THE EFFECTS OF WILDFIRES ON SOIL AND VEGETATION IN SELECTED FOREST RESERVES IN THE TRANSITIONAL ZONE OF GHANA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI IN PATIAL FULFILMENT OF THE REQUIREMENT FOR THE MASTER OF SCIENCE DEGREE IN AGROFORESTRY.

BY

EVELYN OSEI – AKOTO

BSC. (HONS) NATURAL RESOURCE MANAGEMENT, KNUST
KUMASI
FEBRUARY, 2007

DECLARATION

I declare that except references to other people's research which have been duly cited, this thesis submitted to School of Postgraduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi for the degree of Master of science in Agroforestry is my own investigation.

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Evelyn Osei-Akoto

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Dr. Francis Ulzen-Appiah Prof. S. J. Quashie-Sam

SUPERVISOR HEAD OF DEPARTMENT

ACKNOWLEDGEMENT

I am grateful to the almighty God for seeing me through this research work.

I would like to express my sincere appreciation to all lecturers and staff of Agroforestry Department especially Dr. Francis Ulzen-Appiah, Research fellow, Agroforestry Department KNUST for his constructive criticisms and guidance which made my research a reality.

A special acknowledgment is extended to Mr. Oheneba Agyemang, Director Resource Management Support Center (RMSC), Mr. Obiaw Yaw, Manager, Environmental Conservation Unit (RMSC), The Wildfire Management Project (WFMP) and the entire staff of RMSC, for their immense contribution, financial support and encouragement towards my research. A special acknowledgment is also extended to Mrs. Agnes Ankomah of (CSIR Fumesua), for her immense help during my statistical analysis. I am equally indebted to Dr. Tetteh of SRI Kwadaso for his patience, support, contribution and encouragement towards this research and the entire staff at the SRI laboratory for their assistance. I am also grateful to Mr. Owusu, Mr. Eric Adjei my course mates, Gabriel, Sarah, Ibrahim and Lawrence for their assistance, contribution, guidance and encouragement.

Lastly special thanks go to my dearest husband Mr. Andrew Hackman for his love and support, my siblings; Alex Osei-Akoto, Henry Osei-Akoto and Henrrietta Osei-Akoto as well as friends especially Akua Asantewaa and Angelina Amofa for their spiritual support and encouragement which has made my research a reality. God BLESS you all

Abstract

The effects of wildfire on soil and vegetation were evaluated in three forest reserves in the transitional zones of Ghana namely Afram Headwaters, Bosomkese and Worobong South Forest Reserves. These reserves are part of pilots reserves selected for the Wildfire Management Project being implemented by the Forestry Commission of Ghana. This research examined the response of the soil and vegetation following continuous wildfires for about 15 years.

Data from soils in burnt sites within each reserve were compared to that in an adjacent unburnt sites as well as comparing burnt and unburnt sites among the reserves.

Using standard laboratory procedures, both physical and chemical properties (soil texture, bulk density, pH, % organic carbon, total nitrogen, % organic matter, calcium, magnesium, potassium, phosphorus, base saturation and cation exchange capacity) were determined. Again surface organic layers and vegetation (pioneer and successional species) were also examined. .Results indicated a 100% loss of surface organic layers in the burnt site of Afram Headwaters and also a 74% and 4% loss in Worobong and Bosomkese Forest Reserves respectively.

Soil texture increased ($P \leq 0.05$) significantly on burnt site compared to unburnt site with regards to sand, and silt with the exception of clay which declined on the burnt site at Afram Headwaters. However, there was no significant difference on burnt and unburnt sites with regards to texture and bulk density at both Bosomkese and Worobong South forest reserves.

Results presented suggest that wildfires can significantly increase chemical properties like soil pH, potassium, and cation exchange capacity. However, soil levels of organic matter and total nitrogen are reduced after wildfires.

Common pioneer species found within burnt and unburnt sites in reserves include; *Griffonia simplicifolia, Celtis malbraedii* and *Khaya anthotica.* Common successional species recorded include; *Chromolaena odorata* and *Broussonatia papyverifera.*

A better understanding of the role fire plays as a natural disturbance in our forests should allow for intelligent management of these important, yet rapidly vanishing ecosystems.

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CHAPTER ONE

1.0 INTRODUCTION AND BACKGROUND

Fire is an important ecological factor in most of the developing tropical world. Forest wildfires mainly contribute to the destruction of forest and its resources in the transitional zones of Ghana and has created lasting effects on vegetation, wildlife, landscape and soil fauna. Fire has always been a natural and extremely important tool shaping the evolution of species and the functioning of ecosystems in which they occur. Forest fires are becoming increasingly common in the tropics. High rates of subsistence slash-and burn agriculture the most common source of ignition, combined with the drying effects of logging and natural events such as the El Nino-Southern Oscillation are increasing wildfire frequency (Cochrane 1998; Laurance et al., 2001., Roman-Cuesta et al., 2003).

Forest fires can be generally grouped into three: wildfires, prescribed fires, and planned fires. Wildfires are uncontrolled fires occurring on a wildland except a fire under prescription. Prescribed fires are controlled application of fire to wildfuels in either their natural or modified state under specified environmental conditions. Prescribed fires allow the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required to attain planned resource management objectives. Planned fires are fires used in the destruction of forest for agricultural or grazing operations (Pritchett, 1979).

Wildfires whether ignited by people or some natural forces can be extremely destructive of forest stand, ground cover vegetation and forest soils. Whereas wildfires and fires used for agricultural land clearing burn with sufficient heat to kill most of all of the vegetation above the soil surface and degrade surface soils (Chandler et al., 1983). Fire has traditionally been an integrated part of tropical shifting agriculture. Although shifting cultivation in its original form has long since gone out of existence in Ghana, fire is still used in the existing farming systems. Today the prevailing farming practice may be characterized as cropping agriculture with a varying fallow period (Kirby, J. 1999).

Wildfires have contributed to the direct cause of irreversible environmental damage in Ghana. Before 1983, uncontrolled wildfires were relatively uncommon in the country. Since the severe drought of 1982/83, wildfires have become common occurrences in nearly all vegetation types during the dry seasons. In certain areas of the country, land degradation has been hastened due to wildfires, which have permanently destroyed delicate, but vital organic soil materials. Pre-fire conditions play a key role in the effects of wildfires. For example, fuel load can influence burn intensity and, in turn, the degree of soil heating (Hungerford et al., 1990).

Wildfires produce important changes in the physical, chemical, biological and biochemical properties of a soil. The effects of fire are particularly noticeable in the surface horizons, where erosion processes are favored and the nutrient biochemical cycles are altered due to structural changes, the loss of the organic matter and damaged biota. Although, in general, fire increases nutrient availability on the soil surface due to the combustion of organic forms and the addition of ashes from the burnt vegetation, the nutrient content of soil may decrease, remain unaffected or increase (Prieto-Fernandez et al., 1993).

The effect of wildfires on soil and vegetation depends on preburn variability of the soil and vegetation and on fire behavior, season of burning, frequency and severity. Wildfires significantly affect soil properties because fire may reduce the content and alter the composition of surface organic matter; particularly the labile fractions, water-soluble compounds and lipids may be affected although their effects depend on the fire intensity (Giovannini et al., 1990). Wildfires may cause the loss or reduction of soil structure, reduction of porosity and alteration of color. Most frequently, however, one important consequence includes the reduction of surface organic layers. Several changes occur in soil after the occurrence of wildfires. For example soil pH, concentrations of phosphorous and potassium increase and soil nutrients like nitrogen and surface organic layers decrease

(Well , 1979). The immediate impact of burning on soil nutrients is conversion of much of the organically bound nutrients in the forest floor, woody debris and herbaceous vegetation into their inorganic forms. Substantial amount of carbon, nitrogen, sulphur and potassium can also be lost to the atmosphere by volatilization during the combustion of litter, duff and soil organic matter (Chandler et al., 1983).

Wildfires destroy vegetation and open up forest canopy which also lead to the invasion of shrubs and grasses like *Chromalaena odorata,and Panicum maximum*, as well as climbers and severely reduce the productive capacity of the forest in all the agro ecological zones of Ghana. Also wildfires can kill most or all of the plants above the soil surface, the succeeding vegetation tends to be made up of light – seeded species that can move in from outside the burned area, species with perennial root systems capable of sending up new sprouts and species with dominant seeds stimulated by heat (Hungerford et al., 1990)

STATEMENT OF THE PROBLEM

At present a major threat to the long-term conservation of the forest resources and biodiversity in Ghana is wildfires. Indiscriminate use of fire as well as shorter fire-return interval combined with continuous logging could potentially lead to soil and forest degradation. The loss of forest resources and biodiversity as well as degradation of soil and vegetation could have drastic consequences on individual welfare and economic development of the country. Unfortunately, the effects of wildfires on vegetation and soils have not been well studied in Ghana, this is a problem, which requires research effort to address.

JUSTIFICATION

Fire disturbance regimes in forest and rangelands vary widely with respect to fire frequency and severity. This research focuses on the effects of wildfires on vegetation and soil and will contribute information on the effects of wildfires on vegetation and soils. This information generated will bridge the knowledge gap on wildfire effects on soil and vegetation and could be useful for (i) the development of effective means of preventing and controlling wildfire in fire prone areas and (ii) forest rehabilitation through fire prevention and control to ensure the generation of economic and environmental benefits.

OBJECTIVES

The broad objective was to assess the effects of wildfires on vegetation and some selected soil properties in three forest reserves in Ghana, namely; Bosomkese Forest Reserve, Worobong South Forest Reserve and Afram Headwaters Forest Reserve.

The specific objectives were to determine the effects of wildfires on:

(i) Surface organic layers

(ii) Selected soil nutrients and chemical properties: nitrogen, phosphorus, potassium, magnesium, calcium, pH, cation exchange capacity, and organic matter.

(iii) Selected soil physical properties: texture and bulk density.

(iv) Vegetation: successional species and pioneer species.

RESEARCH QUESTIONS AND HYPOTHESIS

In order to meet the specific objectives and assess the effects of wildfire on the soil and vegetation, this research answered three questions and tested four hypotheses. The research questions were:

(i) Is the accumulation of surface organic layer affected by wildfires?

(ii) Which soil nutrients and chemical properties increase or decrease after wildfires?

(iii) What are the effects of wildfires on vegetation?

The specific hypotheses to be tested are:

(i) Surface organic layers will be reduced in frequently burnt sites as compared to unburnt sites.

(ii) Soil levels of P and K would be higher in frequently burnt sites compared to unburnt and that pH and CEC levels would similarly be higher.

(iii) Soil levels of N and OM would decrease in frequently burnt sites compared to unburnt sites.

(iv) More grasses and fire resistant trees will be found in frequently burnt sites compared to unburnt sites.

This research aimed at determining the effects of wildfires on soils and vegetation in the transitional zones of Ghana. For this, different chemical and physical parameters were determined in burnt and unburnt soils within selected forest reserves.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Wildfire effects on soils and subsequent site productivity are related to both the primary effects of combustion and soil heating, and secondary effects of post-fire soil erosion. Many effects on soil physical, chemical and biological properties are related to the amount of organic matter consumed and temperatures reached within the soil. Rapid mineralization of organic matter during combustion typically results in an increase in plant-available nitrogen (Raison, R. J. 1979). However, with increasing temperatures, nutrients can also be lost through volatilization (Blank *et al.,* 1998).

Fire effects on vegetation depend in fire intensity, the season of burning and vegetation type. While certain forest species depend on fire for regeneration, the revegetation potential of other species depends on the maximum temperatures reached within the soil profile during a fire, which affects both established roots and soil seed bank. The effects of wildfires on soil and vegetation are highly variable. These variations are attributed to fire intensity, temperature, vegetation type and amount of soil moisture among other factors (Hungerford et al., 1990).

This chapter reviews literature on fire behaviour, causes of wildfire, fire regimes (fire frequency, intensity and type).

Also reviewed are literature on the effects of wildfires on soil chemical, physical and biological properties, wildfire effects on vegetation and detrimental and beneficial effects of wildfires.

2.2 Fire Behaviour

Forest fires are a calamity for forests of both temperate and tropical climate zones and are among the oldest of natural phenomena. Wildland fires trace their ancestry to early development of terrestrial vegetation and the evolution of the atmosphere. Knowledge of natural fires in ecological and evolutionary function grows almost daily. Wildfire is considered both inevitible and essential and it is a cultural phenomenon and one of man's oldest tools in agriculture (Pyne, 1984).

The use of fire by primitive man in Africa dates back to 50,000 to 60,000 years ago. The use of fire as a tool is probably even older in tropical Asia than in Africa and Central America. It was fires that enabled early big game hunters to begin the exterminations of selected species. Fire assisted hunting and gathering societies to harvest insects, small game, and edible plants that encouraged the spread of agriculture by allowing for rapid land clearing, ready fertilization, and the selection of food grains. The primitive herding of grazing animals also led to

the domestication and the expansion of pasture grass land against climate gradients (Lal, 1987).

The relationship between mankind and fire is reciprocal: fire has made possible most technological and agricultural development, yet fire itself takes on many particular characteristics because of the cultural environment in which it occurs just as it does in response to the natural environment of fuel, topography and weather (Burton et al., 1980).

Fire takes two general forms in the landscape. It exists in a confined form as with various fire appliances and in a free-burning state as with forest and field fires. Wildland fires are propagated by a variety of mechanisms, often erratic and turbulent. Wildland fire involves combustion on a grand scale. The process advances by three stages; a preheating phase, a period of flaming combustion and a stage of glowing combustion (Pyne, 1984).

