1 INTRODUCTION

1.1 Background

Bushfires are uncontrolled fires occurring in the rural landscape (Cheney, 1981). In the savannas of Ghana, bushfires, which are mostly man-made, are very common. These fires are typically grass fires and their intensity is usually lower than that of the forest fires. Fire is a major landscape-scale perturbation in many ecosystems throughout the world (Johnson, 1992; Pyne et al., 1996), but it is especially frequent in the tropical savanna (Goldammer 1990; Andersen et al., 1998). Nevertheless, its cumulative effect has a major impact on the ecosystem functioning.

Fire is the most devastating factor contributing to loss of vegetation, nutrients and especially to natural resource degradation in the savannas of Ghana. Ravaging annual bushfires have reduced the vegetation of the region to the level that can be described as fire-pro-climax, with only fire-resistant species surviving. The densities and mix of tree species vary widely in the more highly degraded areas, with (woody) grassland vegetation dominating (Ekekpi et al., 2000).

During biomass combustion, nutrients can be volatilized or transferred to the atmosphere as particulate matter (Cook, 1992). The particles are likely to be deposited on or near the site of fire, but this is not the case for volatile elements such as carbon and nitrogen. Nutrients remain on the ground in ash and other residue after the fire along with the deposited particles, which are highly susceptible to erosion through runoff (Gillon, 1983; Kellman et al., 1985) and wind.

Additionally, frequent fires have deleterious effects on the nutrition of the savanna plant communities, which grow on nutrient-poor soils with low rates of natural nutrient input. The losses in vegetation and nutrients can lead to loss of watershed protection, leading to drying of rivers, soil degradation and severe impacts on the entire savanna ecosystem.

Bushfires have been identified as one of the causes of the decline in soil fertility in the last two decades in northern Ghana (Abatania and Albert, 1993; Gordon and Amatekpor, 1999). Bushfires thus impact negatively on savanna agro-ecological zones leading to degradation of the soils. This is particularly so for the soils within Sub-Sahara Africa (SSA) which are very fragile and easily degraded and deteriorating at an alarming rate (Vlek, 1993). Comparison of soils in sacred groves with the annually burnt soils shows marked differences in soil quality. For example, the soil in the Chicago sacred grove near Tamale had 13.1 % soil organic matter (SOM), whereas the annually burnt soil on the Tamale-Bolga road a few kilometers away had an SOM content of only 1.8 % (Korem, 1989). More importantly, the process of laterization in the fire-protected grove is much slower than in the annually burnt areas, mainly due to a much higher organic matter content (Korem, 1989).

At a regional scale, savanna fires have significant impact on the regional water, energy, and carbon dioxide exchanges (Lynch and Wu 2000, Beringer et al., 2003) and as a result are likely to have important feedbacks on the atmosphere and regional climate and hydrology. Large variations in the Earth surface reflectance (albedo) occurring over savanna areas of Africa could not be explained by changes in vegetation cover between the wet and dry season and bushfires have been implicated.

The current study has its relevance particularly to savanna zones of Ghana because of the vulnerability of the environment and the concomitant high impact of bushfires. Specific scientific information emanating from this study will assist in developing the right policy framework for bushfire management and overall environmental management.

1.2 Research objectives

Losses of the various carbon and nutrient components of the savanna ecosystem as a result of bushfires have so far not been quantified in the savanna zones of Ghana. The overall objective of this study therefore is to quantify nutrient fluxes due to bushfires in the savanna landscape of northern Ghana.

The specific objectives of the study are:

1) Characterization of the savanna vegetation in the study area
2) Determination of fuel load as well as carbon and nutrient losses due to bushfires
3) Estimation of carbon emissions
4) Assessment of the impact of bushfire on albedo and surface energy fluxes

2 STATE OF KNOWLEDGE

Bushfires are an annual occurrence in the Guinea Savanna of Northern Ghana. They start soon after the rainy season and are characterized by widespread devastation.

