367° E and Latitude 12.7495° N and Bunza 4.0108° E and Latitude 12.0916° N, all the study Sites was protected from anthropogenic activities during the period of research.

Experimental design

Completely Randomize Design (CRD) was adopted for monthly sampling due homogeneity of the experimental Sites, for chosen 20 (1m² x 1m² quadrats) on each sampling date per plot. An online random number table was used in generating 400 (1m² x 1m² quadrats) throughout the study periods and plants species occur at the 20 x 20cm central square quadrats were identified (Ovington *et al.*, 2012).

Plots dimension and demarcation

One plot (30m x 30m) in each study site was marked out and demarcated with iron rods (2 meter above the ground), surrounded with red rough for monthly sampling from June to October, 2020. The plots were divided into quarters and each quarter were then divided into grids of 1m x 1m quadrats to give a total of 225 quadrats (Ovington, *et al.,* 2012).

Plants identification

Plant species occur in the central 20cm x 20cm randomly selected quadrat were identified *in-situ* based on their morphological, structural and floral characteristics with the aid of West African Weeds (Ivens, 1973). Identified plants species were placed in a hard cover exercise book and labelled with codes, transported to Herbarium, Department of Biological Sciences, Federal University Birnin Kebbi (FUBK), Nigeria, for confirmation of species.

Clipping and drying of herbaceous biomass

All aboveground living tissues (leaves, stems, inflorescences and fruits produced during the growing period) of plants at the ground level of central 20cmx20cm randomly selected quadrat were clipped with hand scissors (Ovington *et al.,* 2012). Clipped plant materials were collected, sorted by hands into green and standing dead components directly in the field and longer biomass were cuts with knife into pieces for easy placing into paper bag/s (Condit, 2008). Below ground biomass were collected by digging out 40cm pit, using soil core and hand trowel (Ovington *et al.,* 2012). Live roots were collected with hands and forceps by trial sampling to retrieve at least 80% of roots, and then washed through 2mm sieves (Todd *et al.,* 1998), the sample was allowed to be free from external moisture at a room temperature. Biomass was put in a Paper bags and then transported to the laboratory, to determine fresh weight using a 0.01g sensitive electrical weighing balance (Sartorius ED224S). Paper bags containing the sample were placed into laboratory Oven (DHG-9023) for drying at 65°C for 48hrs.

Collection and preparation of soil samples

Soil samples were collected from the study sites, after clipping aboveground biomass. Twelve samples were randomly collected from each Site at 0–15cm depth using soil auger. The samples were homogenize to make a composite sample and stored in a labelled polythene bags.

The sample was air dried at room temperature for 3 days and then ground with ceramic mortar and pestle to loosen the compacted soil particles. The grounded soil was sieved through a 2mm mesh-size to removed stones and plants particle.

Laboratory analysis

Soil chemical parameters were analysed using standard methods such as Nitrogen (%) using Kjeldahl digestion method (Onyeika and Osieji, 2003), Potassium (cmol/kg) using atomic absorption spectrophotometer (Emmanuel *et al.,* 2014), Phosphorous (mg/kg) using atomic absorption spectrophotometer (Nag, 2007), Organic Carbon (%) using Walkely and Black (1934) method, and Organic matter (%) using method adopted by Fawole and Oso (2004) and Tening *et al.* (2013).

Data analysis

Net primary productivity (NPP) and soil chemical parameters were analysed using General Linear Model on Minitab (Version 18) at 95% confidence interval. The results were considered statistically significantly different when $p<0.05$ and non-significant when $p>0.05$ at 95% confidence interval.

Results and discussion

Soil chemical parameters

The results of soil physicochemical properties in the four study Sites are presented in Table 1. The maximum soil pH 7.31±1.57 values was recorded in Site A and indicating neutral to a slightly basic soil, while Site B and D soil were moderately acidic with soil pH of 5.99±1.22 and 5.93±1.32 respectively and Site C soil is strongly acidic with pH 4.64±1.14.

