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Original Research Article

Effect of Fire on Biomass Accumulation and Productivity of Herbaceous Plants in the Permanent Site, Usmanu Danfodiyo University, Sokoto, Sokoto State, Nigeria

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ABSTRACT

The effects of fire on biomass structure and productivity of herbaceous plants of the Biological Sciences Garden, Permanent site, Usmanu Danfodiyo University, Sokoto (UDUS) were investigated in this study. The experimental site was divided into plots A and B. Plot A was treated with fire (burnt) and plot B was protected from fire (unburnt). The plant samples were hand-clipped in five replicates from each plot after selection by random throws of $20cm^2$ quadrat and their wet and dry biomass determined using an electric weighing balance. It was found that above ground biomass of the herbaceous plants in the burnt plot were higher than that in the unburnt plot. Significant differences were observed between the plant biomass of the burnt plot and unburnt plot for the interval of June to October sampling period at $P<0.05$. The Net Primary Production (NPP) values of the above ground biomass in the burnt plot was found to be 0.0414kg/ha compared with 0.0271kg/ha in the unburnt plot ($P<0.05$). The study also shows grasses and forbs vegetation cover with total count of pin hits on the plant cover as 421 and 284 for burnt plot and the unburnt plots respectively. The study has demonstrated high biomass yield in the burnt plot, indicative of better pasture. With enlightenment and proper control, fire can be used especially in designed grazing areas to provide good nutrition to livestock.

Keywords: Fire, Biomass, Accumulation, Productivity, Savanna, Herbaceous plants

INTRODUCTION

Fire plays a critical role in savannah ecology through direct and indirect effects on interactions between woody and grass species, most savannah fires are surface fires and burn mainly the ground layer of the vegetation (Baruch & Bilbao, 1999; Hoffmann et al., 2012). As a consequence, the accumulation of grass biomass determines the future fire intensity and rate of spread. Accumulation of biomass in the ground layer, especially grasses, increases the probability of ignition, fire intensity and fire extent, in contrast, woody biomass accumulation especially tree cover and stem density has a negative effect on grasses through shading and competition for resources (Cianciaruso, da Silva, & Batalha, 2010). Fire promotes primary productivity by accelerating nutrient cycling, fire decreases growth rates and seedling survival of woody species, but also has an indirect positive effect via the release of nutrients to the soil (Miranda, Bustamante, Miranda, Oliveira, & Marquis, 2002). This pulse of available nutrients is rapidly acquired by shallow-rooted grass species. Hence, fire can transfer nutrients from woody species to grasses (Silva & Batalha, 2010).

Fire and grazing have been the most common disturbances in many grassland and savannah ecosystems for many centuries. However, fire plays a more important role than grazing in forming these savannah dynamics (Carilla, Aragón, & Gurvich, 2011). There are extreme biotic demands on savannah resources such as imprudent use of fire, increased grain cultivation, increased utilization by livestock and urbanization. Savannahs in Nigeria are subjected to annual burning, mostly caused by man (Pantami, Voncir, Babaji, & Mustapha, 2010). It is a well-known fact that fire is not only caused by man but also by certain natural agents such as volcano, earthquake, moving boulders, thunder and lightning (Oono, 2010). However, it is said that although natural agents may cause fire, man is known to handle fire on daily basis due to several reasons. These reasons include, to expand his farmland, obtain new flush of grasses for grazing livestock, remove parasites, hunt game animals, thin down woody vegetation and even for mere satisfaction (Aina, Okayi, & Usman, 2013).

In Nigeria, fire is much more in use than ever before, hence, some plants and animals are reported to depend on fire for good health (FAO, 2004). Many land managers acknowledged that lack of bush burning in some areas may cause dangerous fuel accumulations, which may result in catastrophic fires, diseases and insect problem resulting from deterioration of range, reduced wildlife carrying capacity and decreased watershed yield. This indicates that fire is an essential tool for improvement of savanna with a combination of tree growth and livestock/wildlife management. Over 80% of Nigeria's surface area of about $924,000km^2$ is covered with Savanna (Aina et al., 2013). It becomes imperative that enough attention be given to this vegetation formation as well as its causes for maximum yield. It is of major importance in the country's agricultural economy. Savannas are the main source of food for livestock and other animals, which provide most of Nigeria's meat and milk (first class protein) as well as hides and skins (Fasae, Sowande, & Adewumi, 2010).

