Impact of Fire on Plant Diversity, Regeneration, and Carbon Stock in Community Forests at Lamahi, Dang, Nepal

A Dissertation Submitted for the Partial Fulfillment of the Requirements for the Master's Degree in Botany

To

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DECLARATION

I, Sita Pokhrel, hereby declare that the dissertation work entitled **"Impact of fire on plant diversity, regeneration, and carbon stock in Community Forests at Lamahi, Dang, Nepal"** is a genuine work done by me and has not been published elsewhere for the award of any degree. All the information cited in this piece of work is specifically acknowledged and credited to the respective authors or institutions as references.

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RECOMMENDATION LETTER

This is to certify that Ms. Sita Pokhrel has completed the dissertation work entitled **"Impact of fire on plant diversity, carbon stock, and regeneration in Bakena and Sundabari Community Forests in Lamahi, Dang, Nepal"** under my supervision. The entire work is based on the results of her own fieldwork and laboratory work and has not been submitted to any other academic degree to the best of my knowledge. I, therefore, recommended this dissertation to be accepted for partial fulfillment of Master's Degree in Botany from Amrit Campus, Tribhuvan University.

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LETTER OF APPROVAL

This dissertation work entitled **"Impact of fire on plant diversity, carbon stock, and regeneration in Bakena and Sundabari Community Forests in Lamahi, Dang, Nepal"** submitted by Sita Pokhrel has been accepted for the examination and submitted to Amrit Campus, Tribhuvan University for partial fulfillment of the requirements for Master's Degree in Botany (Ecology).

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ABSTRACT

This study investigated the effects of fire on plant species diversity, biomass, and regeneration at Bakena and Sundabari Community Forests, Lamahi, Dang, Nepal. Altogether 30 quadrats that experienced burnt (Sundabari CF) and 30 quadrats that were not exposed to fire (Bakena CF) were laid for the study. A total of 69 plant species, under 32 families, were recorded in this study from the unburnt Bakena Community forest (BCF), whereas 52 plant species, under 27 families were recorded from burnt Sundabari Community forest (SCF). Among these recorded species, 35 species were herbs, 20 species were trees and 14 species were shrubs in the unburnt forest (BCF), whereas in SCF that experienced fire every year had 22 species of herbs, 16 species of shrubs, and 14 species of trees. Tree species like *Bombax ceiba, Ficus benjamina, Ficus racemosa, Madhuca longifolia, Mallotus philippenis, Phyllanthu emblica,* etc were not recorded in the SCF that were having a fire every year. Similarly, the shrubs like *Jasmine* sp. *Senna occidental, Smilax* sp. *and Thysanolaena latifolia* and herbs like *Acmella paniculata, Acorus* sp., *Ageratum houstonianum, Anaphalis* sp., *Asplenium* sp., etc were not recorded from the SCF (burnt forest). Some of the shrubs and herbs recorded in burnt forest (BF) but absent at unburnt forest (UBF) were *Asparagus racemosa, Dioscorea deltoidea, Phyllanthus* sp., *Nyctanthes arbor-tristis, Adiantum* sp., *Digitaria sanguinalis, Eulaliopsis binate, Galinsoga* sp., etc. The Shannon Weiner diversity index and Simpson diversity index were higher in the non-fire forest (BCF). In the present study, the total density of seedlings, saplings, and trees of all species in UBF were 474.167, 694.167, and 559.167 individuals/ha, respectively whereas in BF seedlings, saplings, and trees were found to be 552.5, 565.83, and 341.667 individuals/ha, respectively. The density of seedlings of *Shorea robusta*, saplings of *Melia azedarach*, and trees of *Acacia catechu,* were found to be higher than other species in BCF i.e unburnt forest. But at SCF, that experience fire every year had the higher density of *Acacia catechu* seedlings, saplings, and trees than other species. Total Carbon stock in UBF was much higher than at the BF. The total carbon stock in trees of UBF and BF was calculated to be 123.690 t/ha, and 23.133 t/ha respectively. *Shorea robusta* had the highest biomass in both above and below ground in both forests i.e 72.293 t/ha in above ground and 14.459 t/ha in below ground in NFF (BCF) and 20.439 t/ha above ground and 4.088 t/ha below ground in FF (SCF). Soil organic carbon decreased after a fire. The % of mineralizable N, available P, and extractable K decreased at FF (i.e SCF) but the bulk density increased at the FF (at SCF).