The higher concentration of soil pH in Site A might possibly be due species richness and accumulation of organic matter. Soil pH affects the abundance, nutrient availability and activity of soil decomposer organism. When soil pH is near neutral (pH = 6.5-7.5), species richness and productivity is high and are often best for availability of nutrients, but declining in both acidic and alkaline soil (Nicol *et al.,* 2008). Soil nutrients including nitrogen (N), phosphorous (P) and potassium (K) in this study ranged from a minimum of 0.09±0.21% in Site C to a maximum value of 0.16±0.05% in Site A, 6.53±0.16 mg/kg in Site C to 12.33±0.93mg/kg in Site A and 0.11±0.09cmol/kg in Site B to 0.17±0.01cmol/kg in Site D respectively, Table 2 shows that, the results were statistically significant ($P<0.05$).

The pattern of total Nitrogen content observed in Site A could be related to the high content of soil organic matter since it is the main source and store of soil Nitrogen. Soil with high organic matter would have high concentration of nitrogen, while soil with low organic matter content will have less mineralization potential (Carney *et al.,* 2004; Salisu and Rabiu, 2019). The highest value of phosphorous may possibly related to the highest value of organic matter recorded in Site A, since it is organic matter that makes exchangeable cat-ions available to plants, and the relative proportion of nitrogen and phosphorous in the soil are important for determine the concentration of potassium in the soil (Salisu and Rabiu, 2019). Exchangeable bases in this study ranges from 0.08±0.04 (Site B) to 0.13±0.11 (Site A and B), 0.61±0.11 (Site C) to 0.85±0.21 (Site A) and 4.19±0.32 (Site C) to 6.33±0.31 and there concentrations decreases in the following series; $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$.

The maximum mean value of soil organic carbon and soil organic matter was recorded in Site A with 0.45±0.02% and 0.77±0.01%, followed by Site C with 0.35±0.05 and 0.60±0.01% respectively and the results were statistically significant ($P<0.05$) at 95% confidence interval, while the minimum concentration of soil organic carbon and soil organic matter was recorded in Site B. These values indicated significant presence of inorganic ions or ionisable materials in the soil. Plants may also alter soil properties through processes such as nitrogen fixation, nutrient cycling, aluminum detoxification, and indirectly by the volume and quality of litter deposition (Gessner *et al.,* 2010; Salisu and Rabiu, 2019). Soil chemical properties were statistically significant ($P<0.05$) at 95% confidence interval.

Table 1. Mean±S.E of Soil Chemical Parameters of Four Study Sites, 2020.

Soil Parameters	Sites				Remarks
	A	B	C	D	
Soil pH	7.31±1.57	5.99±1.22	4.64±1.14	5.93±1.32	The soil in the study Sites are moderately acidic, while Site A soil is neutral to slightly basic.
N (%)	0.16±0.05	0.12±0.04	0.09±0.21	0.15±0.01	N concentration is higher in Site A and D, and lowest in Site C.
P (mg/kg)	12.33±0.93	7.06±0.22	6.53±0.16	6.77 ±0.33	Concentration of P is almost the same in Site B, C and D, while Site A differ significantly higher.
K^+(cmol/kg)	0.15±0.11	0.11±0.09	0.13±0.06	0.17±0.01	K^+ is relatively similar in the study Sites
Na^+	0.13±0.10	0.08±0.04	0.09±0.06	0.13±0.11	Na^+ is equal in site A and D, while similar in Site B and C.
Mg^{2+}	0.85±0.21	0.61±0.11	0.66±0.13	0.76±0.18	Mg^{2+} in the study Sites differ in this order; A > D > C > B.
Ca^{2+}	6.33±0.31	4.28±0.35	4.19±0.32	4.63±0.21	Ca^{2+} is higher in Site A (6.33±0.31) and relatively similar in Site B, C and D with the following trend D > B > C.
CEC	7.35±0.61	4.99±0.43	4.89±0.39	6.51±0.88	CEC is higher in Site A, and relatively similar in Site B and C.
O.C (%)	0. 45±0.02	0.31±0.07	0.35±0.05	0.34±0.02	Organic matter and organic carbon found to be higher in Site A, followed by Site C and lower in Site B.
O.M (%)	0.77±0.01	0.53±0.33	0.60±0.01	0.58±0.08	

Table 2. Analysis of Variance (One-way ANOVA) of Soil Chemical Parameters and NPP in the Study Sites.