The whole area is covered with a mantle of ash and the trees and shrubs are leafless and have charcoal blackened barks.

Generally, there are two major causes of bushfires. These are natural and anthropogenic. The natural cause is through ignition by lightning. Some far-fetched reasons have also been reported though, such as sparks from falling rocks and exploding fruits (Langaas, 1995). However, it is assumed that almost all fires are ignited by humans (Korem, 1985).

The effect of bushfires stems not only from its pervasiveness in modifying the environment, but also from the extensiveness of the area affected in proportion to the human effort applied. Rural inhabitants use fire to facilitate many activities associated with daily life. The most commonly cited causes of bushfires in the study area are: burning to clear lands for agriculture, to improve pasture land by removing unpalatable stubble and initiating off-season regrowth, eliminating reptiles and pests, to drive game for hunting, for tapping honey and charcoal production. The impacts of frequent bushfires include: destruction of the vegetation, soil degradation, nutrient losses, shifts in albedo, contribution to greenhouse effect and global warming.

2.1 Savanna fires and emissions

Savanna is broadly defined as a tropical physiognomic vegetation type consisting of a continuous grass stratum usually with a discontinuous stratum of trees or shrubs. It occupies about 20% of the Earth’s land surface (Cole, 1986; Stott, 1991). In their natural state, savannas can support a high biomass of large ungulates (Cumming, 1982; Walker and Noy-Meir, 1982), but most have been exploited for agriculture, livestock grazing or destroyed by bushfires. Because of intensive overstocking, fuel-wood harvesting and shortened fallow periods between cropping periods, savannas, especially those in Africa, are undergoing rapid changes in vegetation productivity, structure and composition (Walker and Noy-Meir 1982; Jansen, 1988; Lewis and Berry, 1988).

Bushfires emit significant amounts of carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxide (NO_2) and methane (CH_4) into the atmosphere. The annual flux from the world's CO_2 from African savanna burnings has been estimated to equal 30% of the annual flux from the world's industrial sources (Hao et al., 1996).

Changes in the savanna areas may affect the global climate and atmospheric trace gas composition, surface energy balance and hydrological and biogeochemical cycles (Olsson 1985a; Levine, 1991). Some of these effects are already apparent; for example, African savanna fires, almost all resulting from human activities, may produce as much as a third of the total global emissions from biomass burning (Hao et al., 1990; Cahoon et al., 1992; Stott, 1994).

2.2 Fuel load and nutrient losses

Fuel load is the amount of combustible vegetation available for burning, which is determined by the type and amount of vegetation. In the West African savanna environment, the available plant biomass for fire (only counting the grassy biomass) varies from an average 0.5 t ha^{-1}, some local areas having over 10 t ha^{-1} (Menaut, 1983; Goldammer, 1993; Rasmussen, 1998). In the Kruger National Park, it was found that the fuel loads varied between 0.32 and 4.5 t ha^{-1} (Trollope et al., 1996). Results of mean fuel load (grass) from the savannas of Northern Ghana by Saarnak (1999) ranged between 2 and 3 t ha^{-1}. The total fuel load in tropical savanna vegetation was between 3.8 and 4.15 t ha^{-1}, and 6.3 t ha^{-1} in a study by Cook (1994). Similar results of total fuel load of 3 t ha^{-1} were recorded in the savanna of Venezuela by Hernandez-Velencia and Lopez-Hernandez (2002). Brookman-Amissah (1980) reported grass biomass at the end of growing season of 1.8 t ha^{-1} on protected plots, and 2.6 t ha^{-1} and 1.4 t ha^{-1} on early and late bushfire plots respectively in northern Ghana.