Keywords: Burn forest, Unburnt forest, *Shorea robusta, Lagesteroemia parvifolia*

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ACRONYMS AND ABBREVIATIONS

%	Percentage
AGB	Above Ground Biomass
AGCS	Above ground carbon stock
Alt	Altimeter
asl.	Above sea level
BCF	Bakena community forest
BDH	Diameter brest height
BF	Burnt forest
BGB	Below Ground Biomass
BGCS	Below-ground carbon stock
℃	Degree celsius
C	Coverage
CC	Canopy cover
CFUGs	Community forest user's groups
cm	Centimeter
D	Density
D	Diameter
DDC	District Development Committee
et al.	And others
F	Frequency
Fig.	Figure
GHGs	Greenhouse gases
GPS	Global Positioning System

H	Height
ha.	Hectare
ht	Height
IDH	Non-timber forests products
IPCC	Intergovernmental Panel of Climate Change
IVI	Important value index
K	Potassium
Kg/m^2	Kilogram per meter square
m	Meter
N	North
No.	Number
OM	Organic matter
P	Phosphorus
p	Wood density
PgCyr-1	Annual means of carbon budgets
RC	Relative coverage
RD	Relative density
RF	Relative frequency
S	Sulphur
S	South
SD	Seedlings
SOC	Soil organic matter
SP	Saplings
Spp.	Species
SCF	Sundabri community forest

T/ha	Tons per hector
UBF	Unburnt forest

CHAPTER 1: INTRODUCTION

1.1 Background

Humans must have used fire as one of the first tools in the past to reshape the world (Bond and Keeley, 2005). Fossilized charcoal in coal deposits of the Carboniferous age is an evidence of fire at that time (Spinage, 2012). During Carboniferous period there was an adequate number of terrestrial plants and lightning to provide ignition. Charcoal layers have been recorded in more than 400 million years old fossils which are indicators of ancient fires (Komarek, 1973; Jones and Rowe, 1999). Therefore, forest fires are as old as the forests themselves. Forest fires can be regarded as a devastating factor for forest loss of about 10-15 million hectares of boreal and temperate forest, 20-40 million hectares of tropical rain forests. Similarly, fire is also being estimated to be responsible for the loss of up to 500 million hectares of tropical and subtropical savannas, woodlands, and open forests annually (Goldammer, 1995). In many parts of the world, fire has been considered a natural phenomenon and have formed the landscape for many years across all continents (Bond and Van Wilgen, 1996). Fire has been used widely in the management of rangeland all over the as it reduces bush cover, enhances the quality of forage, reduces disease-causing pests, and also influence changes in species composition (Okello et al., 2007). Hence, fire has been regarded as an important factor for changes in plant diversity and vegetation structure in regions where it occurs (Bond, 1997; DeBano et al., 1998).

In Nepal, fire is one of the main causes for forest destruction and on the other hand forest is traditionally linked with rural people's livelihood (Anonymous, 2003). Nepal's Terai (tropical) forests are decreasing at an annual rate of 1.3 % (DFRS, 1999), and reasons for these different human activities like massive deforestation, forest encroachment, premature and over-harvesting, grazing and intentional fire have been identified. Fire usually is the options for preparing fields for crop cultivation because of the nature of the farming system (FAO, 2003). Fire is the easiest and cheapest method for land clearing for most farmers (Kunwar, 2004). Besides this, unemployment and low income, which is nearly 80-90% in the terai (Shrestha et al., 2003), also force people for illegal logging, poaching, and collection of NTFPs to make extra money. In all these activities, number of deliberate and/or accidental forest fires is a common practice. Nepal suffers severely from crawling and crown fire (Parajuli et al., 2015). According to report, Nepal commonly experiences some small forest fires each spring, which is the end of the dry season. However, conditions during the fall and winter of 2008 and 2009 were unusually dry, and fires set by poachers to flush game may have gotten out of control (Parajuli et al., 2015). 268,618 hectares of forest were damaged by the fires in the period from January-May 2016 in Nepal. According to the Federation of Community Forestry Users Nepal (FECOFUN), 50 districts were impacted, and 12,000 community forests were damaged in 2016 (ICIMOD Fire report, 2017). In Nepal wildfire incidences and burnt area were sharply increase from 2000 to 2016. Overall recorded wildfire incidences were 35,374 times and the burnt area was 1,723,920 ha from 2000 to 2016 in Nepal (Bhujel et al., 2017).