Parameters	Source of Variation	AdjSS	df	AdjMS	F	P-value
ANPP	Sites	3021.039	3	1007.013	3.322184	0.019845
	Error	118822.1	392	303.1177		
	Total	121843.2	395			
BNPP	Sites	193.4781	3	64.49269	1.282428	0.280025
	Error	19713.5	392	50.28954		
	Total	19906.98	395			
TNPP	Sites	91204.75	3	30401.58	28.88541	6.8E-17
	Error	412575.7	392	1052.489		
	Total	503780.5	395			
N	Sites	0.033006	3	0.011002	15.1406	2.42E-09
	Error	0.284848	11	0.000727		
	Total	0.317854	14			
P	Sites	662.3541	3	220.7847	8.889581	1.03E-05
	Error	9735.848	11	24.83635		
	Total	10398.2	14			
K	Sites	0.324208	3	0.108069	78.57037	8.16E-40
	Error	0.539175	11	0.001375		
	Total	0.863383	14			
O.C (%)	Sites	8.551024	3	2.850341	181.4016	9.5E-74
	Error	6.159447	11	0.015713		
	Total	14.71047	14			
O.M (%)	Sites	25.51497	3	8.504991	120.3399	2.96E-55
	Error	27.70451	11	0.070675		
	Total	53.21948	14			
Ca^{+2}	Sites	0.311754	3	0.103918	0.126988	0.943752
	Error	49.09998	11	0.818333		
	Total	49.41173	14			
Na^{+2}	Sites	49.41173	3	5.73E-08	0.016153	0.997171
	Error	1.72E-07	11	3.55E-06		
	Total	0.000213	14			
Mg^{+2}	Sites	0.000567	3	0.000189	0.458913	0.712011
	Error	0.024719	11	0.000412		
	Total	0.025286	14			
CEC	Sites	133.973	3	22.3288	12.3296	3.97E-09
	Error	54.8288	11	0.8703		
	Total	55.3426	14			

The P-Values in Bold are statistically non-significance at 95% confidence interval.

Variation of herbaceous net primary productivity (NPP) in Savanna ecosystem

During the study period when the community above and below ground biomass was harvested, Net Primary Productivity (NPP) differed significantly between the months as well as between the study Sites. Generally, minimum ANPP and BNPP occurred in June (when most plants started growing) and the maximum ANPP was measured in September (when most plants attained the maturity stage), while maximum BNPP was measured in October due to soil moisture and lack of aerial growth. Fig. 1 revealed gradual increase of ANPP, BNPP and Total Net Primary Productivity (TNPP), from a minimum values in June; 15±2.5gm^{-2}/month, 7.34±1.22gm^{-2}/month and 22.83±2.66gm^{-2}/month respectively to a maximum values of ANPP in September (154.03±11.23gm^{-2}/month), and decreased in October (141.15±12.44gm^{-2}/month), while BNPP continuously increasing to maximum values in October (62.24±6.39gm^{-2}/month). Between the months, ANPP and BNPP were statistically significant at 95% confidence level, using general linear model ($P<0.05$).

The monthly gradual increase of above and belowground net primary productivity is due to continues growth and development of plant species, since soil nutrients and water are available and are required by all living organisms for survival, when other environmental factors are favourable. The minimum TNPP recorded in June might be related to the onset of rainfall that allowed plants germination, slow growth and developments, while the maximum TNPP recorded in September may possibly be due to the influence of their life cycle, because most grasses and herbs reaches their maximum life stages at the end of September.

Thus, decreased at the end of October may be related to the shortage of rainfall and increased in temperature stress, since plants can be stress by lack of moisture as well as increased in temperature. With regard to below ground biomass that shows a slight increase at the end of October it may be due to the limited soil moisture that enables it to continue growing.

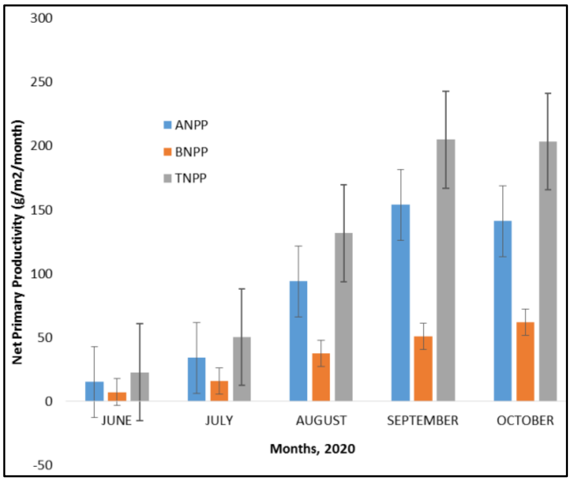

Fig. 1. Monthly Aboveground, Belowground and Total Net Primary Productivity of the Study Sites, 2020. Mean Values of ANPP, BNPP and Total NPP for Study, 2017.