During preheating or pyrolysis, the fuel is brought to its ignition point or kindling temperature. This transfer of heat can occur in several ways: by convection, radiation and by conduction, which is the least effective because wood is a poor conductor of heat. Pyrolysis vaporizes hydrocarbon, driving off free moisture and converting solids into flammable gases. With ignition of these gases, the period of flaming combustion begins. Flaming combustion advances as a wave of

flame, and its energy release is the greatest of any stage of the combustion process. What limits the duration of the flaming stage is primarily the slowness of conduction through wood. The interior of the forest fuel and forest floor can be exposed only by the relatively ineffective transfer of heat by conduction. By the time conduction exposes the unburned interior, the flaming front has already passed. The retarding effect of conduction accounts for the large quantities of charred debris left after a major fire and serves as a reminder that not all fuel is available for combustion. Once the flaming front has passed, the remainder of combustion reverts to a glowing state. Oxidation occurs on the surface of the charcoal residue left from the flaming phase (Burton *et al.,* 1998)

Nevertheless, the combustion of forest fuels is rarely total. Even under the most intense conditions of incineration, such as mass fire, considerable residue remains. In many fires large quantities of dead material may be consumed but equal or greater volumes of living matter may be killed, furnishing fuel for the returns that are sure to follow. Fire spread is more complex than the model of combustion. The problem of fire growth, the pattern of ignition as well as that of combustion is significant. Fires begin as point sources. The sources may be isolated or they may occur in multiples. The burning rate and proximity of starts will determine whether the resulting fires behave as separate events or whether they begin to interact synergistically with greatly magnified burning characteristics. During a fire, the combination of combustion and heat transfer produces steep temperature gradients in soil layers, which can result in the formation of hydrophobic soil layers (De Bano, 1989).

2.3 Causes of Wildfire

There are two main causes of wildfires. These are natural and manmade causes. Evidence of natural fires has been found in carboniferous coal deposits of 400 million years ago and in the tertiary deposits of brown coal. Lightening was the prime cause of these fires before the advent of humans. Meteorites were ignition sources and falling igneous rocks from volcanic eruptions undoubtedly caused local fires then as they do today. Spontaneous combustion and sparks from falling quartzite rocks are rare but documented possible cause of fires. Lightening is estimated to cause about 50,000 wildland fires worldwide each year (Burton *et al.,* 1998).

These natural causes are most common in Europe and America but as far as Ghana is concerned, there are no records on wildfires, which originated from these causes. In the United States, in 1987, the Klamath and Stanislaus national forest in northern California had two of the biggest fires due to a three-year long drought and winter of no snowpack. Lightening strikes accompanying dry thunderstorms ignited over 900 fires, destroying the forest (Fuller, 1995).

Throughout much of the modern world, however, humans have been the most significant cause of wildfires. Wildfires in Ghana are started rarely accidentally but intentionally by man. Many people, especially in the Transitional Zone of Ghana still practice indiscriminate burning. Unfortunately these fires get out of hand leading to wildfires. The man – made causes of wildfires especially in Ghana include: hunting for game which constitute about 90% of causes and very common during the dry season, careless smokers who throw cigarette butts into dry leaves or grasses, also cause wildfires. Farmers use fire in land clearing because it is actually the cheapest, fastest and easiest method of land clearing. These fires usually get out of hand and cause wildfires. Other man made causes of wildfires in Ghana include; gathering of dry firewood and cooking on the farm, burning of pastures and logging (Korem, 1985).

2.4 Fire Regimes

The characterization of fire and the general role and impact of fire on the environment can be classified as different fire regimes. Studies of fire history have led to the definition of fire regime as the kinds of fire and prominent immediate effects of fire that characterize an area. A fire regime is typically characterized by the following features: type, frequency, intensity, size and timing (season of burning). However, three factors, frequency, intensity and fire types are the most important (Chandler et al., 1983).

Frequency

Fire frequency refers to the recurrence of a fire in a given area over time. The return interval is the average number of years between successive fires. Frequency is also expressed as fire cycle; the length of time required to burn over an area equal to that under consideration. Fire frequency affects the floristic composition of ecosystems by selecting the species that will comprise of the vegetation of an area. A species cannot survive if fire occurs too often, too early, or too late in its life cycle. For instance, in any given area the survival of species which do not sprout, may be threatened if fire occurs before they have produced and accumulated seed, or if it occurs after they have disappeared and the seed stock exhausted. In some areas interval between two fires could vary from less than 100 years to a maximum of 500 years whereas in some areas there may be only a few years between fires (Burton et al., 1998).

Fire can be irregular in frequency, intensity, severity and burning pattern. These characteristics are primarily controlled by climate, fuel accumulation and flammability, soil water and especially topography. In addition, fire frequency varies depending on the dryness of the vegetation, how much lightening there is locally, and on factors such as slope, exposure, and altitude (Chandler et al., 1983).

Intensity

Fire intensity refers to the length of the flame or amount of energy generated. The length of the flame limits the possible methods of suppressing it. A high rate of spread in light fuels like grass produces a high intensity fire. In heavy fields, however, even a low spread rate can produce a high intensity fire. The intensity of a fire varies according to the amount of moisture content and structure of the fuel (Chandler et al., 1983).

It is often very difficult to establish clearly the degree of intensity of a fire. Some people judge intensity from observed effects on vegetation or soil. Forest fire intensity varies from low-intensity surface fire to high-intensity crown fires. In low-intensity fires the vegetation suffers little damage despite some damage to the understorey. Species that regenerate vegetatively sprout abundantly (Chandler et al., 1983).

Fire intensity also affects the soil. In the chaparral, intense fires of 700^0C completely destroyed all organic matter on the soil surface. Fire of moderate intensity with surface temperature of 430^0C, are capable of destroying most of the litter. Low intensity fires of 250^0C remove about 85 percent of the litter from the soil surface but only the humid acids are altered at 2.5cm depth (De Bano et al., 1989).

Type

Forest fires can be divided into three main classes as ground fires, surface fires and crown fires. The most common type, the surface fire burns over the forest floor, consuming litter, killing above ground parts of herbaceous plants and shrubs, and typically scorching the bases and crowns of trees. These fires are very sensitive to wind speed. Surface head fires may attain quite high intensity in hardwood stands and in open forest trees (Burton et al., 1998).

Surface fires tend to kill young trees of all species. Survival in a surface fire for most fire – resistant tree species is not typically dictated by damage to the stem cambium but by their susceptibility to root injury and to scorching of the crown by hot gases rising above the flames. Fire sweeping the forest floor may generate ground fires, which burn thick accumulations of organic matter. When they burn below the surface they are flameless, and they kill most plants with roots growing in organic matter. Ground fires burn slowly and generate very high temperatures. Fires, fueled by accumulation of organic matter and wind may ignite crowns of trees, thus generating a crown fire. Intense crown fires may travel from one crown to another in dense even aged stands. Some trees may carry a crown fire but an extensive and devastating crown fires is highly unlikely. Conifers are most susceptible to crown fires because of their high flammability. They occur in pure stands than broad – leaved species. Sparks and burning debris may start new surface fires often far away from the site of the crown fire (Burton et al., 1998).

2. 5 WILDFIRE EFFECTS ON SOIL

2.5.1 Soil Chemical Properties

Nutrients contained in debris and soil organic matter are cycled by biological decomposition processes in environments where temperatures rarely approach 38^{0}C and sufficient moisture is available for sustaining active microbial activity. Under these mild conditions, soil microorganisms decompose organic matter and slowly release many of the essential nutrients over time (Debano, 1976).

Wild fires affect the chemical properties of soils by ashing the organic materials contained in the above ground vegetation. The immediate impact of burning on soil nutrients is conversion of much of the organically bound nutrients in the forest floor, woody debris, and herbaceous vegetation into their inorganic forms. Whether these inorganic nutrients remain on site as solids or are lost through volatilization depends upon the temperatures reached during the burning and the differential volatilization temperatures of the nutrients (Wells, 1979).

However, the responses of individual nutrients differ and each has its inherent temperature threshold. Threshold temperatures are defined as those temperatures where volatilization of a nutrient occurs. These thresholds can be divided into three general nutrient categories; sensitive, moderately sensitive, and relatively insensitive. Nitrogen (N) and sulphur (S) are considered sensitive, because they have thresholds as low as 200^0C and 375^0C, respectively. Potassium (K) and Phosphorus (P) are moderately sensitive, having threshold temperatures of 774^0C (Raison et al., 1985). Magnesium (Mg), Calcium (Ca), and Manganese (Mn) are relatively insensitive, with high threshold temperatures of $1{,}107^0$C, $1{,}484^0$C, and 1962^0C, respectively. Because the threshold temperatures of N, P, K, and S are lower than the flaming temperatures of woody fuels ($1{,}100^0$C) and except for P, lower than glowing combustion temperatures (650^0C), these nutrients are readily volatilized from organic matter during combustion (DeBano, 1976).

Burning materials high in a mineral element increases the concentration of that element in the soil. Conversely, burning the same amount of material low in that element may not measurably change the element's concentration in the soil. Burning, which releases relatively large amounts of basic element changes the acidity of a highly buffered clay soil high in organic mater less than if the elements were released in a sandy soil low in organic matter. Soils are highly variable in chemical properties and the release of relatively large amounts of basic elements by fire would not significantly change the soil if the soil were already rich in those elements (Wells 1979).

2.5.2. Nutrient Losses and Availability

Fire has variable effects on nutrient availability in soils, sometimes mobilizing nutrients, inducing deficiency or causing no effect. Most changes in nutrient availability result from two different processes; (1) insitu changes, and (2) translocation of organic substances downward into the soil. In general, burning increases the available nutrients in the surface soil with the possible exception of nitrogen. Some studies report significant nitrogen loss, but others report small losses or no effect. In general, fire increases nutrient availability at the soil surface. These nutrients are derived from ashes resulting from burnt vegetation and from the combustion of surface organic matter (Traubaud, L. 1983).

Fire temperature at the soil surface affects whether burning may increase or decrease nutrient availability. In fires where the soil surface stays below 100^0C, nutrients held within the plant matter are released in the form of ash to the soil surface and nutrients in the first few centimeters of soil are left unaffected. When soil temperatures rise above 100^0C, organic matter starts to burn and above 200^0C nutrients can be lost to volatilization. Volatile elements such as N, P, S and Cl are lost when burning temperatures exceed the temperature of volatilization Nitrogen and sulphur are most important because they have low volatilization temperatures and are limiting in many ecosystems (Giovannini et al., 1990).

However, evidence from nutrient analyses suggests that soil total nitrogen and total carbon were both lower in burned plot at Cano Negro, but higher in the burned plot at Kukra. This was likely due to greater volatilization of nitrogen and carbon in the organic mater incorporated into the upper centimeters of the soil and leaf litter at Cano Negro. Phosphorus levels were higher in both burned plots suggesting soil P was not volatilized during burning and that a portion of the phosphorus stored in plant material was introduced to the soil in ash deposits. (Blair *et al.,* 2004).

Nutrient loses from most sites are important only if they cannot be resupplied to the ecosystem to meet the requirements for optimum growth within the limits of climate and soil. In the Amazon, it is estimated that 27-33% of P is lost to the atmosphere during agricultural burning (Mackensen et al., 1996)

pH

pH is a standard measure of acidity or alkalinity, and can be neutral on the pH scale of 1 to 14. During the combustion process several previously bound nutrients are released in their element or radical form. Certain positive ions collectively called cations such as Ca, K and Mg are stable at typical combustion temperature and remain on site after burning in the form of ash or uncombusted hydrocarbon. When fire oxidizes organic compounds, elements that form anions (eg, N, P, and Cl) are lost in much greater quantities than cations. The ash left by the fire consists largely of soluble oxides. These oxides which have an alkaline reaction tend to neutralize acidity in the soil. Consequently, soil pH generally increased following wildfires (Kimmins, 1997).

The extent and duration of the increase will depend on the intensity of the fire, the amount of organic matter consumed and buffering capacity of the soil. Several researchers have reported increases in soil pH following fires. (Hernandez *et al.,* 1997) reported an increase in soil pH after fire in a Mediterranean pine forest soils. Although the pH values of the burnt soils were slightly higher than those of the unburnt soil. The increase in soil pH was due to the alkaline nature of the resulting ashes and usually the pH values of the burnt soils tend to return to their initial pre-fire values with time. The length of this time depends among other factors, on the intensity of the fire (Wells, 1979).

(Zabinski et al., 2000) also reported significant increase in soil pH levels between burnt and unburnt sites averaging 5.6 at the burnt sites and 5.1 at the unburnt site. The variation was due to specific site dependent variables. Although one would expect little change in pH after burning, it is not always the case. Campbell et al., (1977) found no difference in pH for soils with sedimentary parent material between burned and unburned soils in Pondorosa pine in northern Arizona. Smaller changes in pH have been reported in areas of eastern and southeastern US. The degree of change is related to the cation exchange capacity of the soil. The growth of herbs return to its original level of acidity by reducing the leaching of cations and by active circulation of nutrients.

The pH increase accompanying fire may be one of the main benefits of burning in tropical shifting agriculture. Highly leached tropical soils derived from poor parent materials often have such a low pH that food crops cannot be grown satisfactorily unless the pH is raised by ash from burning the vegetation (Kimmins, 1997).

Organic Matter

Loss of organic matter is one of the most important effects of fire on soils. Physically the surface organic matter is a protective layer and the organic matter on the mineral soil improves water relations. The loss of surface organic accumulations depends, upon fire duration, intensity, and fuel moisture. Severe fires can remove up to 50cm of organic matter over rock on dry site (Wells, 1979).

Fire speeds up the normal process of mineralization of organic matter. Generally, fire is restricted to the surface organic accumulation because of the need for oxygen and because deeper layers are often too wet to burn. Organic matter incorporated into the mineral soil is normally unaffected by fire, but in extremely severe fires the penetration of heat down into the mineral soil can destroy colloidal organic matter. Fire can penetrate deeply into the soil by burning along dead roots (Kimmins, 1997).