Ecologically both pros and cones can be observed with fire. Fire can kill plants and animals and cause wide-ranging environmental damage, but it can also be highly beneficial for plant regeneration and nutrient recycling (Rowell and Moore, 2000). Impacts of fire depend on its origin, frequency, and damage caused by it. Fire can cause an eruption of plant growth and can also reduce disease in the forest by rapidly decomposing organic matter into mineral components (DeBano et al., 1998). Fire impact on a certain ecosystem depends on its duration, intensity, temperature, and frequency of occurrence (Kennedy, 1992). Fire may also cause extreme damage to the ecosystem and also may show risk the biological, physical, ecological, and environmental potentials (Jaiswal et al., 2002) of that ecosystem.

Forest fire changes the vegetation structure by suppressing certain species and encouraging other species (Syaufina and Nuruddin, 2011). Frequent fires in the same place reduces the growth of all plant life forms, and also accelerates soil erosion (Kandya et al., 1998). The effects of fire on vegetation are mainly due to direct effect of heat and smoke (Dayamba, 2010).

In fire prone areas, fire is a key factors that regulates succession of plants species through selection and regeneration of the fire resistant species. Besides this, fire incidences also influence on recycling nutrients, maintaining diversity, decreasing biomass, controlling insects, and also regulating plant and animal interaction (Agee, 1993; Crutzen and Goldammer, 1993; Mutch, 1994; Keane et al., 2002).

The presence of young plants at the growing stage in the forest is called regeneration. Forest fire directly affect regeneration by killing tissues of seedlings and saplings. Heat generated in the soil during fire is sufficient to kill roots and seeds near the soil surface (Kennard et al., 2002), and also indirectly affects regeneration patterns by killing young trees with thin bark (Pinard et al., 1999; Balch et al., 2008). Forest structure are said to be changed with reduced density of sapling and mid-story trees with fire at short intervals (Hutchinson et al., 2012). Repeated burning in forests results in destruction of the ground flora and reduced vegetative growth rate leading to change in plant community structure (Spanos et al., 1989). Some fires are accidental but most of the fires are initiated deliberately for some purpose such as to collect Sal seeds left after the forest is burnt, to conceal illegal timber extraction, to improve grass growth, to scare away wild animals, to collect honey or some other reasons including political agitations and community conflicts (Bhandari et al., 2012).

The terrestrial ecosystems and the oceans are natural carbon sinks. It is the biomass of plants and animals that retains carbon. So ultimately it is the biomass that determines probable carbon emissions that could be released into the atmosphere due to fire, deforestation, or conversion of forest to non-forest land-use change. It is estimated that approximately 86% of the terrestrial aboveground carbon and 73% of the earth's soil carbon are deposited in the forests (Rodger, 1993). The loss of forest biomass due to burning is affected by fire intensity as well as by its structure and flammability of the forest biomass (Xanthopoulos et al., 2012). Human activities, especially the burning of fossil fuel, deforestation, have caused a substantial increase in the concentration of carbon dioxide (CO2) in the atmosphere and leading to global warming. Carbon emissions and carbon recovery rates vary widely depending on variables such as prefire vegetation composition and structure, fire severity and size, and post-fire productivity and successional trajectory (Kashian et al., 2006; Wiedinmyer and Neff, 2007; Campbell et al., 2008; Meigs et al., 2009).

The impact of forest fire on soil is relatively less understood than its aboveground effect (DeBano et al., 1978). Various soil properties like increase in pH have been reported with frequent fire incidences (DeBano, 1990; Certini, 2005). Fire intensity and the duration of fire determines the severity of its impacts on the ecosystem (Neary, 1999). Forest fires can cause a huge loss of soil carbon (Johnson, 1992). Burned soils have lesser total nitrogen, higher calcium, and almost unchanged potassium, magnesium, and phosphorus stocks than unburned soils (Neff et al., 2005). Forest fires can also cause a significant increase in soil bulk density (Certini, 2005; Boerner, et al., 2009), loss of soil macronutrients due to volatilization (Neary et al., 1999; Certini, 2005). Frequent fires cause lower-quality plant residue, and reduced N availability (Johnson and Matchett, 2001; Reich et al., 2001; Hernández and Hobbie, 2008).

