



Tropentag 2012, Göttingen, Germany
September 19-21, 2012

Conference on International Research on Food Security, Natural Resource
Management and Rural Development organised by:

Georg-August Universität Göttingen and University of Kassel-Witzenhausen

Season of burn influences fire induced P-losses in Ghana

Kugbe*^a, Joseph, Manfred Denich^a, Mathias Fosu^c, Lulseged Desta Tamene^b, Paul LG Vlek^a

^aCenter for Development Research (ZEF), Division of Ecology and Natural Resources Management, University of Bonn, Walter Flex Str. 3, D53113, Bonn, Germany. *Email joekugbe@yahoo.com, jkugbe@uni-bonn.de

^bInternational Center for Tropical Agriculture (CIAT), Chitedze Agricultural Research Station, Lilongwe, Malawi

^cSavanna Agriculture Research Institute, Nyankpala, P. O. Box 52, Tamale, Ghana

Abstract

Between November and February of each year about 45-60% of the northern region (29% Ghana) of Ghana gets burned. The fires are associated with plant nutrient transfers of which local losses of P is of major concern given that it is relatively unavailable to crops in the prevailing Fe rich soils. Bush fires, however, provide essential cultural and socio-economic goods and services (as in hunting and land preparation for agriculture) at relatively cheap cost to the local populations: making it difficult to implement fire prevention strategies across the region. The need arise therefore to device means by which fires may be used to provide the usual services but at a reduced cost to soil P losses. In this study early (November) and late (January) burn season losses are estimated by a difference in P load before (plant tissues) and after (ash) combustion for each combusted IGBP (International Geosphere Biosphere Program) land cover type. The seasonal variations are then compared to provide ecological insights into efficient means of reducing the nutrient losses during burns. Least mean loss (kg km^{-2}) occurs across shrublands (127-148) while highest losses occur across grasslands (129-402). Given that 88% and 10% of the annual burns occur across savanna and woody savanna vegetations, the respective P losses of 170-260 and 158-270 has greater impact on local P losses than the relatively high losses across shrubland and grassland vegetations. Besides woody savanna vegetation where P losses are highest during early burns than late burns, late burn losses across savanna, grassland and shrubland vegetations are higher than early burn losses due to comparable tissue concentrations but higher combusted dry material in the late season. Comparatively low tissue moisture also enhances combustibility and render late burns vulnerable to higher P losses. Early burns are suggested to reduce local P losses. The patches of unburned vegetation created by the early burns also inhibit late burn occurrence, may enhance wildlife sustenance and promote tree seedling growth and establishment.

Key words: Bush fire, food security, fuel load, phosphorus nutrition, savanna

Introduction

Phosphorus (P) is considered to be the second most important plant nutrient after nitrogen to have impact on crop production in the northern region of Ghana, where the soils are inherently low in plant available P. Coupled with the decline in stock of rock phosphates used for the synthesis of P-fertilizers, and the general rising cost of P fertilizers that farmers cannot afford, it has become increasingly necessary to find means to reduce P losses from soils in the region for sustainable crop production.

Between November and February of each year, about 45-60% of the northern region of Ghana (29% of Ghana) gets burned. The fires are associated with plant-bound P transports and subsequent loss from soils, which has impact on the productivity of the local soils. Fires, however, provide essential cultural and socio-economic goods and services (e.g., in hunting and use in land preparation for agriculture) at relatively cheap cost to the local populations- making it difficult to implement strict fire prevention strategies across the region. The need arise therefore to device means by which fires may be used to provide the usual services but at a reduced cost to the soil-P losses. The aim of this study was to assess if early-burn season (November) losses differed from that of the late-burn season (January), and to identify the best season to undertake burns, with a relatively less loss of P nutrient.

Material and Methods

The study was carried out in the northern region of Ghana. The four most burned International Geosphere Biosphere Programme (IGBP) vegetation types (sum of area burns = 98%, Kugbe et al. 2012) were selected with the help of a cover type guide (Bagamsah 2005). The selected vegetation types are shown in Table 1. Two experiments were undertaken on each vegetation type, one in the early-burn season (November 2010) and the other in the late-burn season (January 2011). The P-loss experiment was undertaken by assessing the amount of leaf (Lf), twig (T) and herbaceous (H) load (kg km^{-2}), the P concentration in these tissues prior to burn (C, mg g^{-1}), and the P load prior to combustion (L_T , kg km^{-2}). Similarly, the ash load, ash-P concentration and ash-P load after combustion (L_A , kg km^{-2}) were quantified after the ash was sieved and fractionated into fine (<1 mm) and coarse fractions (>1 mm).