Organic matter acts as the primary reservoir for several nutrients and therefore, is the source for most of the available phosphorus (P) and sulfur (S), and virtually all of the available nitrogen (N). Organic matter also serves as a powerful aggregating agent and as such, plays an important role in creating and maintaining a well-aggregated soil. Soil aggregation improves soil structure that creates macro pores and improves soil aeration. The welfare of soil microorganism all depends on organic matter because it provides both a suitable environment and C compounds that serve as an energy source for soil microorganisms (De Bano, 1989).

In a 20-year burning study in South Carolina burning increased organic matter in the 0-5 cm layer of mineral soil but had no effect in the 5-10 cm layer. When the influence of fire on organic matter in both the forest floor and 0-10 cm of mineral soil was taken into account, the effect of burning was redistribution of organic matter within the profile but no reduction of organic matter. Reduction of organic matter are greatest on unproductive and sub marginal forests where the organic matter is not incorporated into the soil or where there is only a thin layer of organic matter over parent material (Wells, 1979).

Calcium and magnesium

Calcium and magnesium commonly behave similarly under fire conditions. Numerous studies have reported increase in calcium and magnesium following fire. Calcium increased from 4.04 cmol (+)kg^{-1} to 10.5 cmol (+)kg^{-1} in the surface 10 cm after burning in the central western wheat belt of New South Wales (Fraser et al., 2001).

A few studies have found no changes or an actual decrease in soil concentrations of these cations (Trabaud, 1980). These results are probably related to changes in the CEC that is commonly decreased by fires as the organic matter content of the soil is reduced. DeBano and Conrad 1978 found that 45Kg ha^{-1} of Ca and 5.3Kg ha^{-1} of Mg are transported to soil as ash following a chapparel fire, but even larger amounts are lost through post fire run-off and debris erosion.

2.5.3 Soil Physical Properties

Fire influences soil physical properties and erosion to a degree depending upon intensity of the fire, and understory vegetation destroyed, forest floor consumed, heating of the soil, proportion of the area burned, and frequency of fire occurrence. Most frequently, however, the important consequences include the reduction of organic matter, exhibition of increased hydrophobicity

Bulk density

Bulk density is defined as the mass of a unit volume of dry soil. This volume includes both solids and pores. There are several practical methods of determining soil bulk density. All the methods involve obtaining a known volume of soil, drying it to remove the water and weighing the dry mass. Soils with high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. Any factor that influences soil pore space will affect bulk density. Fine-textured surface soils such as silt loams, clays and clay loams generally have lower bulk densities than sandy soils. The organic matter contents in sandy soils are low, the solid particles less likely to be aggregated together and the bulk densities are commonly higher than in the finer textured soils (Campbell *et al.,*1977)

The bulk densities of clay, clay loam and silt loam surface soils normally range from 1.00 Mg/m^3 to as high as 1.55 Mg/m^3 depending on their conditions.
The system of land management employed on a given soil also influences its bulk density. Increased bulk densities are often indicative of reduced infiltration of rainwater and restricted root growth. For cropland, the addition of crop residues or farm manure in large amounts tends to lower bulk densities of surface soils. Intensive cultivation operates in the opposite direction. Measurement of bulk density is by core method and clod method excavation. All these methods involve obtaining a known volume soil, drying it to remove water and weighing the dry mass (Brady, 1990)

Soil texture

Soil texture is defined as the relative proportion of the different soil separates in a soil. Soil separate is one of the individual – sized groups of mineral soil particles, sand, silt or clay and is based on the effective diameter of soil particle. Soil texture properly applies to the fine earth fraction of soil with particle sizes not greater than 2mm. The texture of a soil determines the nutrient-supplying ability of soils, as well as the ability of the soil to hold and conduct air necessary for plant growth (Anderson, 1976).

Furthermore, the texture of a soil is not easily modified. For instance on large-scale agricultural, forestry and wildland areas, soil texture is not changed by cultural management although pedologic processes such as weathering, erosion, illuviation and deposition over very long periods of time can alter the texture of various soil horizon. The size of soil particles and the relative proportions greatly influence the surface area present in a given mass of soil. Many soil properties and processes are very much affected by surface area and texture because the surface of soil particles is the site of water adsorption, mineral weathering, cation exchange and microbial colonization (Diaz-Fierros *et al.,*1990)

Soil textural class are names used to convey information on the textural make up of soils and to indicate their physical properties. There are three broad classes of soil texture and these are sandy soil, loamy soils and clayey soils, each with subdivisions. Sandy soils comprise of at least 70% sand and 15% clay of the material by weight. They are coarse textured and are dominated by properties of sand. Two specific textural classes are found and these are sand and loamy sand (Wright *et al.,* 1976)

Loamy soils are defined as soils with a mixture of sand, silt and clay particles that exhibits the properties of these separates in about equal proportions. Their specific textural classes are: moderately coarse sandy loam and fine sandy loam;

medium, very fire sandy loam, loam, silt loam and silt and moderately fine; sandy clay laom, silty clay loam and clay loam. Clayey soils are dominated by clay separates and are fine textured. Three specific textural classes are sandy clay, silty clay and clay (Lal, 1987)

There are two general method of determing soil textural class. These are the feel method, which is the common field method of determining the textural class of a soil by its feel. The second method is the laboratory particle size analysis or mechanical analysis.

The effects of heating on change in soil texture have been reported by several researchers. These researchers observed change in soil texture only by temperatures exceeding 400^0C. They observed that heating up to 200^0C had no effect on particle size distribution but at 400^0C and 600^0C the sand content increased and the clay content decreased (Lal, 1987).

Soil textural changes with heating were more pronounced in a vertisol with higher initial clay content than in a coarse-textured soil. The texture of the vertisol with 55% clay changed to sand. These textural changes were attributed to fusion of clay particles into sand-sized particles (Lal, 1987).

2.6 WILDFIRE EFFECTS ON PLANTS

Fire has always been a natural, regularly occurring part of plant succession that permits the rejuvenation of some plants populations. However, the continued action of fire has led to the evolution of a large number of fire adapted communities, some of which actually depend for their maintenance on the regular occurrence of fire. Fire may affect any stage in a plants development, for example at the vegetative, flowering, fruiting or dormant stages and there is a corresponding variety of adaptive traits (Chandler et al., 1983).

Fire Adaptations in the Vegetative Stage.

Plants can be classified into several categories based on vegetative characteristics that affect their reaction to fire. Some plants achieve resistance by protecting themselves from damage, whereas others are able to tolerate the damage. Fire resistant bark is one of the common adaptations to surface and ground fires. Some trees develop a very thick layer of dead bark as they mature which enables them to survive quite severe ground and surface fires such as some eucalyptus species which have fire resistant barks. Where replacement of the bark is slow, a severely burned bark may be susceptible to subsequent fire of much lower intensity (Kimmins, 1997).

Species that shed bark rapidly and accumulate bark and other above ground litter around their base will generally be more susceptible to fire damage than those without such an accumulation. Species with high foliar moisture content and low resin or oil content will generally be much more fire resistant than the resin-and oil rich conifers. Many species are able to replace entire aerial shoots by developing new shoots from underground buds that survive the fire. Many angiosperms trees, shrubs, herbs and even some conifers have this ability. Plants that have lignotubers are able to produce new shoots more rapidly than those lacking this adaptation because of the food reserves provided by the tuber. A lignotuber is a conspicuous swelling of the main axis mostly or entirely below the ground surface. Plants that have rhizomes (horizontal, underground sterms) are also able to sprout rapidly following fire and are highly resistant to damage by fire (Kimmins, 1997).

Adaptations to fire in the reproductive phase

Fire has been shown to cause a stimulation of flowering in some plants. This may be a temperature response or may merely reflect a reduction in competition for light, moisture, and nutrients. It could also be an effect of smoke. Seed dispersal is influenced by fire in some species. In most species, seed release involves the breaking of a zone of abscission cells. Desiccation increases the tension across this abscission zone and in many species this is sufficient to open the fruit. In others, the additional heat treatment provided by fire is necessary (Lal, 1987).

Strategies of species persistence

Plant species persist in fire-prone ecosystems, regenerating themselves either by seed or by vegetative means. Rowe (1983) distinguished kinds of strategies based on an understanding of fire adaptations, life cycle and mode of persistence of plants in ecosystems. Some strategies of species persistence are described below.

Plants propagated primarily by horizontal and vertical extension of vegetative parts are termed the resisters and endurers. Invaders are the early arrivers that are successful due to copious production of short-lived, wind-disseminated seeds. Once established they flower and fruit profusely or spread vegetatively. They are typically the shade-intolerant pioneering, firewood plants that establish after fire regardless of its cycle length and intensity. Evaders, store seeds in the canopy, humus or mineral soil. Their strategy is placement of seeds to evade high temperatures, followed by rapid seed germination and establishment. The plants themselves may be killed by fire but their seeds are protected. They include intolerant to shade species that persist into later successional stages (Rowe, 1983).

Avoiders arrive late in succession and prosper where fire cycles are long. They essentially lack direct adaptations to fire and are often said to occupy unburned areas. They are the tolerant members of ecosystems relatively undisturbed by fire. Resisters are the few tolerant species whose adult stages can survive low severity fires. They continue growing vegetatively in spite of fire, whereas evaders are likely to be killed by fire. Endurers are composed of the large and diverse group of species, shade tolerant and intolerant, that resprout following fire. They regenerate from roots, root collars, rhizomes and other below ground organs (Lal, 1987).

These groups of species are closely related to the site-specific ecosystems where they occur and its particular fire cycle and fire behavior. Ecosystems characterized by high severity fires favour invaders and endurers, those with low intensity surface fires favor resisters as well as evaders and endurers. Species may belong to more than one group (Rowe, 1983).

2.7 Detrimental and beneficial effects of fire

There are situations where fire is obviously catastrophic. These include cases where the soil is composed almost entirely of organic matter and those where the destruction of organic matter exposes highly erodible soils to heavy rain. Fires can cause serious erosion where erosive soils occur on steep slopes, the fires tend to be catastrophic and multiple burns frequently occur. The burning of litter and organic matter in the soil may be significant in causing reduced infiltration, increased surface run off, and erosion in many affected areas.

Fire plays an important role in the formation of water repellent soils. In unburned areas, litter decomposition produces non-wettable organic molecules that coat surface soil particles creating a weak water-repellent layer in the upper soil profile between the litter layers and the soil (DeBano, 1989).

Just as there are cases where fire is catastrophic in its effects on site, so there are cases where it is clearly beneficial. Post fire temperature conditions are often changed drastically by fire. Average maximum soil surface temperatures on burned sites may be from 3 – 16^{0}C higher than on comparable unburned areas. Increased soil temperatures hasten development of roots and shoots on burned areas, speed up decomposition, and promote the activity of soil organisms. On bumt sites, however, fire dependant species are typically adapted to tolerate extreme conditions. In most situations, the effect of fire on site quality is relatively less pronounced (Chandler et al., 1983).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Forest Reserves

My study was conducted in three forest reserves in the Eastern, Brong Ahafo and Ashanti Regions. These happen to be among forest reserves of the Wildfire Management Project, being implemented by the Resource Management Support Centre of the Forestry Commission. The forest reserves are Worobong South in Mpraeso/Begoro District, Bosomkese in Dormaa District and Afram Headwaters in Offinso District. These reserves are described below.

Worobong South Forest Reserve

The reserve lies within Begoro forest district in the Eastern region and lies between latitude 6º 30'' and 6º 40'' North and longitudes 0º 30'' and 1º 00'' West. The gross area is approximately 35,680ha and is made up of 24,785ha of primary forest, 7520ha of pure protection area (Hills) and 3,374ha of admitted farms. The soils are mainly red loam with steep hill side soils which are shallow and rocky. The reserve falls within the Tropical Humid Climatic Zone with two distinct seasons: a dry harmattan season, and a rainy season. Rainfall is bimodal with the major rains occurring between May-June and minor rains in September-October. The mean annual rainfall is 1,200mm with mean temperatures reaching 20^0C minimum and 32^0C maximum. Worobong South stretches between moist semi deciduous and dry semi deciduous forest types. The forest in general appears to be open in the upper canopy with the evergreen trees fairly scattered. Three vertical strata can however be seen in undisturbed areas. The reserve is interspersed in the lower canopy by dense undergrowth of shrubs like; *Chromolaena odorata*, *Mallotus oppositifolus* and other scruffy remnants. Dominant tree species in this reserve include; *Blighia sapida* and *Millitia rodanta.* Fire is an occasional hazard and the main contributory factor to the destruction of approximately 778ha of the reserve (Hall and Swaine, 1981) (Table 1).

Bosomkese Forest Reserve

Bosomkese Forest Reserve is in Sunyani forest district within the Brong Ahafo region. The reserve lies between latitude 7º 00” and 7º 15''N and longitudes 2º 05” and 2º 30'' W and covers approximately 138.35 km^2. The underlying rock is metamorphosed sediments of schist and phyllites which give rise to clay soils. Generally soils are relatively infertile with an iron pan near the surface. There are two well defined seasons, a rainy season from April to October and a dry season from November to March. Annual rainfall is about 1,350mm. Mean humidity is 80% and mean temperatures reaching 30^0C maximum and 24^0C minimum (Lee, 1974).