This study investigates the impact of fire on diversity, carbon stock, and regeneration status of unburnt forests and burnt forests in the Dang district of the mid-western region of Nepal. Population data such as density of individuals, DBH, height, and species diversity were taken by the quadrat sampling method. Similarly, canopy cover, ground vegetation cover, soil samples, GPS points, slope, aspect, and disturbance were also taken from each sample plot.

1.2 Rationale of Study

There is a large number of research works related to plant diversity and forest regeneration in community forests in various parts of Nepal. But there is very little research work related to the impact of forest fire on plant diversity and forest regeneration in a community forest in the Mid-Western region of Nepal. Thus, this study will help to fulfill this gap. So, this work will be one of the pioneer's works for Mid-Western Nepal which will give the idea about the impact of fire on plant diversity and forest regeneration status of community forests. Thus, this study will establish the baseline information about the status and impact of fire and will be helpful in planning, management, and conservation strategies of fire at the community, regional or national levels

1.3 Justification

The general practice in Bardiya National Park and Banke National Park is to induce control fire for the growth of new shoots of grasses, which is suitable for herbivores. It is not known if the biodiversity, regeneration and carbon stock of that area increases or decreases after the fire. Hence this study intends to study plant diversity, regeneration and carbon stock in two community forest that experience fire every year i.e Sundabari community forests and the other experience no fire i.e Bakena community forests at Lamahi, Dang.

1.4 Research Questions

- **i.** What are the variations in species diversity, carbon stock, and regeneration between the forests that experience fire every year and the one with no fire?
- **ii.** What are the relationships between tree biomass and soil parameters in two different forests that experience fire every year and the one with no fire?

1.5 Objectives

1.5.1 Overall objective

The overall objective of this study was to determine the impact of fire on plant diversity, forest regeneration, and carbon stock in Bakena and Sundabri community forests at Lamahi, Dang.

1.5.2 Specific objectives

- To identify the plant species in the study area.
- To determine the effect of fire on plant diversity.
- To analyze the effect of fire frequency on the regeneration pattern of a forest.
- To determine the effect of fire on the carbon stock of trees.
- To determine relation between tree biomass and soil parameters (NPK, SOC, and bulk density).

1.7 Limitation

i. Due to lack of instrument, canopy cover was estimated by the visual method.

ii. Only the tree carbon stock was calculated.

iii. Other soil parameters such as soil moisture, soil texture, and pH were not calculated.

CHAPTER 2: LITERATURE REVIEW

2.1 Biodiversity

Fire is an important ecologically significant event that leads to various impacts on vegetation and environment (Whelan, 1995; Keane et al., 2002). Fire acts as an external disturbance factor and strongly affect the composition of plant communities (Crutzen and Goldammer, 1993, Danthu et al., 2003). Fire has also been reported to be responsible to impact on different aspects of plant growth and development such as flowering, fruiting, seed dispersal, seed germination, seedling establishment, and plant mortality (Walters et al., 2004; De Luis et al., 2005).

Competitive exclusion, disturbance processes, and environmental heterogeneity have been regarded as the three key determinants of plant species diversity in terrestrial ecosystems

(Connell, 1978; Huston, 1994). In the process of plant-plant competition, strong competitors first destroy weak competitors and later on it may lead to local extinction, which is called Competitive exclusion. This process of competition exclusion decreases species diversity. Disturbances is another factor that can change plant species diversity either by removing disturbance-sensitive species, or by adding new species in the area through opening up growing space and resources for use by colonizing species. Thus disturbance helps to maintain species richness by slowing or preventing competitive exclusion, and alter spatial heterogeneity in plant community (Huston, 1994). The intermediate disturbance hypothesis (IDH) (Connell, 1978; Huston, 1994) predicts that species diversity will be maximized at intermediate disturbance as it will provide space for the new species. Although the intermediate disturbance hypothesis is well studied (Roxburgh et al., 2004), but reestablishment of all the plant species after fire event may not occur in nature as forest fire suppresses certain species and encouraging other species and ultimately changes in vegetation composition (Syaufina and Nuruddin, 2011).