MATERIALS AND METHODS

Study area

This research work was carried out in the Biological Sciences Garden(situated between Longitude 5° 11" 30'E and 5° 14" 30'E and Latitude 13° 8" 30'N and 13°7"0'N (Arc GIS, 2016) (Figure 1) of Usmanu Danfodiyo University, Sokoto, Permanent site in Wammako Local Government Area of Sokoto State, Nigeria (SERC, 2014). Sokotolies between Longitude 4^{o}8'E and 6^{o}54'E and latitude 12^{o}N and 13^{o}58'N with an attitude of 351m above sea level within Sudan Savanna Region of Nigeria. The climate of the area is hot, semi-arid tropical type. It is characterized by a long and severe dry season lasting from October to May, and short but intensive wet season from May/June until September. The rainfall pattern is characteristically distributed with a peak in August. Sokoto falls under the Sudan savanna agro-ecological zone (North-Western Nigeria). The area has annual rainfall range of 550-700mm and mean annual temperature ranging from 38^{o}c to 42^{o}c or more around April. The lowest mean temperature in December-January (Harmattan period) is about 13-15 ^{o}c. The mean maximum temperatures are highest generally from Mach to June. The mean relative humidity reaches its peak of over 90% in August and lowest in December and January (10-30%) (SERC, 2014). There are hot humid days during the raining days (Adejuwon, 2016). The soil of the area is sand-loam. Wind direction is North-West and south-west for dry and wet seasons respectively (SERC, 2014).

A piece of demarcated land measuring 30m by 18m was divided into two separate plots; (A and B) of 30m by 9m each. Plot A was subjected to a controlled burning while plot B was left unburnt. Five replicate (n=5) samples of the plant species were then sampled by harvest method (Wang, Sample, Day, & Grizzard, 2015) from each plot at the end of every month from June to September, 2015 with the use of a 20x20cm quadrat and their wet and dry biomass were determined using a weighing balance. The dry weight of the plant sample was obtained by oven drying to a constant weight at 75^0c for 24hrs.The experiment was set up in a Complete Block Design (CBD). Mean of five replicates was taken from each plot at the end of every month and compared. The 20cm x 20cm quadrat was first thrown backward into each plot at random by standing at the edges of the plots to obtain five random (replicate) samples from each plot. The above ground parts of the plants in each quadrant was clipped separately by a scalpel into the number of random samples in each plot and then taken to the Ecology laboratory for further investigation. The below ground parts were also collected by digging round the plant to a depth of about 20-30cm to gently remove the roots with a fine jet of water (Thakur, Kumar, & Kunhamu, 2015)

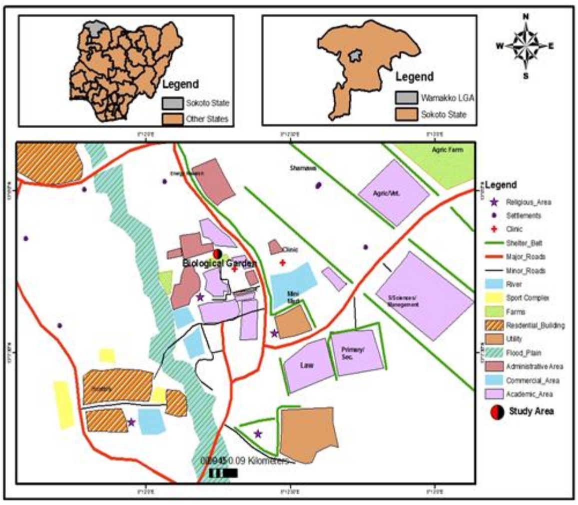

Figure 1: Map of Usmanu Danfodiyo University, Sokoto, showing the Biological Sciences Garden (The study Area

The Net Primary Production (NPP) of the above aground parts including green and non-green parts and below ground parts of the plants was determined by summing all the positive values of the increase in mean dry biomass (kg/ha/month) respectively in the burnt and unburnt plots within the sampling periods from June to October and recorded appropriately(Mganga et al., 2010). Point frame estimates was used to determine the percentage cover of the herbaceous plants in plots A and B (the burnt and the unburnt plots respectively) in the following ways:

An improvised pin frequency frame of 10 pins 10cm between pin and 100cm height was placed vertically in an area within the plot each covered with vegetation. A thin metal pin slid into the guide hole was lowered through the frame until it reaches the plant cover and down to the ground. Number of hits on the vegetation by each pin was counted as against the number of the frame placements (10) that was made (Mapako, 2011). The percentage cover of the plant was calculated using the formula bellow:

% cover= Number of hits on the vegetation per placement x 100
Hit total of the frame

RESULTS AND DISCUSSION

Wet and Dry Biomass: Results of the wet and dry biomass of the above and below ground parts of the herbaceous plants in the burnt (plot treated with fire) and unburnt (controlled) plots are presented in Tables 1 and 2. The wet and dry biomass of the above parts of the plants in the plot treated with fire were compared with that in the control plot as well as wet and dry biomass of the below ground parts (Table 2) respectively on monthly basis from June to October, 2015, expressed in kilogram per hectare (kg/ha). The result in Table 1 shows that there is significant difference at $P<0.05$ in wet biomass (0.0100 and 0.0026) of the burnt and unburnt plot in June, (0.0107 and 0.0013) in July and dry biomass (0.0098 and

0.0022) in June. No significant difference in dry biomass in July, wet and dry biomass in August as well as dry biomass in October.

Significant difference was also observed at P<0.05 in wet biomass of July (0.0171 and 0.0107), in dry biomass (0.0224 and 0.0142) in September. The values increased systematically from June to September in both wet and dry biomass of the above ground parts of the plant with a decrease in dry biomass of above in October. In Table 2, significant difference is only shown at P<0.05 in the wet biomass (0.0013 and 0.0010) in June and in July wet (0.0024 and 0.0013) in below ground parts.

Table 1: Biomass of Above Ground parts of Herbaceous Plants on Wet and Dry Weight Basis between the Burnt and Unburnt plots, June to October, 2015 (kg/ha).

MONTH	WET/DRY	BURNT PLOT	UNBURNT PLOT	LEVEL OF SIGNIFICANCE
June	Wet	0.0100±0.0038	0.0026±0.0009	0.039*
	Dry	0.0098±0.0024	0.0022±0.0005	0.021*
July	Wet	0.0171±0.0046	0.0107±0.0013	0.037*
	Dry	0.0041±0.0011	0.0028±0.0040	0.072^{NS}
August	Wet	0.0455±0.0133	0.0293±0.0080	0.511^{NS}
	Dry	0.0164±0.0062	0.0086±0.0023	0.233^{NS}
September	Wet	0.0511±0.0096	0.0367±0.0037	0.079^{NS}
	Dry	0.0224±0.0043	0.0142±0.0014	0.012*
October	Wet	0.0537±0.0115	0.0295±0.0079	0.687^{NS}
	Dry	0.0189±0.0060	0.0098±0.0049	0.252^{NS}

Values are expressed as Mean±Std Error mean of n=5.
NS – Not Significant. * - Significant at P<0.05.

Table 2: Biomass of Below Ground parts ofHerbaceous Plants on Wet and Dry Weight Basis between the Burnt and Unburnt plots, June to October, 2015 (kg/ha).

MONTH	WET/DRY	BURNT PLOT	UNBURNT PLOT	LEVEL OF SIGNIFICANCE
June	Wet	0.0013±0.0004	0.0010±0.0002	0.009*
	Dry	0.0010±0.0003	0.0004±0.0001	0.070^{NS}
July	Wet	0.0024±0.0007	0.0013±0.0010	0.033*
	Dry	0.0008±0.0002	0.0005±0.0001	0.101^{NS}
August	Wet	0.0037±0.0010	0.0034±0.0007	0.763^{NS}
	Dry	0.0015±0.0005	0.0012±0.0003	0.535^{NS}
September	Wet	0.0038±0.0008	0.0025±0.0003	0.310^{NS}
	Dry	0.0023±0.0005	0.0014±0.0002	0.276^{NS}
October	Wet	0.0062±0.0008	0.0037±0.0006	0.535^{NS}
	Dry	0.0023±0.0006	0.0014±0.0003	0.290^{NS}

Values are expressed as Mean±Std Error mean of n=5.
SN – Not Significant. * - Significant at P<0.05