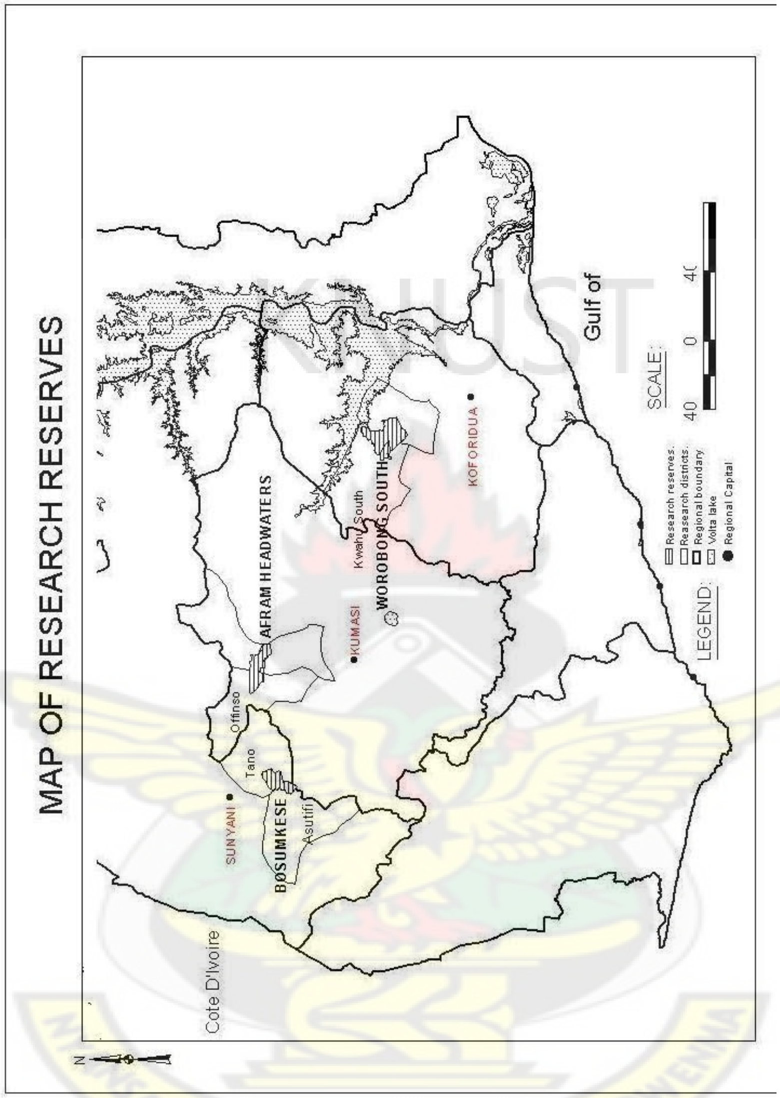
The reserve is of the Tropical Moist Semi-deciduous Forest with parts of the forest appearing to have been derived from savannah woodland as evidenced by the occurrences of species such as *Larnnea macrocarpa* and patches of elephant grass. In order of frequency the dominant trees which are scattered throughout the forest consist mainly of *Triplochiton scleroxylon, Entandrophragma cylindricum, Celtis adolfi, Celtis zenkeri. Antiaris africana*, *Entandrophragma utile* and *Terminalia superba.* Generally the high forest structure shows discontinuous upper and middle canopies and a usually closed lower storey. The forest does not exhibit any obvious aftermath of a past farming impact and may be regarded as semi-natural. Species found in this forest include *Entandrophragma angolensis, Kahya ivorensis, Chlorophora excelsa, Afromosia elata* among others.

There has been increasing incidence of uncontrolled fires spreading from adjacent farms which cause considerable damage to the vegetation (Lee, 1974) (Table 1).

Afram Headwaters Forest Reserve

Afram Headwaters lies in Offinso north east forest district within the Ashanti region and lies between longitude 1º 32" and 1º 48'' W and latitude 7º 0" and 7º 15'' N. The reserve covers approximately 20,100ha. The underlying rocks in the reserve are the upper and lower Birrimian rocks. These give rise to forest ochrosols and lithosols with forest gleisos along riparian areas (Asumang et al., 1971). The reserve lies within the Tropical Humid Climatic Zone. It is characterized by uniform high temperature and two peak rainfall seasons in June and October and a dry season from December to March and dominated by desicating winds blowing from the north-east of the Sahara. The mean annual rainfall is 1,250mm. The mean humidity is 80% and the mean temperatures reaching 30^{0}C maximum and 22^{0}C minimum. Afram Headwaters lies within the moist semi-deciduous forest type and in the fire zone subtype. This type of forest is fire dominated with many of the typical species being present due to fire tolerance. Many of the trees found in this type are those that occur in both the savannah and forest. Odum (*Milicia excelsa*) is the typical commercial species of this zone.

The typical structure of the forest is of a single high canopy with a sparse woody understorey. Three vertical strata can however be seen in undisturbed areas. The reserve is interspersed in the lower canopy by dense undergrowth of shrubs like *Chromoleana odorata,* and *Griffonia simplicifolia.* The invasion of the reserve by the introduction of *Chromoleana odorata* has greatly increased the fire hazard. This weed is an annual weed that readily colonises disturbed grounds, and grows rapidly to about 3m. In the dry season the dead and dry stems are very flammable. This leads to a vicious circle where the fires encourage the weed which in turn encourages fires (Hall and Swaine 1981) (Table 1).


MAP OF RESEARCH RESERVES
Cote D'Ivoire
SUNYANI
BOSUMKESE
Asutifi
Tano
Offinso
AFRAM HEADWATERS
KUMASI
Kwahu South
WOROBONG SOUTH
KOFORIDUA
Gulf of
SCALE:
40
0
40
LEGEND:
Research reserves.
Reasearch districts.
Regional boundary
Volta lake
Regional Capital
N

3. 2 Field Methods

The study was carried out in both burnt and unburnt sites within each reserve. Burnt and unburnt sites were selected by visually assessing the sites and with the help of GPRS and compasses. Burnt and unburnt sites selected were designated as treatments. Hundred meter transects were laid across each treatment within each reserve in a north-south orientation. Ten plots of size 10m x 10m were randomly laid along each transect at 10m intervals in an east-west orientation. All plots were laid 2m away from the transects as those areas were already disturbed. From each treatment, plots were randomly selected for soil studies, surface organic layer assessment and vegetation studies as described below.

Three for soil studies, three for surface organic layer assessment and three for vegetation studies.

Soil Sampling

Three representative soil samples were collected from each treatment for soil chemical analysis. Ssoil augers were used to collect soil from 0-5cm depth from randomly selected spots within each treatment. Samples were bulked and sub-samples put into polythene bags, labeled and transported to laboratory for chemical and textural analyses.

Three representative soil samples for bulk density determination were collected from each treatment using a special coring instrument to obtain an undisturbed sample of known volume. Samples were extracted from randomly selected spots within the plots selected for soil sampling. Core samplers were driven into soil with the help of a hammer to 5cm and removed from the soil. The core rings were removed and trimmed on the ends with a knife to make sure they were properly filled with soil. They were then covered with lids and transported to the laboratory.

Surface organic layer assessment

Surface organic layers were assessed within the selected plots by collecting litter from three randomly selected points from within quadrats of size 50m x 50m. Litter collected were put into polythene bags labeled and transported to the laboratory for oven-dry weight determination.

Vegetation studies

All plant and grass species within the selected plots for vegetation studies were identified. Plant with diameters at breast height (dbh) of 10cm and above were measured using diameter tape and recorded.

3.3 Laboratory Methods

Soil chemical analyses

The soil samples were air-dried and ground to pass through a 2mm mesh sieve and stored in labeled soil bags at the laboratory of Soil Research Institute, Kwadaso-Kumasi. Sub-samples were taken from each soil sample and analysed for soil pH, soil organic carbon, total nitrogen, organic matter, calcium, magnesium, available phosphorus and potassium, exchangeable acidity, cation exchange capacity and base saturation.

Soil pH

Soil pH was determined in a 1:2.5 suspension of soil and water using a HI 9017 Micro-processor pH meter. A 20 g soil sub-sample was weighed into 100 ml polythene bottle. To this 50 ml distilled water was added from a measuring cylinder and the bottle capped. The solution was shaken on a reciprocating shaker for two hours. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

Soil organic carbon

Organic carbon was determined by a modified Walkley - Black method. This procedure involves wet combustion of organic matter with a mixture of potassium dichromate and sulphuric acid. After the reaction, the excess dichromate is titrated against ferrous sulphate. One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Ten milliliters of 1.0 N (0.1667 M) potassium dichromate solution was added to the soil and the blank flask. To this, 20 ml of concentrated sulphuric acid was carefully added from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250 ml) and concentrated orthophosphoric acid (10 ml) were added and allowed to cool. One milliliter of diphenylamine indicator was added and titrated with 1.0 M ferrous sulphate solution to a clear bluish end point.

The organic carbon content of soil was calculated as follows

$$\% \text{ Organic C} = \frac{M \times 0.39 \times mcf \;(V_1 - V_2)}{s} \qquad \text{Eqn. 1}$$

where

M = molarity of ferrous sulphate solution

V_1 = ml ferrous sulphate solution required for blank

V_2 = ml ferrous sulphate solution required for sample

s = weight of air-dry soil sample in gram

mcf = moisture correcting factor (100 +% moisture) / 100)

0.39 = 3 x 0.001 x 100% x 1.3

Where

(3 = equivalent weight of C).

1.3 = a compensation factor for the incomplete combustion of the organic matter.

Total Nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). A 0.5 g soil sub-sample was put in a Kjeldahl digestion flask and 5 ml distilled water added to it. After 30 minutes, 5 ml concentrated sulphuric acid and selenium mixture were added and mixed carefully. The flask was then placed on a Kjeldahl digestion apparatus for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water, mixed well and allowed to cool. The volume of the solution was made to 100 ml with water and mixed well. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40% NaOH solution was added followed by distillation. The distillate was collected in 2% boric acid. The distillate was titrated with 0.02N HCl solution with bromocresol green as indicator. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

The % N in the soil sample was calculated as:

$$\%N = \frac{N x (a - b) x 1.4 x mcf}{s} \qquad \text{Eqn. 2}$$

where:

N = concentration of HCl used in titration.

a = ml HCl used in sample titration

b = ml HCl used in blank titration

s = weight of air-dry soil sample in grams.

mcf = moisture correcting factor (100 +%moisture)/100

1.4 = 14 x 0.001 x 100%

(14 = atomic weight of nitrogen)

Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1 M ammonium acetate (NH_4OAc) extract and the exchangeable acidity (hydrogen and aluminum) were determined in 1 M KCl extract.

Determination of the exchangeable bases

A 10 g soil sub-sample was transferred into a leaching tube and leached with 250 ml 1M NH_4OAc solution. For the determination of the calcium plus magnesium, a 25 ml portion of the leachate was transferred into an Erlenmeyer flask and the volume made to 50 ml with distilled water. A 1 ml portion of hydroxylamine hydrochloride, 1 ml of 2.0 per cent potassium cyanide, 1 ml of 2 per cent potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01 M EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour. A 20 ml 0.01 M magnesium chloride solution was also titrated with 0.01 N EDTA in the presence of 25 ml of 1 M ammonium acetate solution to provide a standard blue colour for the titration.

Determination of Calcium

A 25 ml portion of the leachate was transferred into a 250 ml Erlenmeyer flask and the volume made to about 50 ml with distilled water. Hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml of 2% solution) and potassium ferrocyanide (1 ml of 2%) solution were added. After a few minutes, 4 ml of 8 M potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01 M EDTA solution to a pure blue colour. Twenty millilitres of 0.01 M calcium chloride solution was titrated with 0.01 M EDTA in the presence of 25 ml 1 M ammonium acetate solution to provide a standard pure blue colour.

The concentration of calcium + magnesium or calcium were calculated as

$$\text{Ca + Mg (or Ca) (meg/kg soil)} = \frac{0.01 \text{ x } V_a - V_b \text{ x } 1000}{0.1 \text{ x W}} \qquad \text{Eqn. 3}$$

$$\text{Ca = Mg (or Ca) (meg/kg soil)} = \frac{0.01x(Va - Vb)x1000}{0.1xW} \qquad \text{Eqn. 4}$$

Magnessium was then determined by subtracting the value of exchangeable Ca from the value of exchangeable (Ca + Mg) as follow:

Exchangeable Mg = exchangeable (Ca + Mg) – exchangeable Eqn. 5

Where

W = weight in grams of oven – dry soil extracted

V_a = ml of 0.01 M EDTA used in the titration

V_b = ml of 0.01 M EDTA used in blank tritration.

0.01 = concentration of EDTA used

Exchangeable potassium and sodium determination

Potassium and sodium in the leachate were determined by flame photometry. Standard series of potassium and sodium solutions were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by pouring a 25 ml portion of each solution into a 250 ml volumetric flask and adding water to make the volume. Portions of 0, 5, 10, 15, and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. One hundred milliliters of 1 M NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the leachate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Exchangeable K was calculated as

$$\text{Exchangeable K (cmol/kg soil)} = \frac{(a - b) \times 100 \times mcf}{10 \times 39.1 \times s} \quad \text{Eqn. 6}$$

$$\text{Exchangeable Na (cmol/kg soil)} = \frac{(a - b) \times 100 \times mcf}{10 \times 23 \times s} \quad \text{Eqn. 7}$$

where

a = mg/l K or Na in the diluted sample leachate

b = mg/ K or Na in the diluted blank percolate

s = air – dried sub-sample weight in grams

mcf = moisture correcting factor

Exchangeable acidity

Exchangeable acidity is defined as the sum of Al + H. The soil sample was extracted with unbuffered 1M KCl, and the sum of Al + H was determined by titration. Fifty grams of soil sub-sample was put in a 200 ml plastic bottle and 100 ml of 1 M KCl solution added. The bottle was capped and shaken for 2 hours and then filtered. Fifty millilitre portion of the filtrate was taken with a pipette into a 250 ml Erlenmeyer flask and 2 – 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1M NaOH until the colour just turned permanently pink. A blank was included in the titration.