2.2 Regeneration

Regeneration and establishment of plants in the forest are regulated various factors like drought, pest infestation or forest fire. Plants do have some resistance mechanism to fight against drought and pest to some extent and may help them to persist in nature. But the fire event is disastrous to plants as it burns leaves and kills stem tissues of seedlings and saplings. Besides this the heat generated during fire events increase the soil temperature and is sufficient to kill roots and seeds near the soil surface (Kennard et al., 2002). Fire also indirectly affects regeneration patterns by killing young trees which are having thin bark (Pinard et al., 1999; Balch et al., 2008).

In the case of seeder plants, fire can be beneficial as it can break the seed coat and eradicate chemicals that inhibit germination and ultimately help in the germination. Fire events also remove litter and plants at forest floor and increase the solar radiation, which ultimately affect phytochrome to initiate seed germination (Mazzoleni and Esposito, 1993). In the case of plants that re-sprouts, fire can remove leaves or the whole stem, but it may stimulate the surviving buds to produce new shoots (Barro and Conard, 1991). To persist after a fire event in fire-prone environment, re-sprouting is a common strategy among fire tolerant plant species.

The effect of fire on regeneration also differ with seasons, which might be due to difference in moisture content in the forest fuel. Fire behavior has been reported to be controlled by the water content of the fuel, for instance low water content increases the risk of crown fire. Similarly, the availability of fuel during wild fire is determined by some main climatic factors like relative humidity, droughts, and wind. (Ryan, 2002). In Grassy woodland of Australia, the seedling emergence of all shrub species was promoted by the fire of spring season, but fire season had little impact on the survival of seedlings (Knox and Clarke, 2006).

2.3 Tree biomass and Carbon stock

The terrestrial ecosystem, especially forest ecosystem and the oceans are natural carbon sinks as they can hold carbon in their biomass. The tropical forests, which store up about 46% of the world's terrestrial carbon pool and about 11.55% of the world's soil carbon pool, play a key role in the global carbon cycle and constant sink of atmospheric carbon (Brown and Lugo, 1982; Medina and Klinge, 1983; Soepadmo, 1993). But due to fire events, deforestations, urbanization and commercial farming, tropical forests are now considered as the main contributors to terrestrial carbon cycling. Though researches on carbon cycling are going on but its exact quantification of Carbon emission contribution by tropical forests are is still challenging (Golley and Lieth, 1972; Chave et al., 2008). Fire can influence woody vegetation biomass, composition, and structure. Despite the importance of fire in shaping savannas, it remains poorly understood how the frequency, seasonality, and intensity of fire interact to influence woody vegetation structure, which is a key determinant of savanna biodiversity (Smit et al., 2010).

Aryal et al. (2017) studied impact of surface fire on Carbon sequestration and CO2 mitigation of *Pinus roxburghii* forest in Langtang National Park, Nepal. They measured total carbon stock and CO_2 mitigation of unburned and burned forest of different intensities namely: high frequency and high intensity (HFHI), high frequency and moderate intensity (HFMI), high frequency and low intensity (HFLI). They found, total CO_2 mitigation in all four forest according to higher to lower values as 3346.27, 3345.16, 2484.14 and 2037.95 t/ha in HFMI, HFHI, HFLI and CON, respectively.

In tropical deciduous forest fire is quite usual annually. During dry summer season, chances of fire events are high as above-ground biomass, especially during dry months' act as a substantial source of fuel. Carbon fluxes and trace gases emission after fire events, contaminate the atmosphere and contribute to global climate change (Qin et al., 2014). Estimates of carbon losses annually from forest fires globally varied from 2.0–2.5 Pg C yr-1 (Andreae and Merlet, 2001) to 3.8–4.3 Pg C yr-1 (Kasischke and Bruhwiler, 2003). In contrast, carbon loss from land-use change and fossil fuel emissions globally have been estimated to be 1.1 Pg C yr^{-1} and 7.9 Pg C yr^{-1} respectively (Le Quéré et al., 2009). During fire, a part of understory biomass is destroyed and one fraction directly emit GHGs and another fraction is transferred to the dead organic matter pool, which later on decays and release carbon indirectly (Chiriacò et al., 2013).