Phosphorus loss due to combustion in each season was then estimated as:

$$L_T - L_A \tag{1}$$

ANOVA was used for the statistical comparisons of the means of three or more groups (e.g., comparison of P losses in the four vegetation types). The difference in mean of two groups (e.g., elemental losses between early and late burns) were analyzed with the pair-wise t-testing procedure, both at an alpha level of 0.05. Post hoc tests were run with the Duncan's multiple range test to determine the direction of variation and which classes differed.

Results and Discussion

With the exception of the late burns across the grassland (735°C) and woody savanna (693°C), the maximum burn temperatures (Table 1) were above the 774-777°C volatilization temperature of P (Miller et al., 2010). As a result, plant tissue P should volatilize during the burns.

Table 1: Plant tissue load before and after (ash) combustion, P concentration and gross losses of P due to bush fire in different vegetation types during the early and late burns in northern Ghana. Except maximum temperature, values are means, standard error (below mean) in brackets.

	Savanna		Woody savanna		Grassland		Shrubland		Sig. level	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Maximum burn temperature °C										
	814	898	791	693	808	735	868	790		
Combusted fuel load (Mg km ⁻²)										
Leaves	49 ^b (30)	18 ^B ^C (5.5)	33 ^b (9)	65 ^B (8)	3 ^b (2)	0 ^C (0)	114 ^a (18)	253 ^A (40)	0.001	<0.001
Herbs	409 ^a (47)	386 ^B (34)	374 ^a (68)	205 ^C (26)	474 ^a (59)	542 ^A (34)	153 ^b (34)	76 ^D (17)	0.001	<0.001
Twigs	41 ^b (8)	23 ^{AB} (10)	8 ^c (3)	57 ^A (21)	3 ^c (1)	8 ^B (5)	84 ^a (11)	22 ^{AB} (3)	<0.001	0.049
Total	499 (66)	426 ^B (32)	416 (70)	326 ^B (27)	480 (58)	550 ^A (45)	351 (36)	350 ^B (27)	0.347	<0.001
Mass of ash after combustion (Mg km ⁻²)										
Fine ash	81 ^a (6)	45 ^B (3)	57 ^b (6)	39 ^B (3)	26.8 ^c (4)	47 ^B (4)	88 ^a (9)	66 ^A (4)	<0.001	<0.001
Coarse ash	19 ^b (2)	3 ^B (1)	33 ^a (5)	10 ^B (2)	5 ^c (1)	9 ^B (23)	33 ^a (5)	22 ^A (4)	<0.001	<0.001
Total	100 ^a (6)	48 ^B (4)	91 ^a (11)	49 ^B (4)	32 ^b (5)	56 ^B (5)	121 ^a (14)	89 ^A (4)	<0.001	<0.001
Phosphorus concentration of plant tissues and ash(mg g ⁻¹)										
Leaves	0.58 ^b (0.02)	0.75 ^A (0.07)	0.81 ^a (0.06)	0.57 ^B (0.03)	0.58 ^b (0.11)	NL	0.71 ^{ab} (0.04)	0.79 ^A (0.07)	0.005	0.034
Herbs	0.63 ^b (0.01)	0.85 ^A (0.03)	1.03 ^a (0.05)	0.91 ^A (0.03)	0.59 ^b (0.03)	0.93 ^A (0.04)	0.69 ^b (0.04)	0.56 ^B (0.05)	<0.001	<0.001
Twigs	0.51 ^c (0.02)	0.51 ^C (0.08)	1.03 ^a (0.06)	0.45 ^C (0.04)	0.51 ^c (0.01)	1.1 ^A (0.09)	0.8 ^b (0.06)	0.7 ^{AB} (0.03)	<0.001	<0.001
Fine ash	1.44 ^b (0.04)	1.66 ^A (0.14)	1.7 ^b (0.08)	1.62 ^A (0.13)	5.98 ^a (1.5)	1.9 ^A (0.11)	1.24 ^b (0.11)	1.17 ^B (0.09)	<0.001	0.001
Coarse ash	0.85 ^b (0.03)	1.13 ^B (0.05)	1.34 ^a (0.05)	1.47 ^A (0.13)	0.89 ^b (0.04)	1.48 ^A (0.11)	0.95 ^b (0.07)	1 ^B (0.04)	<0.001	0.001
Loss of phosphorus during combustion										
kg km ⁻²	170 ^{ab} (34)	261 ^B (26)	269 ^a (78)	158 ^C (34)	129 ^b (25)	402 ^A (46)	127 ^b (31)	148 ^C (35)	0.046	<0.001
%	51 (5)	76 (3)	58 (6)	67 (5)	51 (9)	77 (3)	42 (8)	54 (5)	0.509	0.235

Values with different superscripted letters (horizontal direction) show significant differences ($P \leq 0.05$) across the different vegetation cover types according to post hoc test- Small superscripted letters for the early sampling, capital superscripted letters for the late sampling.