Exchangeable acidity was calculated as

$$\text{Exchangeable acidity (cmol/kg soil)} = \frac{(a - b) \times M \times 2 \times 100 \times mcf}{s} \quad \text{Eqn. 8}$$

Where:

a = ml NaOH used to titrate with blank

b = ml NaOH used to titrate with blank

M = molarity of NaOH solution.

s = air – dried soil sample weight in gram

2 = 100/50 (filtrates / pipetted volume)

mcf = moisture correction factor ((100 + %moisture) /100)

Bray's No1 Phosphorus (Available phosphorus)

The readily acid – soluble forms of P were extracted by HCl: NH_4F mixture called the Bray's No. 1 method as described by Olsen and Sommers (1982). Phosphorus in the extract was determined using a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent

A 2 g soil sub-sample was weighed into a 50 ml shaking bottle and 20 ml of extracting solution of Bray-1 (0.03 M NH_4F and 0.025 M HCl) was added. The sample was shaken for one minute by hand and then immediately filtered through a Whatman No. 42 filter paper. One ml of the standard series, the blank and the extract, 2 ml boric acid and 3 ml of the coloring reagent (ammonium molybdate and antimony tartarate solution) were pipetted into a test tube and homogenized. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer at 660nm wavelength.

A standard series of 0, 1.2, 2.4, 3.6, 4.8, and 6 mg P/l was prepared from a 12-mg/l stock solution by diluting 0, 10, 20, 30, 40, and 50 ml of 12 mg P/l in 100 ml volumetric flask and made to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 6 ml of the 100 mg P/l of the standard solution were put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water and measured on a spectrophotometer at wavelength of 660nm.

Available phosphorous was calculated as

$$P\ (mg/kg) = \frac{(a - b) \times 20 \times 6 \times mcf}{s} \qquad \text{Eqn. 9}$$

Where

a = mg/l P in sample extract

b = mg/l P in blank

s = sample weight in gram

mcf = moisture correcting factor

20 = ml extracting solution

Soil physical analyses

Determination of Bulk density

Soil samples were oven dried in the laboratory for 2 days at a temperature of 105^0C. Samples together with core rings were weighed with a balance scale after which soil samples alone were weighed without the core rings. Volumes of the core rings were determined. Bulk densities were then calculated for each soil sample as below.

$$\text{Soil bulk density } (g/cm^3) = \frac{\text{oven dry weight}}{\text{Volume of soil}} \qquad \text{Eqn 10}$$

Determination of particle size distribution

A 50g of soil sub-sample was weighed into a beaker and 50 ml of Calgon reagent (sodium hexametaphosphate) added to it after which the solution was heated to a temperature of 100^0C. The mixture was then removed and transferred into a cup of high speed stirrer and the volume made to about 500ml and stirred continuously for 15 mins. The mixture was dispersed into a 1000 ml cylinder to a volume of 950 ml and left overnight. The suspension (% clay and silt) in the cylinder was well mixed and allowed to stand at a constant temperature. The first reading was taken at 40 seconds to represent silt and clay fractions (H_1). Hydrometer reading for clay was then taken after 5 hrs together with room temperature (H_2).

Percentage sand, clay and silt were calculated as

Sand = $100 – (H_1 + 0.2(T_1 – 20)-2) \times 2$ Eqn. 11

Clay = $(H_2 + 0.2(T_2 - 20) - 2) \times 2$ Eqn. 12

Silt = 100 – (% sand + % clay) Eqn. 13

Where

T_1= temperature at 40 sec

T_2 = temperature at 5 hrs

0.2 (T – 20) = temperature correction to be added to hydrometer readings

H_1 = hydrometer reading at 40 sec

H_2 = hydrometer reading at 5 hrs

Particle size distribution was determined using soil textural triangle.

Determination of surface organic layers

Litter collected for surface organic layer assessments were transferred into envelops at the laboratory of Faculty of Renewable Natural Resources. They were then sealed, labeled and oven dried at temperature of 65^0C. Samples were later removed from oven and weighed on a scale after every 24hrs until constant weights were obtained and recorded for each sample.

4.0 RESULTS

This section presents results on the effects of wildfire on surface organic layers, soil chemical properties and soil physical properties in both burnt and unburnt sites within the selected forest reserves. Also presented are results on wildfire effects on vegetation within the reserves.

4.1 Comparison of soil chemical properties within sites

Afram Headwaters

Within 0-5cm soil depth, soil pH, cation exchange capacity (CEC), calcium (Ca), potassium (K), total exchangeable bases (TEB), Exch. Al and Base sat were similar at the burnt and unburnt sites. However, except for Phosphorus (P), Nitrogen (N), organic matter (OM) and magnesium (Mg) levels were significantly higher on the burnt sites than unburnt sites($P \leq 0.05$) (Table 1).

Bosomkese

Within 0–5cm soil depth, pH, CEC, Base sat. and TEB were significantly higher on burnt sites than unburnt sites ($P \leq 0.05$). However, P and Ca declined significantly on burnt sites than unburnt sites ($P \leq 0.01$ and $P \leq 0.05$). Soil levels of K, %OC, Total N, %OM, Mg, and Exch. A were similar in burnt and unburnt sites (Table 2).

Table 1. Comparison of selected soil chemical properties in burnt and unburnt sites within 0-5cm soil depth in Afram Headwaters Forest Reserve using student's T-test[1]

Properties	Burnt	Unburnt	P- values
pH (H_2O)	7.36 (0.13)	7.33 (0.07)	0.852^{ns}
OC (%)	3.23 (0.31)	4.5 (0.23)	0.025*
Total N (%)	0.28 (0.03)	0.39 (0.02)	0.024*
OM (%)	5.58 (0.53)	7.88 (0.40)	0.025*
Ca (cmols/Kg)	26.19 (5.45)	28.05 (5.77)	0.826^{ns}
Mg (cmols/Kg)	3.12 (0.08)	4.99 (0.43)	0.013*
K (cmols/Kg)	1.55 (0.17)	0.82 (0.42)	0.185^{ns}
P (ppm)	27.36 (6.72)	7.93 (0.57)	0.022*
TEB	31.01 (5.72)	34.37 (6.05)	0.707^{ns}
Exch. A (Al+H)	0.08 (0.01)	0.12 (0.03)	0.269^{ns}
CEC (cmols/Kg)	31.09 (5.72)	34.49 (6.08)	0.704^{ns}
Base sat (%)	99.72 (0.10)	99.66 (0.03)	0.563^{ns}

[1]Figures in parentheses are standard errors; ns is no significant difference, *, **, *** is significant at 0.05, 0.01. 0.001 probability levels

Table 2. Comparison of selected soil chemical properties of burnt and unburnt sites within 0-5cm soil depth in Bosomkese Forest Reserve using student's T-test[1]

Properties	Burnt	Unburnt	P- values
pH (H_2O)	7.00 (0.10)	5.28 (0.44)	0.019*
OC (%)	4.91 (0.42)	3.81 (0.64)	0.226 ^{ns}
Total N (%)	0.39 (0.02)	0.33 (0.06)	0.393 ^{ns}
OM (%)	7.72 (0.47)	6.57 (1.11)	0.394 ^{ns}
Ca (me/100g)	2.69 (1.79)	11.95 (1.55)	0.011*
Mg (me/100g)	6.81 (2.63)	5.08 (0.98)	0.571 ^{ns}
K (me/100g)	1.36 (0.12)	0.87 (0.48)	0.385 ^{ns}
P (ppmP)	7.39 (0.38)	23.56 (3.18)	0.003**
TEB	31.00 (3.98)	18.18 (2.32)	0.050*
Exch.A (Al+H)	0.10 (0.03)	0.14 (0.01)	0.158 ^{ns}
CEC (cmols/Kg)	31.10 (3.96)	18.32 (2.33)	0.050*
Base sat (%)	99.66 (0.13)	99.20 (0.08)	0.043*

[1]Figures in parentheses are standard errors; ns is no significant difference, *, **, *** is significant at 0.05, 0.01. 0.001 probability levels.

Worobong South

Within 0-5cm Soil levels of %OC, Total N, %OM, Mg, K, P and Base sat. were similar on both burnt and unburnt sites, However, except for Exch. A, soil levels of pH, Ca, TEB and CEC were significantly higher on the burnt sites than the unburnt sites at ($P \leq 0.05$) (Table 3).

4.2 Comparison of soil chemical properties between locations

4.2.1 Afram Headwaters and Bosomkese Forest Reserve

Burnt Sites

Within 0–5cm soil depth, Mg, K, TEB, Exch. A, CEC, and Base Sat. were similar. Soil pH, Ca, and P were significantly higher ($P \leq 0.05$) on Afram Headwaters compared to Bosomkese. On the other hand,%OC, Total N, and %OM were significantly higher at Bosomkese compared to Afram (Table 4).

Unburnt Sites

Within 0-5cm soil depth, total N, %OM, Mg, K and Exch. A were similar. However, pH, %OC, Ca, TEB, CEC, and Base Sat. were significantly higher ($P \leq 0.05$) on Afram Headwaters compared to Bosomkese. Alternatively, P was higher ($P \leq 0.05$) on Bosomkese compared to Afram Headwaters (Table 4).

Table 3. Comparison of selected soil chemical properties in burnt and unburnt sites within 0-5cm soil depth in Worobong South Forest Reserve using student's T-test[1]

Properties	Burnt	Unburnt	P- values
pH (H_2O)	5.99 (0.19)	5.07 (0.14)	0.018*
OC (%)	2.04 (0.07)	2.30 (0.33)	0.496 ns
Total N (%)	0.18 (0.01)	0.20 (0.03)	0.441 ns
OM (%)	3.52 (0.12)	3.96 (0.57)	0.491 ns
Ca (cmols/Kg)	9.15 (1.64)	3.23 (0.31)	0.024*
Mg (cmols/Kg)	0.88 (0.44)	1.10 (0.59)	0.783 ns
K (cmols/Kg)	0.34 (1.12)	0.28 (0.02)	0.662 ns
P (ppm)	17.90 (3.89)	16.88 (1.02)	0.406 ns
TEB	10.42 (1.29)	4.63 (0.95)	0.022*
Exch.A (Al+H)	0.08 (0.01)	0.48 (0.10)	0.017*
CEC (cmols/Kg)	10.50 (1.28)	5.11 (0.85)	0.025*
Base sat (%)	99.23 (0.18)	89.22 (3.99)	0.066 ns

[1]Figures in parentheses are standard errors; ns is no significant difference, *, **, *** is significant at 0.05, 0.01. 0.001 probability levels.

Table 4. Comparison of selected soil chemical properties of burnt and unburnt sites within 0-5cm soil depth between Afram Headwaters and Bosomkese Forest reserves using student's T-test.[1]

	Burnt			Unburnt		
Properties	Afram	Bosomkese	P – value	Afram	Bosomkese	P – value
pH H_2O	7.36	6.99	0.049*	7.33	5.28	0.005**
OC %	3.23	4.91	0.016*	4.57	3.81	0.014*
Total N %	0.28	0.39	0.016*	0.39	0.33	0.171 ns
OM %	5.58	7.72	0.019*	5.56	6.57	0.232 ns
Ca me/100g	26.19	6.81	0.016*	26.05	11.95	0.027*
Mg me/100g	3.12	6.81	0.117 ns	4.99	5.08	0.469 ns
K me/100g	1.55	1.37	0.204 ns	0.82	0.87	0.471 ns
P ppmP	27.36	7.39	0.021*	7.93	23.56	0.004**
TEB	31.01	31.00	0.499 ns	34.37	18.18	0.033*
Exch.A Al+H	0.08	0.10	0.270 ns	0.12	0.14	0.25 ns
CECme/100g	31.09	31.10	0.499 ns	34.49	18.32	0.033*
Base sat %	99.72	99.66	0.354 ns	99.66	99.20	0.033*

[1]ns is no significant difference. *, **, *** is significant at 0.05, 0.01 and 0.001 probability levels respectively.

4.2.2 Afram Headwaters and Worobong South Forest Resrve

Burnt Sites

Within 0–5cm soil depth, P and Exch. A were similar. However, pH, %OC, %OM, total N, Ca, Mg, Kg, TEB, CEC and Base Sat were significantly higher ($P \leq 0.01$and 0.05) on Afram Headwaters compared to Worobong South forest reserve (Table 5).

Unburnt Sites

Within 0–5cm soil depth, K and Base Sat. were similar. However, pH, %OC, %OM, total N, %OM, Ca, Mg, TEB, and CEC were significantly higher ($P \leq 0.01$and 0.05) on Afram Headwaters compared to Worobong South forest reserve. On the other hand P and Exch. A were higher ($P \leq 0.01$and 0.05) on Worobong compared to Afram Headwaters forest reserve (Table 5).

Table 5. Comparison of selected soil chemical properties of burnt and unburnt sites within 0-5cm soil depth between Afram Headwaters and Worobong South Forest reserves using student's T-test[1]

	Burnt			Unburnt		
Properties	Afram	Worobong	P – value	Afram	Worobong	P – value
pH (H_2O)	7.36	5.99	0.002**	7.33	5.07	0.03 *
OC (%)	2.23	2.04	0..009**	4.57	2.30	0.050*
Total(N %)	0.28	0.18	0.010**	0.39	0.20	0.002**
OM (%)	5.38	3.52	0.009**	7.88	3.96	0.002**
Ca(cmol/Kg)	26.19	9.15	0.020*	28.05	3..23	0.006**
Mg(cmols/Kg)	3.12	0.88	0.004**	4.99	1.10	0.003**
K me/100g	1.55	0.34	0.002**	0.82	0.28	0.132^{ns}
P ppm	27.36	17.90	0.145^{ns}	7.93	16.88	0.000***
TEB	31.01	10.42	0.012*	34.37	4.63	0.004**
Exch.A Al+H	0.08	0.08	0.50^{ns}	0.12	0.48	0.013*
CEC(cmols/Kg)	31.09	10.5	0.012*	34.49	5.11	0.004**
Base sat %	99.72	99.23	0.038*	99.66	89.22	0.300^{ns}

[1]ns is no significant difference. *, **, *** is significant at 0.05, 0.01 and 0.001 probability levels respectively.

4.2.3 Worobong South and Bosomkese Forest Reserve

Burnt Sites

Within 0–5cm soil depth, Exch. A and Base Sat. were similar. However, Ca, and P were higher ($P \leq 0.05$) on Worobong compared to Bosomkese. On the other hand, pH, %OC, %OM, total N, K, Mg, TEB, and CEC were significantly higher ($P \leq 0.01$, $P \leq 0.05$) on Bosomkese compared to Worobong forest reserve (Table 6).