2.4 Soil properties

The effect of forest fire on soils is complex and relatively less understood than its aboveground effect (DeBano et al., 1998). Fires can reduce the number of soil nutrients in a forest by losses from volatilization, smoke, ash transport, leaching, and erosion. These changes can produce several secondary effects like increased hydrophobicity, due to that infiltration rate decreases and runoff increases which can result in soil erosion (DeBano, 2000). The impact of forest fires on soil depends on two factors mainly; intensity of fire and the duration of fire.

Changes in soil properties generally occurs after fire and it may be favorable or harmful to the whole ecosystem (Neary et al., 1999). Bulk density increases due to clogging of air space in the soil by the ash, as a consequence permeability and porosity of soil decreases (Certini, 2005). The bulk density increases with ash depth (Cerdà and Doerr, 2008). The impact of forest fire on soil organic matter are also affected and it depends on fire type, fire severity, and dryness of the surface organic matter (Neary et al., 1999).

Burned soils have lesser total nitrogen, higher calcium content, and almost unchanged potassium, magnesium, and phosphorus content than unburned soils (Neff et al., 2005). Nutrients present in live twigs and dead plant materials can either be lost by volatilization during a fire or released and deposited on the soil in a highly soluble form, which are later used as nutrient by plants (DeBano and Conrad, 1978). Phosphorus (P), Potassium (K), and Sulphur (S) from the soil are partially lost by high-intensity of fire (DeBano and Conrad, 1978).

Nepal experience fire every year, but a few studies have been conducted to evaluate the biodiversity change and soil properties in burnt forest. Hence the present study attempts to compare the biodiversity difference and soil properties in two community forests of Lamahi, Dang, lying side by side. Bakena community forest experience no fire but Sundabri experience fire almost every year.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

This study falls in the Dang District. Dang is located in the inner Tarai, about 380 km west of the capital city, Kathmandu, Nepal. It lies in Lumbini Province located in the Inner Terai of mid-western Nepal. This district covers an area of 2977 square km with a population of 552583 (male population: 261059 and female population: 291524) (DDC Dang, 2012). It ranges between 28°07'.00'' N and 82°18'.00'' E. Dang district is also known as inner Tarai. The south of this district falls at the border with India and to the north are Pyuthan, Salyan, and Rolpa. Kapilbastu lies at the east and towards the west Banke district. This district bordered the Mahabharat range and Churia range. The climate of the Dang district is distinguished into three types: lower tropical (below 300 m and occupy 18.1 %), upper tropical (300 to 1000 m and occupy 69.9 %) and subtropical zone (1000 to 2000 m and occupy 12.0 %). Dang has 192155 ha (65.02 %) forest, 12950 ha (4.38 %) grassland, 69950 ha (23.67 %) agricultural land and 20445 ha (6.92 %) unproductive area (DDC Dang, 2012).

(a)

Source; © 2007-2022 https://d-maps.com

(b)

Source-https://hamrodang.files.wordpress.com/2009/08/map-of-dang.jpg

(c)