Fuel load distribution before burn

The tissue moisture content in the early burn season was significantly higher ($P < 0.05$) than in the late season except in the grassland, where no seasonal differences were observed. The amount of fuel load combusted varied depending on the type of vegetation, the combusted plant part and the season of burn (Table 1). Generally, the herbaceous materials were the easiest to be combusted due to their high combustibility, which is promoted by the package of the fuel stock, nature of the fuel material and adequate aeration space that together promotes early drying and facilitate burn. Significantly high quantities of herbaceous materials were burned in the early season than the late season ($P < 0.05$). The leaves and twigs from trees in the woody savanna were only combusted if they happened to have fallen to the ground, which occurred mostly in the late season. This explains the low quantity of combusted twigs in the woody savanna during the early burn. In the shrubland and savanna vegetation, plant-bound leaves were also burned. Fewer leaves and twigs were, however, burned in the savanna compared to the woody savanna. During the late burn in the grassland, there were no leaf or twig covers so that only the herbaceous materials were burned. While significant variation in total combusted fuel load was observed for the different vegetation types in the late season, this was not observed in the early season.

Ash load distribution after burn

The amount of coarse ash collected was generally lower than that of the fine ash ($P < 0.05$) and comparable to values reported in the study area (Bagamsah 2005). The total ash that remained in the late burns were significantly lower than that in the early burns for all vegetation types and is attributed to the relatively dry and water stressed condition that may have constrained plant growth and reduced biomass accumulation. The high moisture in the early season also impeded the burn and resulted in high amount of incompletely burned ash-materials. Early burns are thus susceptible to high ash-bound-P losses than the late burns.

Tissue P-concentration before burn and ash P-concentration after burn

The plant tissue P-concentration was not significantly different ($P < 0.05$) between the vegetation parts in the early season, but differed during the late season and was in the order grass/herbs>leaves>twigs. In the woody savanna vegetation, the concentration of leaves and twigs in the early season was higher than that of the late season and was attributed to the redistribution of leaf-P to other parts of plants before leaf senescence and subsequent combustion (Gusewell 2005). Plants thus conserve P in this manner, which also explains why the consistent annual burns and related P transports are not reflected in short term loss in productivity of the soils (Gyasi et al. 2006). The grass P-concentrations in the early season were generally lower than that in the late season for all the vegetation types, except in the woody savanna vegetation where the opposite was observed. There was no significant difference in the seasonal P-concentrations of fine ash in all vegetation types except in the grassland, where the concentration in the late season was lower than that of the early season. The concentration of P in coarse ash was lower than that of the fine ash ($P < 0.001$) and attributed to the lower degree of burn in the coarse ash and the less volatilization of volatile elements like nitrogen (N) and carbon (C).

Phosphorus load before and after combustion, and losses

The quantity of P in the fuel load before combustion was higher than that in the ash after combustion across all vegetation types and in both seasons. For the shrubland and woody savanna, the early season plant-tissue P-load was higher than that of the late season due to the high combustible fuel load availability (Table 1). The early season P losses were, however, not significantly different from that of the late season. In the grassland and savanna vegetations, which respectively comprise ~0.3% and ~87.7% of the total burned area across the northern region (Kugbe et al. 2012) the late burns were associated with comparatively higher fuel load-P amount and significantly higher fire-induced P-losses ($P < 0.05$). The least of mean P-loss (kg km^{-2}) occurred in the shrubland (127-148) while the highest loss occurred in the grassland (129-402). Given the high percentage of total annual burns in the savanna (~87.7%) and the woody savanna (~10%) vegetations, the respective P losses of 170-260 and 158-270 has greater impact on local P-losses than the relatively high losses across the grassland vegetation.

The findings show that early burns favor P conservation in savanna vegetations than late burns. The early burns are associated with high moisture content that impedes the spread of fire, and results in comparatively more charred ash that is susceptible to after-burn P losses by secondary means than the late burns. The late burn on the other hand is associated with higher direct P-losses that are higher in amount than the total P-remains in ash after burn (see % losses, Table 1). Considering the short duration between the early and late burn-season, and given that not all the P-remains in ash are lost through after-fire secondary pathways such as erosion and leaching, while the estimated direct losses are quantified local losses, early burns could be used to reduce local P-losses across the savanna region of Ghana while providing similar services as the late burns.

Conclusions and Outlook

The season of burn can be used to reduce local fire-induced phosphorus losses in savanna vegetations. The loss per unit burn area in the late season is higher than that in the early season. Comparatively low tissue moisture in the late season enhances combustibility and increases the total combusted fuel load amount per fire event, which render late burns vulnerable to higher P-losses. Early burns are suggested to reduce the losses. The patches of unburned vegetation created by the early burns also inhibit late burn occurrence, may enhance wildlife sustenance through early regrowth and promote tree seedling growth and establishment.

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