Burning of the vegetation can have catastrophic effects on ecosystem productivity. Fire affects the organic matter of the vegetation and litter in several ways. It directly consumes part or all the standing aboveground plant material and litter. When vegetation burns, it liberates nutrients tied up in the plant tissues. Portions of the elements contained in the combusted material are transferred to the atmosphere and transported over long distances in smoke plumes and thus lost to the immediate environ (Evans and Allen, 1971; Smith and Bowes, 1974; Raison, 1979; Mackensen et al., 1996). Air currents and updrafts during fire carry particles of ash and these remove nutrients from the site.

Transfers of nutrients to the atmosphere during the annual burning in the savanna of Congo amounted to 85%, 25%, 39%, 21% and 28% of the amounts of N, P, K, Ca and Mg, respectively, accumulated in the aerial biomass and litter component (Laclau et al., 2002). In a similar work done in the savanna region of Calabozo, Venezuela, about 95% of the biomass, 97% of N, 61% of P, 76% of K and 65% of Ca and Mg were transferred to the atmosphere. Ash deposition returned between 21-34% of Mg, Ca, K and P and 0.2% of N. As a consequence of frequent burning, the soil of the savanna showed lower organic matter and available P and K content when compared to 32-year protected savanna (Hernandez and Lopez, 2002). Estimates from the work of Vijver (1999) in East African savanna systems indicate that the loss of nutrients through volatilization was as follows; N 93%, P 32%, K 60%, Ca 42% and Mg 12%.

Nutrient losses reported by Sommer (2000) in woody fallow vegetation were, 96%, 98%, 90%, 58%, 59%, 70% and 89% for C, N, P, K, Ca, Mg and S, respectively. Element transfer to the atmosphere due to burning through particle transport and volatilization were 94-98% C, 95-98% N, 27-33% P, 17-23% Na, 16-31% K, 9-24% Ca, 17-43% Mg, and 67-68% S of the initial element stock in the burnt debris in the Amazonia secondary forest (Mackensen et al., 1996). Trabaud (1994) estimated that losses of N, C and P from combustible plant matter woody scrub exceeded 98%, 97% and 79%, respectively.

Preliminary analysis (Cook, 1992, 1994) of data on the effects of fire on the savannas indicates that annual fires might result in the net losses of nitrogen, and possibly also potassium and magnesium from the ecosystem. Estimated rates of biological fixation of nitrogen appear to be insufficient to replace the annual losses of this element. It is therefore concluded that a regime of annual fires that completely burn the available grassy fuel would deplete nitrogen reserves in savanna, unless there are other sources of biologically fixed N, which are unknown at present (Cook, 1994).

2.3 Effect of fire on soil

Wildfire can lead to detectable losses of mineral soil N as demonstrated by Grier (1975), who noted significant losses (855 kg ha^{-1} of N and 282 kg ha^{-1} of K) from an intense wildfire. Nitrogen losses due to wildfire ranged from 0 kg ha^{-1} in black spruce (*Picea mariana*) forest (Dyrness et al., 1989) to 855 kg ha^{-1} in mixed coniferous forest (Grier, 1975). Prescribed fire can cause as much N loss as wildfire: nitrogen losses due to post-harvest slash burning range from an apparent gain of 192 kg ha^{-1} yr^{-1} to a net loss of 666 kg ha^{-1} yr^{-1} (Little and Ohmann, 1988). In a comprehensive review of N losses due to slash burning in British Columbia, Feller (1982) reported N loss values ranging from 7 to 604 kg ha^{-1} yr^{-1}.

Methods for classifying burns based on litter and soil appearance after a fire have been described by Wells et al., (1979) and Chandler et al., (1983). Low intensity or lightly burned areas are characterized by black ash, scorched litter and duff, low plant mortality, and maximum surface temperatures during burning of 100 to 250^{o}C. Moderate burning produces surface temperatures of 300 to 400^{o}C and consumes most of the plant materials, thus exposing the underlying soil, which otherwise is not altered. High intensity or severe burning produces surface temperatures in excess of 500^{o}C, and can be recognized by the white ash remaining after the complete combustion of heavy fuel and the reddening of the soil. Sertsu and Sanchez (1978) found that heating three soils to 400^{o}C in the laboratory resulted in redder hues and brighter chromas. Boyer and Dell (1980) also described a blackened layer underlying the reddened soil in a severely burnt area. They suggested that the black color is due to the charring of organic matter by heat conducted through the top layer of the soil during fire.