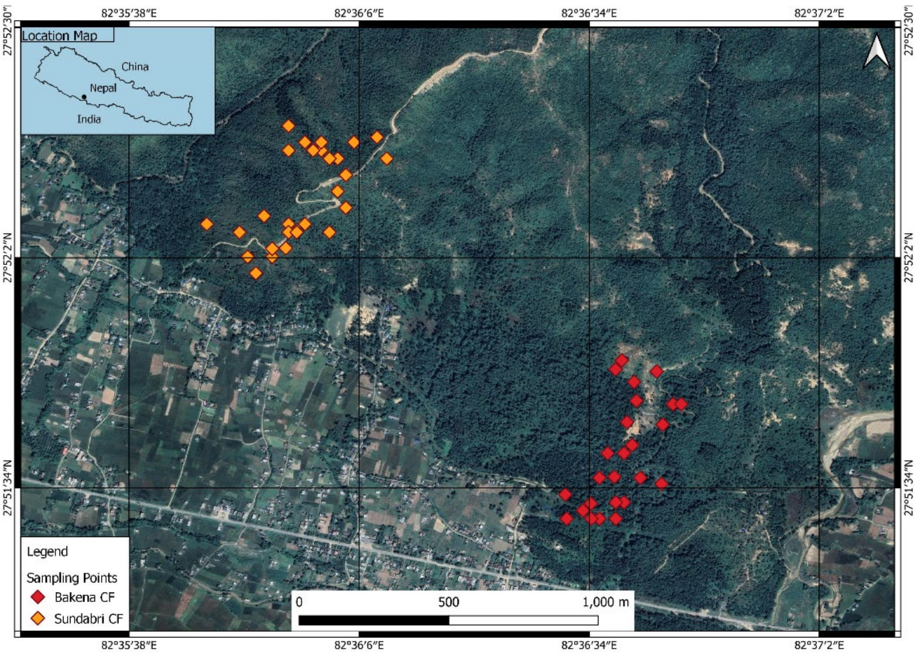
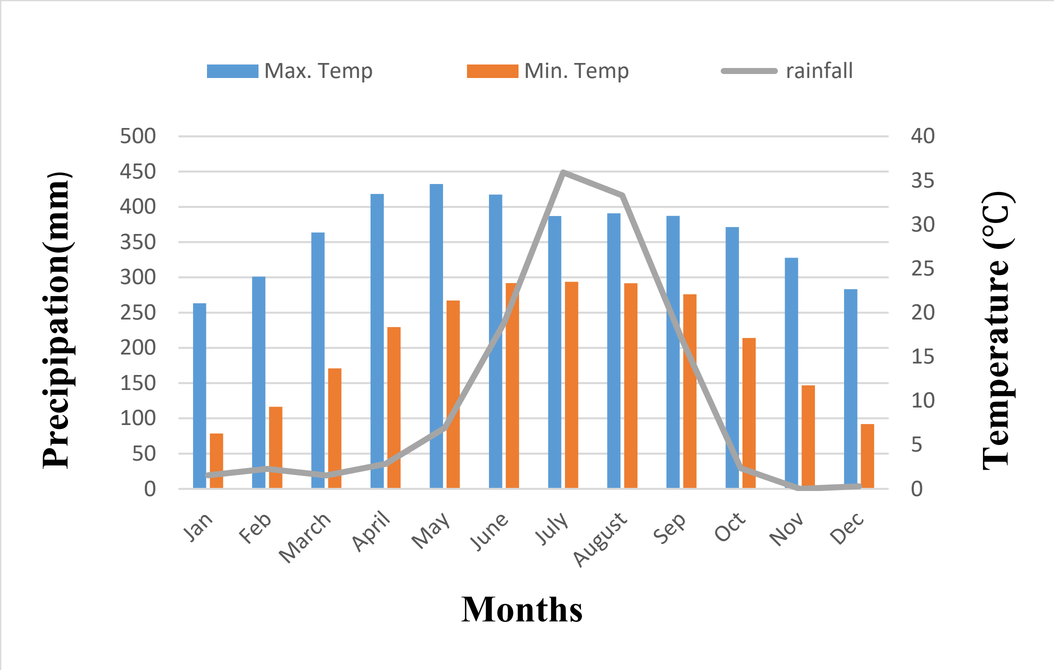


Figure 1: Map showing the study area (a)map of Nepal (b) map of Dang district and (c) map of Bakena and Sundabri community forest showing sampling plots.

3.1.1 Climate and Hydrology

Dang is located at 180 m above sea level. The summer season of this region is very hot and winter is very cold. In summer the temperature rises to 38°C and in winter the temperature falls below 4.8°C. The average annual temperature was 29°C and the average annual rainfall was 139 mm of Dang. As shown in the table the average maximum temperature was 34.6 °C in May and the minimum temperature was 6.3°C in January. Maximum rainfall was 448.8 mm in July and minimum rainfall was 0.1mm in November (Figure 2).



(Source: climatedata.org)

Figure 2: Variation in monthly average (minimum and maximum) temperature and precipitation of last 11 years (2010-2020) at Dang.