The biomass production herbaceous plants were significantly higher in the above ground parts in the burnt plot than in the unburnt plot. This result suggests that fire stimulates biomass production of the above ground parts of grasses and forbs in Savanna vegetation. This is in agreement with other studies on savannas(Kozlowski, 2012; Soong & Cotrufo, 2015) which showed that fire has significant role on forage production and biomass structure of grassland and Savanna regions. The decrease observed in the value of biomass production in the month of October may be as a result of decrease in the growth of plant species after the rain had stopped, suggesting that biomass production is also dependent on water availability. However, the biomass of the herbaceous plants in the below ground parts of the plants in the burnt plot remained significantly higher than that in the fire protected plot. This agrees with the earlier report of (Booysen & Tainton, 2012; Pivello et al., 2010) who noted that primary production of the herbaceous and woody plant species are generally higher in savanna region with early burning than the region with late burning and fire protection. This result is also consistent with other studies by Hopkins (1965) and Afoloyan (1988), who were all of the opinion that fire destroys trees and shrubs, prevents forest encroachment and grassland production.

The observed higher biomass production of both grasses and forbs in the burnt plot could be attributed to an increase in growth resource such as light and nutrients which favours seedling recruitment and establishment. Besides, change in soil temperature during burning could have important repercussions for post fire plant development. The nutrient released may then facilitate post-fire plant growth. It is therefore not surprising that higher grasses and forbs biomass occurred at some stage after burning in the burnt plot than in the non-burnt plot.

Furthermore, the germination of many seeds often stimulated by fire, hitherto function as a pre-germination treatment for such seeds (Russell *et al*., 2000). In agreement with other studies in African Savannas, this result on biomass structure shows that burning affect the Savanna structure of the study area by removing dead materials including litter and through post fire growth (Fynn, 2012; Stock, Bond, & Van De Vijver, 2010). This result further showed temporal differences in plant biomass structure between the burnt and non-burnt plots. Fire was found to stimulate growth at early post-fire stages, even throughout the sampling period (June to October, 2015). This finding agrees with the results of other studies in grasslands showing that fire stimulates re-growth(Green, Roloff, Heath, & Holekamp, 2015; Strauch & Eby, 2012)and the standing crop of leaves(Hassan & Rija, 2011).

Net Primary Production: The (NPP) of the plants under consideration within the sapling periods was determined as presented in Table 3. The positive value of the NPP in the burnt plot (0.0414kg/ha) as against (0.0271kg/ha) in the Unburnt plot in Table 3 significantly shows that there is higher net primary production in the burnt plot than in the unburnt plot.

Table 3: Determination of Net Primary Production (NPP) of Above Ground and Below Ground Parts of the Herbaceous Plants in the Study Plots (kg/ha) in 2015.

MONTH	BURNT	PLOT	UNBURNT	PLOT
	Above Ground	Below Ground	Above Ground	Below Ground
June	---	---	---	---
July	-0.0057	-0.0003	0.0006	0.0002
August	0.0414	0.0007	0.0265	0.0007
September	-0.0232	0.0008	-0.0151	0.0001
October	-0.0035	0-0000	-0.0044	0.0000
NPP VALUES	0.0414	0.0015	0.0271	0.0004

The Net Primary Production (NPP) values of the above ground biomass of the herbaceous plants, including green and non-green parts in the burnt plot was found to be significantly higher compared with that in the unburnt plot most likely because fire stimulates biomass production or accumulation in savannas. This result agrees with the findings of Brockway and Lewis (1997), who observed that standing biomass of herbaceous plants in Savanna to be higher on all fire treated plots than the control areas. This also concurred with the findings of (Augustine, Derner, & Milchunas, 2010)that certain ecosystems periodically treated with fire are known to produce two or more times more herbaceous biomass than those unburned. Other authors concluded that burning resulted in an increased accumulation of carbohydrates due to improved plant growth conditions (Rose, Raymond, Bloomfield, & King, 2015). Although a number of studies have shown that frequent fires affect herbage production, litter accumulation, and following stalk production of the burned prairie sites (Soong & Cotrufo, 2015). Except in very wet, very cold or very dry regions; fire has always been an important factor in terrestrial environment.

Percentage Cover of the Herbaceous Plants: The percentage cover of the herbaceous plants in the study plots was estimated by point frame quadrat. The number of hits was counted against each pin per placement, summing up as 421 and 284 as presented in Tables 4 and 5 for the burnt and unburnt plots respectively, showing that the vegetation cover of the burnt plot is higher than that of the unburnt plot. Each totalhit per placement was expressed in percentage (See Table 4 and 5).