Unburnt Sites

Within 0–5cm soil depth, pH, %OC, %OM, K and P were similar. However, except Exch. A, all other nutrients were higher ($P \leq 0.01$, $P \leq 0.05$) on Bosomkese compared to Worobong south forest reserve (Table 6).

Table 6.comparison of selected soil chemical properties of burnt and unburnt sites within 0-5cm soil depth between Worobong South and Bosomkese Forest reserves using student's T-test[1]

	Burnt			Unburnt		
Properties	W.South	Bosomkese	P – value	W. Soutth	Bosomkese	P – value
pH(H_2O)	5.99	6.99	0.005**	5.07	5.28	0.338 ns
OC %	2.04	4.91	0.001**	2.30	3.61	0.052 ns
Total N %	0.18	0.39	0.000***	0.20	0.33	0.050*
OM %	3.52	7.72	0.000***	3.96	6.57	0.052 ns
Ca(cmols/Kg)	9.15	6.81	0.046*	3.23	11.95	0.003**
Mg(cmols/Kg)	0.88	6.81	0.045*	1.10	5.08	0.013*
K (cmols/Kg)	0..34	1.37	0.002**	0.280	0.873	0.143 ns
P (ppm)	17.90	7.39	0.024*	16.88	23.56	0.058 ns
TEB	10.42	31.00	0.004**	4.63	18.18	0.003**
Exch.A Al+H	0.08	0.10	0.270 ns	0.48	0.14	0.014*
CEC(cmols/Kg)	10.50	31.09	0.004**	5.11	18.32	0.003**
Base sat %	99.23	99.66	0.07 ns	89.22	99.20	0.033*

[1]ns is no significant difference. *, **, *** is significant at 0.05, 0.01 and 0.001 respectively.

4.3 Comparison of soil physical properties within sites

At Afram Headwaters, soil texture (sand, silt and clay) was significantly different between burnt and unburnt sites at ($P \leq 0.01$, $P \leq 0.05$). Bulk density on the burnt sites of 1.64 was similar to bulk density of 1.95 on the unburnt sites. However, soil texture (sand, silt and clay) at Bosomkese was similar in both burnt and unburnt sites. Again bulk density was similar in burnt and unburnt sites. Also at Worobong South, soil texture (sand, silt and clay) was similar in burnt and unburnt sites whiles bulk density was similar in both burnt and uburnt sites though it decreased in the burnt sites as compared to the unburnt sites (Table 7).

Table 7 Comparison of selected soil physical properties within 0-5cm of soil depth of burnt and unburnt sites using student's T-test[1]

Site/Properties	Burnt	Unburnt	P-values
Afram Headwaters Forest Reserve			
Sand	59.92 (0.96)	42.26 (2.60)	0.004**
Silt	36.19 (1.57)	48.83 (1.34)	0.004**
Clay	4.94 (0.59)	8.91 (1.27)	0.047**
Bulk density	1.64 (0.35)	1.95 (0.03)	0.432 ns
Bosomkese Forest Reserve			
Sand	32.31 (1.10)	43.77 (8.20)	0.238 ns
Silt	50.55 (0.86)	46.74 (7.89)	0.656 ns
Clay	17.14 (1.84)	9.55 (2.36)	0.064 ns
Bulk density	1.75 (0.09)	1.95 (0.03)	0.09 ns
Worobong South Forest Reserve			
Sand	69.97(1.59)	62.89 (11.49)	0.574 ns
Silt	23.72 (1.69)	28.28 (12.62)	0.738 ns
Clay	6.31 (0.27)	8.85 (1.71)	0.216 ns
Bulk density	1.50 (0.18)	1.63 (0.26)	0.713 ns

[1]Figures in parentheses are standard errors; ns is no significant difference, *, **, *** is significant at 0.05, 0.01. 0.001 probability levels.

4.3.1 **Comparison of soil physical properties between Sites**

Afram Headwaters and Bosomkese Forest Reserves

There were no significant difference with regards to soil texture (sand silt and clay) and bulk density in the unburnt sites between Afram Headwaters and Bosomkese Forest reserves. Similarly bulk density and sand in the burnt sites were similar. Silt and clay were significantly higher on Bosomkese compared to Afram Headwaters ($P \leq 0.001$ and 0.01) respectively on the burnt sites (Table 8).

Afram Headwaters and Worobong South Forest reserves

Soil texture (sand, silt and clay) and bulk density were similar. Similarly, clay and bulk density on the burnt site did not differ significantly. Sand and silt differed significantly in the burnt sites ($P \leq 0.01$) (Table 9).

Worobong and Bosomkese Forest Reserves

Soil texture (sand, silt and clay) and bulk density did not differ significantly in the unbrnt site. Similarly, sand and silt did not differ significantly. Clay differed significantly in the burnt site at ($P \leq 0.01$) (Table 10).

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Table 8.Comparison of selected soil physical properties within 0-5cm soil depth in burnt and unburnt sites between Afram Headwaters and Bosomkese Forest reserves using student's T-test[1]

	Burnt			Unburnt		
Properties	Afram	Bosomkese	P – value	Afram	Bosomkese	P – value
Sand	58.92	32.31	.685 ns	42.26	43.77	0.435 ns
Silt	36.19	50.55	0.000***	48.83	46.74	0.807 ns
Clay	4.94	17.14	0.002**	8.91	9.55	0.411 ns
B. density	1.64	1.75	0.392 ns	1.95	1.95	0..500 ns

[1]ns is no significant difference. *, **, *** is significant at 0.05, 0.01 and 0.001 respectively.

Table 9. Comparison of selected soil physical properties within 0-5cm soil depth of burnt and unburnt sites between Afram Headwaters and Worobong South Forest reserves using student's T-test[1]

	burnt			unburnt		
Properties	Afram	Worobong	P – value	Afram	Worobong	P – value
Sand	58.92	69.92	0.002**	42.26	62.87	0.077 ns
Silt	36.19	23.92	0.003**	48.83	28.28	0.090 ns
Clay	4.94	6.31	0.051 ns	8.91	8.85	0.489 ns
B. density	1.64	1.50	0.373 ns	1.95	1.63	0.140 ns

[1]ns is no significant difference. *, **, *** is significant at 0.05, 0.01 and 0.001 respectively.

Table 10 Comparison of selected soil physical properties within 0-5cm soil depth of burnt and unburnt sites between Worobong South and Bosomkese Forest reserves using student's T-test[1]

	burnt			unburnt		
Properties	Worobong	Bosomkese	P-value	Worobong	Bosomkese	P –value
Sand	69.97	32.31	2.045 ns	62.89	43.77	0.124 ns
Silt	23.72	50.55	7.180 ns	28.28	46.74	0.141 ns
Clay	6.31	17.14	0.002**	8.85	9.55	0.410 ns
B. density	1.50	1.73	0.143 ns	1.63	1.95	0.140 ns

[1]ns is no significant difference. *, **, *** is significant at 0.05, 0.01 and 0.001 respectively.

4.4 **Comparison of surface organic layers within sites**

Surface organic layers in burnt and unburnt sites within Bosomkese were similar whereas surface organic layers between burnt and unburnt sites within Worobong South and Afram headwaters were significantly higher ($P \leq 0.05$ and 0.001) on unburnt sites compared to burnt sites (Table 11).

4.4.1 **Comparison of surface organic layers between sites**

Surface organic layers on burnt and unburnt sites of Afram Headwaters and Bosomkese forest reserves were significantly higher ($P \leq 0.001$ and $P \leq 0.05$) at the unburnt sites compared to burnt.

Surface organic layers at unburnt sites of Afram Headwaters and Worobong South forest reserve were also significantly high ($P \leq 0.01$ and $P \leq 0.001$) compared to burnt sites. Surface organic layers at burnt sites of Bosomkese and Worobong South forest reserves was significant ($p < 0.0$) but did not differ significantly between the unburnt sites (Table 12).

Table11. Comparison of surface organic layers of burnt and unburnt sites within forest reserves using student's T-test[1]

Site	Burnt ($Kg\ ha^{-1}$)	Unburnt ($Kg\ ha^{-1}$)	P – value
Bosomkese	6684.00	6974.67	0.401 ^{ns}
Worobong South	2028.00	7686.00	0.021*
Afram Headwaters	0	4943.00	0.000***

[1]ns is no significant difference; *, ** is significant at 0.05, 0.01 and 0.001 probability levels.

Table 12. Comparison of surface organic layers on burnt and unburnt sites between forest reserves using student's T-test [1]

	Sites ($Kg\ ha^{-1}$)		
Treatment	Afram Headwaters	Bosomkese	P - value
Burnt	0	6684.00	0.00***
Unburnt	4943.00	6975.00	0.04*
	Afram Headwaters	Worobong South	
Burnt	0	228.00	0.00***
Unburnt	4945.00	7686.67	0.01**
	Worobong South	Bosomkese	
Burnt	2026.00	6684.00	0.01**
Unburnt	7686.67	6974.67	0.30^{ns}

[1]ns is no significant difference; *, **, *** is significant at 0.05, 0.01 and 0.001 probability levels.

4.5 **Vegetative studies within sites**

Afram Headwaters Forest Reserve

Pennisetum purpereum was the only species found at the burnt site of Afram Headwaters. However, at the unburnt site shrub and tree species found include *Griffonia simplicifolia, Chromolaena odorata, Baphia nitida, Blighia sapida and Broussonatia papyverifera* (Table 13)

4.5.1 Bosomkese Forest Reserve

Shrub and tree species found on the burnt site include; *Baphia nitida, Griffonia simplicifolia, Chromolaena odorata, Mallotus oppositifolius, Celtis malbraedii,, Blighia sapida, Sterculia tragaganta, Trema gumiensis, Ficus exasperate, Phyllantus reticulate, Triplochiton scleroxylon, Mantochloa leucantha.*

However, at the unburnt site, shrub and tree species found at the unburnt site include; *Griffonia simplicifolia, Celtis malbraedii, Blighia sapida, Baphia nitida, Sterculia tragaganta, Newbouldia laevis, Khaya anthotheca, , Microdesmis puberula, Trichillia prieuriana, Erythrophyleum ivorenses* (Table 14).

Table 13. Species found in burnt and unburnt sites in Afram Headwaters[1]

Burnt	Unburnt
Grass	Shrub
Pennisetum purpereum	*Griffonia simplicifolia*
	Chromolaena odorata
	Tree
	Baphia nitida
	Blighia sapida
	Broussonatia papyverifera

Table 14. Species found within burnt and unburnt sites in Bosomkese forest reserve[1]

Burnt	Unburnt
Shrub	Shrub
Baphia nitida	*Griffonia simplicifolia*
Griffonia simplicifolia	
Chromolaena odorata	Tree
Mallotus oppositifolius	*Celtis malbraedii*
	Blighia sapida
Tree	*Baphia nitida*
Celtis malbraedii	*Sterculia tragaganta*
Blighia sapida	*Newbouldia laevis*
Sterculia tragaganta	*Khaya anthotheca*
Trema gumiensis	*Microdesmis puberula*
Ficus exasperate	*Trichillia prieuriana*
Phyllantus reticulate	*Erythrophyleum ivorenses*
Triplochiton scleroxylon	
Mantochloa leucantha	
Thaumatococcus daniellii	

4.5.2 Worobong South Forest Reserve

Grass, shrub and tree species found at the burnt site include; *Pannicum maximum, Chromolaena odorata, Mallotus oppositifolius, Blighia sapida, Baphia nitida, Millitia rodanta*.

On the other hand, shrub and tree species found at the unburnt site include; *Griffonia simplicifolia, Funtumia elastic, Trichillia prieuriana, Blighia sapida, Microdesmis puberula, Millitia rodanta, Celtis malbraedii, Piptadeniastrum Africana, Baphia nitida* (Table 15)

Table 15. Species found within burnt and unburnt sites in Worobong South forest reserve[1]

Burnt	Unburnt
Grass	Shrub
Pannicum maximum	*Griffonia simplicifolia*
Shrub	Tree
Chromolaena odorata	*Funtumia elastica*
Mallotus oppositifolius	*Trichillia prieuriana*
	Blighia sapida
Tree	*Microdesmis puberula*
Blighia sapida	*Millitia rodanta*
Baphia nitida	*Celtis malbraedii*
Millitia rodanta	*Piptadeniastrum africana*
	Baphia nitida
	Glyphaea brevis
	Guarea senegalensis
	Albizia species
	Voacanga africana

4.5.2 **Comparison of common pioneer species**

Common pioneer species found within burnt and unburnt sites in reserves include; *Griffonia simplicifolia, Celtis malbraedii* and *Khaya anthotica*.

All the common pioneer species were found in Bosomkese. *Griffonia simplicifolia* and *Celtis malbraedii* were found in Worobong South only at the unburnt sites. Afram Headwaters recorded only Griffonia *simplicifolia* at the unburnt sites (Fig. 3).