Among the study Sites Fig. 2 shows, the highest ANPP (132.9±11.71gm^{-2}/month) and BNPP (49.64±4.32gm^{-2}/month) values recorded under Site A, followed by Site C with 105.32±7.65gm^{-2}/month and 43.20± 2.73gm^{-2}/month, ANPP and BNPP respectively, while the lowest ANPP (98.52±8.72gm^{-2}/month) and BNPP (40.29±2.43gm^{-2}/month) was recorded under Site B and the results of ANPP was statistically significant ($P<0.05$) at 95% confidence interval (Table 2), while BNPP was not statistically significant ($P>0.05$) at 95% confidence interval. The variation of net primary productivity in the study Sites may be due to soil influence and plants species composition, since the four study Sites are located in similar geographical location receiving almost the same amount of temperature and precipitation. In Nigerian, Milligan and Sule (1990) provides the approximate range of maximum productivity of herbaceous biomass in September or October ranges between 150gm^{-2}-1800gm^{-2} and may differed due to differences in climate, rainfall, soil and human activities such as burning, livestock grazing and farming (Aina *et al.,* 2013). These factors affect both distribution, diversity and productivity of savannah vegetation. Usman (1990), in the Northern part of Nigeria (Kainji lake National Park) obtained a range of 115.05 to 468.73gm^{-2} and De-Leeuw (1978) obtained a ranges from 201gm^{-2} to 450gm^{-2} in North-Eastern Nigeria.

A mean of $1092.62 gm^{-2}$ was obtained from Opi-lake area, Eastern Nigeria (Usman, 1990), while Isichei, (1979) reported $448 gm^{-2}$ for Olokemeji-Western Nigeria and $331 gm^{-2}$ for Igbeti, Southern Nigeria.

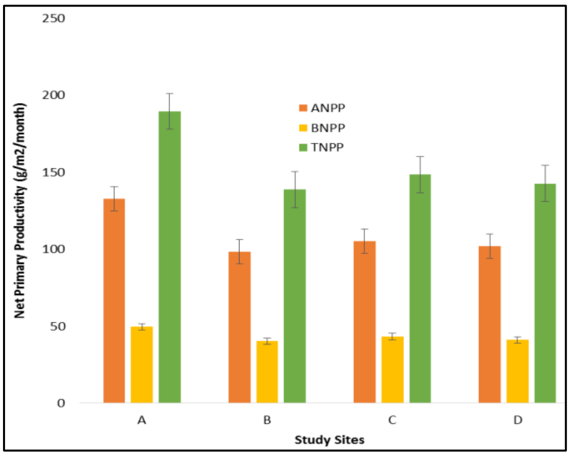

Fig. 2. Aboveground Net Primary Productivity, Belowground Net Primary Productivity and Total Net Primary Productivity of the Study Sites, 2020.

Conclusion

Herbaceous Net Primary Productivity is higher in neutral to slightly basic soil than strongly acidic or basic soil. The results shows higher productivity in soil near neutral to slightly basic and high availability of edaphic fertility that supports rapid plant growth and development, while productivity declining in strongly acidic soil. High soil organic matter is among the most important parameters affecting soil nutrients, while Nitrogen and phosphorus gradually increased with an increase of soil organic matter. From the results, herbaceous NPP continuously increase slowly from the onset of rain according to the rate of plants growth and become maximum toward the completion of herbaceous life cycle. However, soil chemical parameters are strongly affecting herbaceous Net Primary Productivity in terrestrial ecosystems.

Recommendations

i. Further research on Net primary productivity of the most dominant herbaceous species should be conducted.
ii. Research should be conducted to study the effects of grazing, Nitrogen and Phosphorous amendment on the productivity.
iii. The relationship between species diversity and productivity of herbaceous species should be determine.

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Abbreviation

NPP= Net Primary Productivity, BNPP= Belowground Net Primary Productivity, TNPP= Total Net Primary Productivity, O.C= Organic Carbon, O.M= Organic matter and CEC= Cat-ions Exchange Capacity.

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