Table 4: Percentage Plant Cover Estimate of the Burnt Plot in the Biological Sciences Garden, Permanent Site UDUS in August, 2015.

NO. OF FRAME	NUMBER OF HITS PER PIN									HIT	TOTAL
PLACEMENT	1	2	3	4	5	6	7	8	9	TOTAL	Hit (%)
1	6	4	3	2	7	3	3	6	3	37	8.78
2	3	3	3	1	4	4	3	4	2	27	6.41
3	5	9	3	6	7	7	8	5	2	52	12.35
4	2	3	4	3	1	7	8	3	6	37	8.79
5	6	6	6	2	5	6	7	5	2	45	10.69
6	7	2	9	3	2	2	2	6	3	36	8.55
7	5	3	9	5	3	4	1	7	6	43	10.21
8	2	4	3	2	5	3	2	6	5	32	7.6
9	3	5	2	2	6	2	3	3	4	30	7.13
10	2	2	5	3	7	9	2	2	9	41	9.74
11	6	3	6	4	8	5	1	6	2	41	9.74
TOTAL										421	99.99
		Σhit totals = 421, Ẋ Hit total =38.27 % Cover = 99.99%									

Table 5: Percentage Plant Cover Estimate of the Unburnt Plot in the Biological Sciences Garden, Permanent Site, UDUS in August, 2015.

NO. OF FRAME	NUMBER OF HITS PER PIN									HIT	TOTAL
PLACEMENT	1	2	3	4	5	6	7	8	9	TOTAL	Hit%
1	3	4	1	4	3	3	4	3	4	29	10.21
2	1	2	3	6	2	1	6	2	2	25	8.80
3	2	2	3	2	3	5	6	2	4	29	10.21
4	6	2	4	2	3	2	1	2	5	27	9.51
5	1	5	2	1	2	3	0	2	0	16	5.63
6	3	1	2	3	3	5	4	1	6	28	9.86
7	2	2	4	5	3	2	3	6	5	32	11.27
8	3	2	5	0	2	6	4	5	1	28	9.86
9	6	2	2	0	2	3	2	3	2	22	7.77
10	1	3	3	4	6	1	2	1	3	24	8.45
11	3	3	4	1	3	4	3	2	1	24	8.45
TOTAL										284	99.96
		Σhit totals = 284 Ẋ Hit total =25.82 % Cover = 99.96%									

In percentage cover of the herbaceous plants, the total hits on plants in the burnt plot was found to be significantly higher than that in the unburnt plot, indicating that fire must have favoured the vegetation cover of grasses and forbs in the burnt plot. This result also indicated that fire must have earlier stimulated the seed germination and shoot spread in the burnt plot as reported earlier by Russell *et al*. (2000) on pre-germination treatment on seeds.

CONCLUSION

Fire influences the structures of savannas all over the world through complex effects, such as changes in light availability, soil surface temperature, plant nutrient availability, and the amount of accumulated dry biomass on the ground(de Paula Loiola, Cianciaruso, Silva, & Batalha, 2010). This study has provided sufficient light on the interrelationship between fire, vegetation cover, forage and biomass accumulation as well as the actual yield (NPP) of the above ground and below ground parts of the herbaceous plants (grasses and forbs) in the biological sciences garden of UDUS, permanent site. This result, especially on biomass accumulation and NPP has proven that prescribed burning could be a management tool in protected areas and a common practice of range management by pastoralist as well as farmers in managing their farm lands and in other to improve quality forage resource for livestock. Therefore, the research work has demonstrated fulfilment of the desires of farmers and pastoralists in the management of farm lands and shooting of high quality forage for their livestock respectively. Parallel to that, the study has demonstrated presence of high biomass and NPP on burnt plot than on non-burnt plot of the Sudan Savanna region of the permanent site, UDUS, Sokoto. The hit total value of the burnt plot also indicates that fire enhances plant sprouting and shooting of the vegetation cover during the period of growth, hence, higher quality forage supply and much vegetation cover on burnt plot than on non-burnt plot during the sampling period. In other words, the study has demonstrated high biomass yield in the burnt plot, indicative of better pasture for the livestock. With enlightenment and proper control, fire can be used especially in designed grazing areas to provide good nutrition to livestock.

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Competing interests

The authors declare that they have no competing interests

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