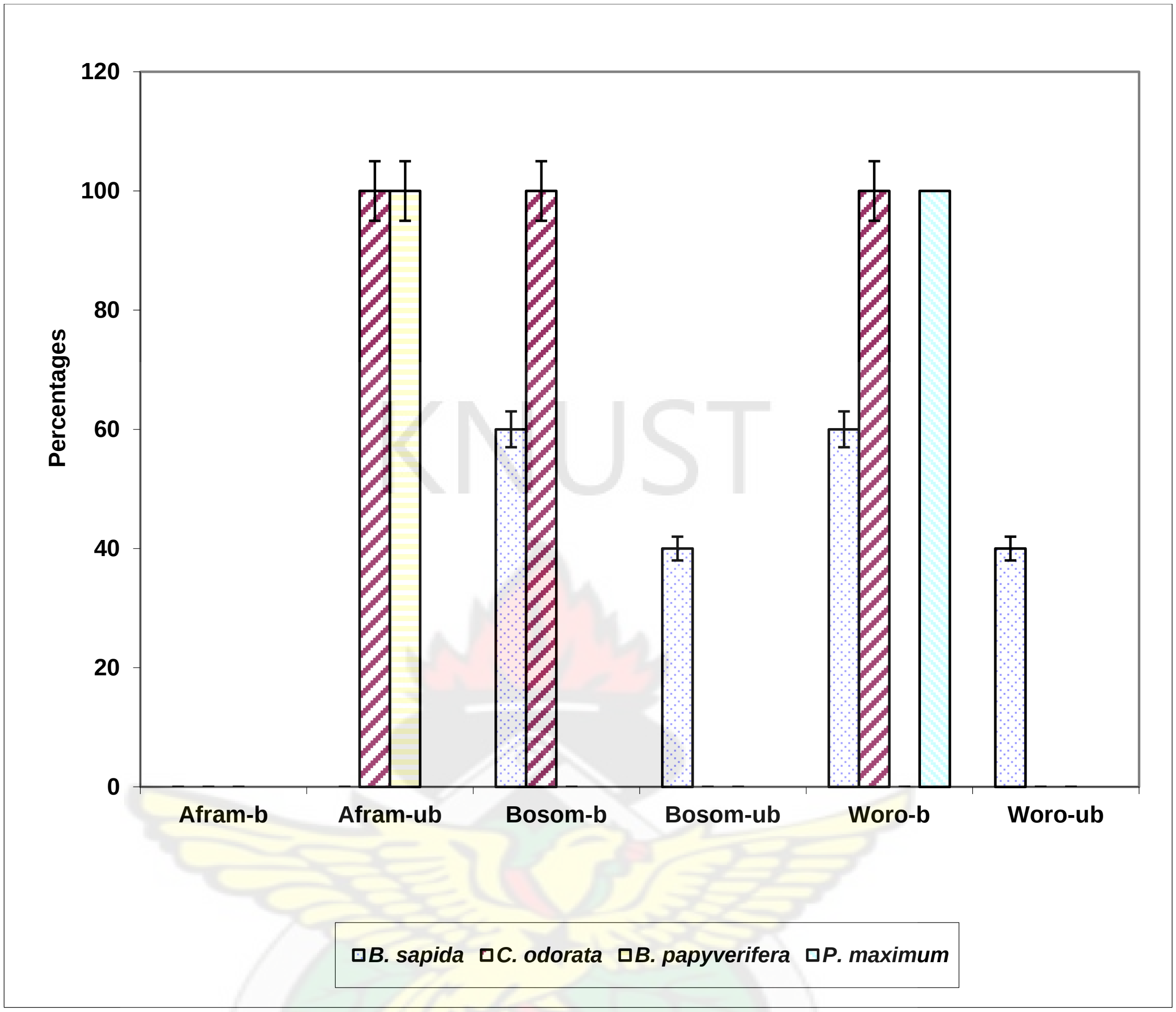

Figure 3. Comparison of common pioneer species in burnt (b) and unburnt (ub) sites within Afram Headwaters (Afram-), Bosomkese (Bosom-) and Worobong South (Woro-) forest reserves.

4.5.3. Comparison of common successional species within reserves

Common successional species recorded in Afram Headwaters include; *Chromolaena odorata* and *Broussonatia papyverifera* only at the unburnt sites. Bosomkese recorded *Blighia sapida* and *Chromolaena odorata* at the burnt sites whiles the unburnt sites recorded only *Blighia sapida.* Blighia sapida, *Chromolaena odorata* and *Pannicum maximum* were the common successsional species found at the burnt sites of Bosomkese, however, the unburnt sites recorded only *Blighia sapida (*Fig. 3)*.*

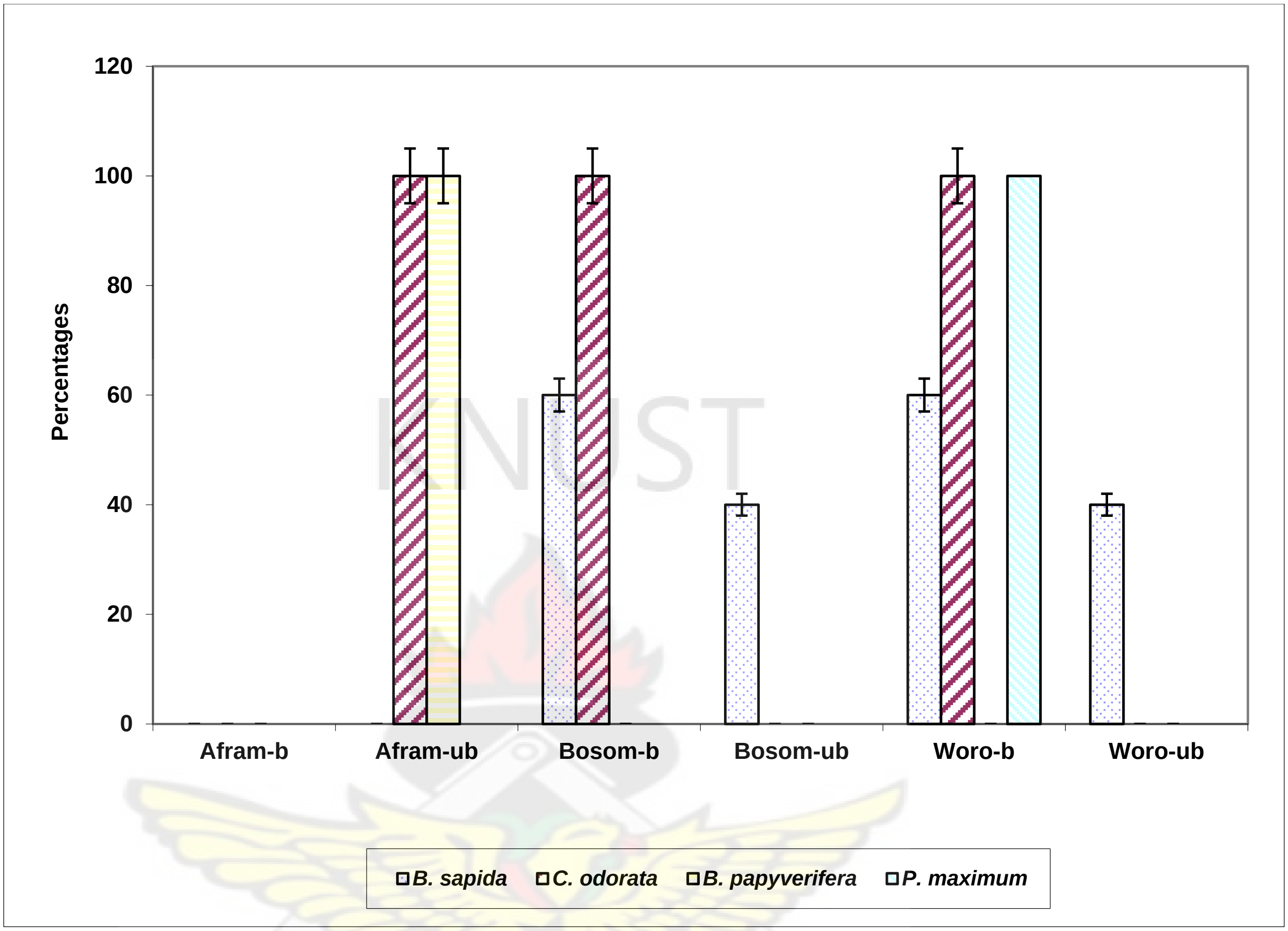

Figure 3. Comparison of common successional species in burnt (b) and unburnt (ub) sites within Afram Headwaters (Afram-), Bosomkese (Bosom-) and Worobong South (Woro-) forest reserves.

CHAPTER FIVE

5.0 DISCUSSION

5.1 **Introduction**

Fire has been a powerful manipulator of tropical ecosystems. With time, it has had lasting effects on soil and vegetation. Effects of fire on chemical and physical properties of forest soils vary from minimal to profound, depending on factors such as intensity, and duration of the fire, soil type, soil moisture content at the time of the fire, and duration and intensity of post fire precipitation events (Chandler et al., 1983. Pyne et al., 1996).

Wildfires release from plant materials to the soil about half of the nitrogen and phosphorus in the burning biomass and practically all of the other nutrients in the form of ash (Sanchez, 1994). The released nutrients as well as high temperatures affect the chemical and physical properties of soils. The effects could enhance nutrient availability, induce nutrient deficiency or cause no effect.

Wildfires influence on soil physical properties may cause the loss or reduction of soil structure, reduction of porosity and alteration of colour. However, one important consequence includes the reduction of surface organic layers.

Wildfires also destroy vegetation by killing most of all of the plants and weed seeds, above the soil surface. This chapter discusses the effects of wildfire on soil chemical and physical properties as well as vegetation presented in chapter four.

5.2 Effects of Wildfire on Soil Chemical Properties within Sites

This research hypothesized that soil chemical properties such as K, pH and CEC within 0-5cm soil depth would be higher in the burnt sites as compared to the unburnt sites. The research also hypothesized that soil N and OM would be lower on burnt sites as compared to unburnt.

Within Afram Headwaters forest reserve, the results validate the hypothesis with respect to soil total N and %OM. However, for soil pH, K and CEC the hypothesis was rejected. Within Bosomkese forest reserve, the results validate the hypothesis with respect to soil pH and CEC whiles Total N, % OM and K rejected the hypothesis. Results obtained within Worobong South forest reserve validated the hypothesis with respect to soil pH and CEC. However, total N, % OM and K rejected the hypothesis.

Soil organic matter

As hypothesized, %OM within Afram Headwaters showed a significant difference ($P \leq 0.01$) between burnt (5.58) and unburnt sites (7.88).. The reduction of organic matter in the burnt site could be due to the nature of the layer of organic matter over the parent material which is not incorporated into the soil in most cases. However, there was an unusual increase of % OM on burnt sites (7.72) within Bosomkese forest reserve as compared to unburnt site of 6.57 though not significantly different. The amount of biomass and the fire intensity affects the level of organic carbon after fire. The high organic matter content on the burnt site might be due to a high initial biomass and incomplete combustion.

This implies that both vegetation and litter were burnt but not soil organic matter. A similar study in South Corolina indicated increased organic matter in a 20-year burning within 0-5cm layer of mineral soil. When the influence of fire on organic matter was taken into account, the effect of burning was redistribution of organic matter within the profile but no reduction of inorganic matter (Wells, Carol G. 1979).

Total nitrogen.

Total nitrogen level at Afram Headwaters forest reserve showed a significant difference ($P \leq 0.01$) between burnt and unburnt sites. This could be attributed to the high temperatures during fire which releases N from the debris, which is lost to the atmosphere as ammonia and oxides of N. However, there was an unsual increase of total N on the burnt site within Bosomkese forest reserve. Although Worobong South forest reserve recorded a decrease in total N on the burnt site (0.18) as compared to the unburnt site (0.20), though not significantly different. This could be due to the intensity of fire and the accumulation of debris on the site as well as organic matter consumed during fire. This also reflected in the % OC content which was also different in the two sites. In general, burning increase the amount of ava ilable nutrient in the surface soil with the possible exception of nitrogen.

Soil acidity pH

Soil pH is affected by fire because of the large quantity of ash elements that is released from organic debris. As hypothesized, soil levels of pH within Bosomkese and Worobong south forest reserves showed significant difference ($P \leq 0.01$) between burnt (6.50) and unburnt sites (5.17).

The increase in pH could be attributed to the release of bases into the soil in the form of ash from burnt organic debris (Kimmins, 1997). The main cations that affect soil pH are calcium, magnessium and potassium. The extent and duration of the increase could depend on the intensity of the fire, amount of organic matter consumed and buffering capacity of the soil. Table 2 however, shows that total exchangeable bases was higher in the burnt than the unburnt site. Calcium content was significantly higher in burnt sites than unburnt site. In Table 6 the higher soil pH in burnt site could be attributed to the high Ca and total exchangeable bases as well as low exchangeable acidity in the burnt sites. The rise in pH stimulates mineralization of organic matter.

Although one would expect a change in pH after burning, it is not always the case; the non-significant difference between soil pH levels in burnt and unburnt sites Table 4 also correlates with no difference in Ca, Mg, K and total exchange base levels of the burnt and unburnt sites. The non-significant difference could also be attributed to the intensity of fire, amount of organic matter consumed, buffering capacity of the soil as well as the parent material. A similar result by Campbell *et al*., (1977) indicated no difference in pH for soils with sedimentary parent material between burnt and unburnt soils in Ponderosa pine in Northern Arizona. Usually, soil pH values of burnt soils tend to return to their initial pre-fire values with time, but this will depend on the rate of leaching, flow out of site and the concentration of other basic cations among other factors (Wells, 1979).

CEC

Cation exchange capacity increased significantly between burnt and unburnt sites within Bosomkese and Worobong south forest reserve at ($P \leq 0.05$). This increase could be due to the increase in the quantity of soluble inorganic ions provoked by the combustion of the organic matter. Every 1.0% decline in SOM content is equivalent to 3.0 me/100g soil decline in CEC (Kimmins,1997).

CEC did not show significant difference between burnt and unburnt sites within Afram Headwaters forest reserve. This could be due to the fact that CEC values tend to fall subsequently after fire due to precipitation, salt fixation and leaching (Hernandez *et. Al.,* 1997).

Exchangeable Ca

Calcium content increased significantly at burnt and unburnt within both Worobong and Bosomkese forest reserves at ($P \leq 0.05$) whereas there was no significant change in Ca content at Afram headwaters. CEC and exchangeable Ca content followed the same trend. Calcium is therefore the most determining factor in CEC.