Soil texture changes have also been observed in response to fires and laboratory heating. Dyrness and Youngberg (1957) found a significant decrease in the clay content of severely burned soils and a corresponding increase in sand, suggesting the aggregation of clay-sized particles into stable and sand-sized secondary particles. Similar results were noted by Sreenivasan and Aurangabadkar (1940) in that the decreased clay content corresponded with increased silt and fine sand content in fire-heated Vertisols. Ulery and Graham (1993) confirmed that the particle size distribution shift was due to the fusion of clay into sand-sized particles. Laboratory heating to 400^{o}C also significantly reduced the clay fraction of chaparral soils from southern California (Duriscoe and Wells, 1982) and of Vertisols from India (Puri and Asghar, 1940) and Ethiopia (Sertsu and Sanchez, 1978).

Frequent burning can reduce the rate of infiltration of rainwater into soil (Phillips, 1930; Daubenmire, 1968; Schacht et al., 1996; Bijker et al., 2001). This may be explained as follows: Firstly, soil organic matter, which usually increases soil aggregation and consequently the rate of infiltration (Dyrness and Younberg, 1957;

Pikul and Zuzel, 1994; Cook et al., 1992), tends to decline in soils that are burnt frequently (Bird et al., 2000). Secondly, ash particles may block pores at the soil surface (Mallik et al., 1984). Thirdly, the removal of vegetation increases the exposure to raindrops, which would increase breakdown of aggregates, dispersion of clay and thus soil crusting (Hillel, 1998). Results reported by Mills and Frey (2004) conclude that soil from 0-1cm in burnt plots had lower total carbon (means of 0.8 % vs. 2.7 % for burnt and unburnt plots, respectively), total N (0.07 % vs. 0.23 %), $(NH_4)OAc$-extractable Ca (7 vs. 17 mmol kg^{-1}), Mg (2 vs 7 mmol kg^{-1}), K (0.8 vs. 1.5 mmol kg^{-1}), and greater exchangeable Na percentage (17 % vs. 8 %). The results also indicate that burning increases soil crusting.

2.4 Fire effect on albedo and surface energy fluxes

Albedo is the fraction of the total incident solar radiation that is reflected by a body or surface. Land surface albedo is a key parameter in the global system. It quantifies the radiometric interface between the land surface and the atmosphere. It influences the climate system and defines the shortwave energy input into the biosphere. Natural and anthropogenic changes in vegetation and land use practices affect the spatial, temporal and spectral distribution of its value.

Extensive and frequent fires in the savannas are intensive in the late dry season and cause crown damage of > 90 %. The scorched canopy reduces the leaf area index (LAI) of the canopy and these surface changes are likely to result in altered energy partitioning (enhanced sensible heat flux) and shifts in albedo. A fire event also causes a loss of functional canopy leaf area and subsequent reduction in canopy, photosynthesis and evapotranspiration, greatly influencing post-fire fluxes (Beringer et al., 2003).

Fire in the savanna is likely to radically alter the surface energy through reduced albedo. The pre-burn albedo of the savanna sites were 0.11 and 0.12 for low and moderate intensity burns, respectively. Following fire, the flat savanna surface was blackened and became highly absorptive. Albedos were reduced to almost half at the study sites to 0.06 and 0.07, respectively (Beringer et al., 2003).

Scholes and Walker (1993) also reported a halving of the African savanna albedo to 0.06 immediately following fire, with a recovery to unburnt values after six weeks. The effect of burning on flooded stands decreases the average daily albedo from 0.16 for an unburned stand to 0.08 in the burned stand, whereas the effect of flooding on