Exchangeable Mg

Exchangeable Mg content declined significantly at Afram headwaters following ($P < 0.05$). However, at Worobong and Bosomkese forest reserves there were no significant differences between the burnt and unburnt sites. These observations are different from findings of Nye and Greenland (1960). At Kade, Ghana, where Mg values increased following clearing and burning.

5.2.1 Between Sites

Afram Headwaters and Bosomkese Forest reserves

The unburnt site of Afram Headwaters and Bosomkese showed a significant difference in the accumulation of surface organic layers, averaging 4943Kgha-1 at AframHeadwaters and 6974.67Kgha-1 at Bosomkese. Following wild fires there was 100% removal of the surface layers at Afram Headwaters whiles Bosomkese had about 4%.

This reduction reflected on soil chemical properties found on both sites. Soil pH, Total N, OM, CEC and K increased on burnt site at Bosomkese though not significant with regards to Total N, OM, and K. This could be attributed to the incomplete combustion of organic layers causing the release of nutrients, which were retained and protected from being lost through run – off by the remaining debris on the burnt site. Trabaud, 1983 also documented an increase in organic matter content following fire. However, soil levels of OC, OM, and CEC declined at Afram Headwaters. This decline could be attributed to the complete removal of the surface layers and the sandy nature of the soil. Following wildfires the soil might have been exposed to extreme temperatures, causing the loss of nutrients through volatilization, leaching and erosion as there was no cover on the surface soil.

Afram Headwaters and Worobong South Forest Reserve

There was a high accumulation of organic layers at Worobong South forest reserves as compared to that of Afram Headwaters at the unburnt site averaging 7686.67 Kg ha-1 and 493 Kg ha-1 respectively. At the burnt sites, there was a 100% removal of the organic layers at Afram Headwaters whiles Worobong South had about 70% reduction of the organic layers. This reflected in the level of nutrients found in each site.

Although Worobong had a high accumulation of surface organic layers than that of Afram Headwaters, the organic matter content at Afram Headwaters was higher than that of Worobong South. This could be attributed to the poor litter quality which might not be breaking down fast to add up to the soil organic matter content. In addition, the sandy nature of soil at the site could not hold nutrients together hence resulting in the loss of organic matter.

At the burnt site, soil pH increased in both sites whereas CEC only increased at Worobong South. The dramatic decrease of CEC at Afram Headwaters from 34.49 me/100g - 31.09 me/100g could be attributed to infiltration and erosion as there was no litter cover at the burnt site exposing the soil to run – off.

Bosomkese and Worobong South

Both Bosomkese and Worobong South had considerable high quantity of organic layers at the unburnt site. Soil pH and CEC increased at both locations following wildfires. Total N and OM both decreased at Worobong whereas it increased at Bosomkese. The increase in Total N and OM following fires at Bosomkese was as a result of low intensity of fire at the burnt site as well as the high clay content at the burnt site which held the organic matter.

5.3 Effects of Wildfire on Soil Physical Properties

Soil texture

Soil texture varied significantly between burnt and unburnt sites within 0-5cm soil depth with regards to sand, silt and clay at Afram headwaters forest reserve. Sand, silt and clay varied significantly at $P \leq 0.01$, 0.01 and 0.05 respectively. However there were no significant difference between burnt and unburnt sites with respect to sand, silt and clay at both Bosomkese and Worobong south forest reserve.

Clay content declined on the burnt site at both Afram headwaters and Bosomkese forest reserves, whiles the sand content increased. This could be due to the fact that excessive heat denatures colloids and OM in clay, hence loosing its plasticity and subjecting soil particles to run-off and leaching, as a result, causing increase in the sand fraction at the burnt sites.

A similar results obtained by Fosu, 2004, indicated a modification in soil texture with a significantly higher sand content and lower clay fraction. Although there was an increase in clay content in absolute figures at the burnt site at Bosomkese forest reserve and a decline in clay content at Worobong south forest reserve, they were not statistically different, when the increase in clay content could be due to the fact that OM was not completely combusted hence plant debris adding up to the clay content and causing a corresponding decrease in the sand fraction.

Bulk density

There were no significant differences in the bulk density of soil in Afram Headwaters, Bosomkese and Worobong South Forest Reserve. Bulk density which is directly related to the amount of space and to the infiltration rate of soil is not affected by wildfire. This has important implications for potential soil erosion on these sites. Fire can contribute to soil erosion by lowering infiltration rates and increasing the repellency of soil (Diaz-Fieros *et al*., 1990), both of which can lead to increased surface flow. Although there was no significant difference between burnt and unburnt sits, absolute figures declined on the burnt sites. Diaz-Ferros et al, 1990 also reported lower values of bulk density in burned soils, which in turn led to increased rates of superficial water flow and soil erosion.

5.4 Wildfire Effects on Surface Organic Layers

The loss of the forest floor represents one of the more obvious alterations to soil caused by wildfire. The litter layer is an important source of nutrient and organic matter, providing a carbon and nutrient substrate for microbial activity (Wagner and Wolf, 1998), as well as acting as insulation from abrupt changes in soil temperature and moisture content.

As hypothesized, there was a reduction of surface organic layers on the most frequently burnt sites as compared to the unburnt sites. Afram Headwaters and Worobong South forest reserves showed a significant difference (0.000 and 0.021) respectively ($P \leq 0.001$) between the burnt and unburnt sites. This could be due to the fact that Afram Headwaters had a purely grass stand of *Pennisetum perpureum* hence having no floor litter following wildfires. The unburnt sites of the reserve had a substantial floor litter. This could be due to the different vegetation types.

Similarly there was a significant deference ($P \leq 0.05$) in surface organic layers within Worobong South forest reserve (unburnt-7686.00Kg ha^{-1}, burnt-2028.00 Kg ha^{-1}). The burnt site had about 74% loss of surface organic layers. This difference could also be attributed to the kind of vegetation, frequency of fire and fire intensity on the burnt site. Plant species were sparsely distributed at the burnt site whereas the unburnt had a densely populated plant species.

Surface organic layers showed no significant difference between the burnt (6684.00Kg ha^{-1} and unburnt (6974.67 Kg ha^{-1}) site. This could be attributed to the fact that the two sites had almost the same number of trees and shrubs hence having almost the same quantity of floor litter. Reasons could also be that the burnt site had not been suffering frequent wildfires or there was incomplete combustion of litter because the burnt site recorded only 4% loss in surface organic layer.

Areas experiencing wildfire after a prolong absence of fire can lose as much as 4,000 – 9,000kg ha o^{-1} organic matter from the forest floor (Pritchett and Fisher, 1987). Wells 1971 and Olsen, 1981 observed that a reduction in the litter layer can result in an increase in organic matter in the first 5cm of soil, offsetting the reduction of organic matter on the soil surface.

5.5 Effects of Wildfire on Vegetation

Afram Headwaters

Afram headwaters lies within the moist semi-deciduous forest type and in the fires zone subtype. The typical structure of the forest is of a single high canopy with a sparse woody understorey.

Results obtained from this research indicates that *Broussonatia papyverifera* is the predominant species at the unburnt site followed by *Blighia sapida* and *Baphia nitida*. The unburnt site is interspersed by dense undergrowth of shrubs and like *Griffonia simplicifolia* and *Chromoleana odorata* which are pioneer species of the site.

Following wildfire there was a total shift in vegetation composition. Results obtained from the burnt site indicates that there was a total destruction of vegetation as the whole site was found to be purely grassland of *Pennisetum purpereum*. *Pennisetum purpereum* is a fire-resistant species because of the perculiar nature of its roots which makes it difficult to be destroyed by fire since it is embedded in the soil. Budowskwi (1982) also made a similar observation of a shift in vegetation composition following burning which created initial dominance of fire-resistant species, which were eventually eliminated by the constant killing of regeneration until replaced by the fire resistant grasses and isolated tree species that constituted the predominant vegetation. One of the most fire-resistant grasses he observed was *Imperata* species which could not burn because of its rhizomes.

Bosomkese Forest Reserve

The reserve is of the tropical moist semi-deciduous forest with two main forest types, a secondary forest, which covers the southern part of the reserve, and a high forest which covers the rest of the reserve. Species found on the unburnt sites include: *Celtis malbraedii* and *khaya anthotica.* The dominant tree species found on the unburnt site was *Blighia sapida*.

At the burnt site, there was a shift in vegetation at the burnt site and was predominated by fire resistant trees like *Phyllantus reticulates*, and *Trema gumiensis*. The fire-sensitive species were all eliminated following wildfire including juvenile trees, seeds and seedlings. *Chromoleana odorata* was the dominant species on the burnt site.

Frequent fire eliminates species that flower infrequently or only after a long juvenile period (Kimmins, 1997). Hopkins (1965) studied the vegetation shift in the Olokemeji forest reserve in Nigeria by annual burning from 1959 to 1964.

Following wildfires all the trees and shrubs 2m or more high on research plots were enumerated. Of the 139 individuals present in 1959, only 92 were alive 5 years later.

Some species like *Celtis malbraedii* could also survive fires due to its size and height. *Celtis malbraedii* found on the burnt site had its diameter at breast height greater than 20cm hence there were visible effects of fire on the bark of the tree.

Worobong south forest reserve

This reserve stretches between moist deciduous and semi deciduous forest types. Following fires, most of the fire-sensitive trees and shrubs were destroyed including seeds and seedlings. Successional species that have taken over from pioneer species following fires included *Baphia nitida, Chromoleana odorata and Pannicum maximu were.* the predominant species of the burnt site. There was a decline in biodiversity at the burnt site as compared to the unburnt site. This could be due to the intensity, duration and frequency of the fires as well as most of the species being fire sensitive (Lal, 1987).

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and conclusions

The properties of soils and vegetation in the transitional zones of Ghana have undergone drastic changes due to annual cycles of wildfires. Data from this study suggest soil properties vary in their response to wildfires as well as vegetation.

This research tested four hypotheses; first, that surface organic layers will be decreased in frequently burnt sites as compared to unburnt sites. Results indicated a 100% loss of surface organic layers in the burnt site of Afram Headwaters and also a 74% and 4% loss in Worobong and Bosomkese Forest Reserves, respectively There was a significant difference in surface organic between burnt and unburnt sites within Afram Headwaters and Worobong ($P \leq 0.001$ and 0.05) respectively. However, Bosomkese recorded no significant difference between burnt and unburnt sites although absolute figures decreased on the burnt site following wildfires.

The second hypothesis was that soil levels of P and K would be higher in burnt sites as compared to unburnt and that soil pH and CEC levels would similarly be higher. Generally within 0 – 5cm soil depth, P and K were significantly higher ($P \leq 0.05$) in the burnt sites averaging 22.63ppmP and 0.95me/100g respectively as compared to the unburnt sites. Similarly soil pH and CEC were significantly higher ($P \leq 0.05$) in the burnt sites averaging 6.8 H_2O and 24.2 me/100g respectively as compared to the unburnt sites of 5.9 H_2O and 19.31 me/100g. However, the hypothesis was rejected at Afram Headwaters because soil pH and CEC did not differ significantly although absolute figures of soil pH increased on the burnt site whereas CEC reduced on the burnt site by 11%.

Thirdly it was hypothesized that, soil levels of N and OM would be lower in the burnt sites as compared to the unburnt sites. Generally within 0 – 5ccm soil depth, Total N and %OM were lower in the burnt sites averaging 0.28 and 5.6 respectively as compared to the unburnt sites of 0.3 and 6.1 although they were statistically different ($P \leq 0.05$) only at Afram Headwaters.

Wildfire effects on soil and vegetation varies with differences in location as in Afram Headwaters, Bosomkese and Worobong South Forest Reserves. Although all the reserves are in the transitional zones of Ghana, there were significant variations following wildfires. The variations were due to differences in vegetation, frequency and intensity of fire as well as soil texture. In areas where burning had been extremely high, organic matter, total nitrogen and phosphorus declined. Texture also affected the level and accumulation of some nutrients like Organic matter, Total nitrogen and CEC. Areas with sandy soils like Afram Headwaters and Worobong South recorded lower levels of these nutrients.

The adverse effects of fire are its role in transformation of the vegetation. Specific fire-adapted vegetation associations have developed through gradual evolution where periodic wildfires have been a normal feature of the environment as in the transitional zones of Ghana. Lastly, it was hypothesized that, more grasses and fie resistant trees would be found in burnt sites as compared to unburnt sites. Results from this research indicated that, following wildfires, large trees like *Celtis maldbraedii*, *Blighia sapida*, *Khaya anthotheca* have given way to fire-resistant shrubs and grasses like *Pennisetum purpureum*, *Phyllantus reticulate* and *Trema guiniensis*. Frequent wildfires have also given way to some successional species like *Baphia nitida*, *Chromolaena odorata*, *Broussonitia papyverifera* and *Pannicum maximum*.

From the results of this study, a number of conclusions can be drawn

First, that wildfires can significantly affect some soil chemical properties like soil pH, organic matter, total nitrogen, phosphorus, potassium and cation exchange capacity. However it does not significantly affect some soil physical properties like, bulk density and texture.

Secondly, wildfires can cause a shift in plant species composition as well as causing loss in biodiversity in forest reserves and fringe communities in the transitional zones of Ghana.

6.2 Recommendations

The widespread use of fire as a management tool in plantation forestry and agriculture in the transitional zones of Ghana is likely to continue due to its low cost and ease of implementation. In light of these findings on the effects of wildfires on soil and vegetation, I recommend that

1. More attention should be placed on educating natives of fringe communities around our forest reserves on the deleterious effects of wildfire on the forest and environment as a whole through educational campaigns.
2. More firebreaks should be established around forest reserves not only in the transitional zones of Ghana but in other ecological zones to prevent further degradation of our ecosystem. Already established firebreaks should also be regularly monitored and tendered.
3. In addition, further research is needed on the long term effects of fire on ecosystem dynamics in the other ecological zones of Ghana.

Moreover, the widespread replacement of forests with exotic plantation species implores further investigations in ecosystem structure and function as well

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