3.1.2 Study Forest

The two Community Forests of Lamahi Municipality, Dang, which are lying adjacent to each other, namely Bakena Community forest (BCF) that experience no fire (here after called unburnt forest UBF) and Sundabri Community forest (SCF) which experience fire every year (here after called burnt forest BF), were selected for this study. These forests lie 2-5km away from the Lamahi east-west highway. The elevation of these Community Forests ranges between 160 m to 280 m above sea level (asl). These two community forests covered an area of about 910 hectares. The climate here of these forests falls under the tropical monsoon type and has three pronounced seasons: summer, rainy and winter. These areas receive about 139 mm of average annual rainfall and the average temperature ranges between 20.5°C to 28.9°C (DDC Dang, 2012). *Shorea robusta* is a major species which are found dense and deciduous in this forest. The other associated species are *Dalbergia sissoo, Acacia catechu, Terminalia tomentosa, Lagesteroemia parvifolia* etc. These forests are highly disturbed by human settlements. Forest fire, firewood collection, timber cutting, and grazing are major disturbances that highly affect the biodiversity of these forests. Soil is clay and sandy loam in these areas.

3.2 Field Sampling

A stratified random sampling method was used for locating the sampling plots; the forest blocks designated by the CFUGs were considered strata. Square quadrat of 20 m × 20 m was defined with the help of clinometers (for maintaining aspect so that each corner of the plot is 90^{o} to each other), an iron peg and rope at each earlier randomly selected location. Each tree and shrub species enrooted inside the plots were recorded. Trees on the border were included if ≥ 50% of their basal area fell within the plot and excluded if < 50% of their basal area fell inside the plot. Thus, trees overhanging the plot were excluded, but trees with their trunk inside the sampling plots and branches outside were included. Tree height (H > 137 cm) and Diameter at breast height (DBH, 137 cm) of all individuals of tree species were measured. While measuring the DBH of trees of unusual shape (like trees with forked stems, trees with a bulged or curved stem at 137 cm, trees inclined in-ground, etc.), a standard forestry practice of MacDicken (1997) was adopted. DBH tape was used for measuring the diameter and a clinometer was used to estimate the tree height. Altogether 30 quadrats of 20 m × 20 m were laid at BCF (i.e UBF) and 30 quadrats of the same size at SCF (i.e BF) for trees. Within each quadrat of 20m x20m, 2 sub-plots of 5m ×5m were laid for shrubs and 3 plots of 2m × 2m were laid for herbs. For regeneration individual plants were categorized into seedling (ht < 1.3 m), saplings (dbh < 10 cm and ht > 1.3 m) and trees (dbh > 10 cm).

The geographical location (latitude, longitude, and elevation) of each plot (20m × 20m) was recorded using an altimeter from the center of the plot. Slope and aspect were measured by clinometers. The canopy cover for each plot was estimated by the visual estimation method from the center of the plot. The sample field data sheet (Appendix I) used for geographical location had been presented in Appendix II.

Most of the plants were identified at the time of quadrat study with the help of field guides (members of the community forest) and consulting with local experts. Unidentified species were collected tagged and pressed with the help of a newspaper and these unidentified specimens were identified with the help of experts, relevant books (Polunin and Stainton; 1984).

Soil samples

For bulk density, soil samples were collected from 4 corners and center of each quadrat using a steel ring of 2 cm and 15cm height and with internal diameter of 2cm. The soil samples were collected separately for bulk density and then packed in air-tight plastic bags wrapped in aluminum foil for laboratory analysis. Soil samples for organic carbon, Nitrogen, Phosphorus, and Potassium were collected from the quadrat from three different depths viz. 0-2 cm (Top), 2- 15 cm (Middle), and 15-30 cm (Bottom). The soil samples were then dried in shade for a week and finally packed in airtight plastic bags until laboratory analysis. Altogether 108 soil samples were collected, i.e 9 soil samples from each depth of both UBF and BF Sal forest and 9 soil samples of each depth from both UBF and BF Khayer forest.

3.3 Lab Work

Soil samples were air-dried at room temperature for further analysis. The soil physicochemical parameters bulk density, soil organic carbon, nitrogen, phosphorus, and potassium were examined. The bulk density was calculated after drying in a hot air oven for 24 hours and by taking the final weight of the soil at the Department of Botany, Amrit Science Campus, Kathmandu. Soil organic carbon, nitrogen, phosphorus, and potassium were examined in the Forest Research and Training Center Babarmahal, Kathmandu.

3.4 Quantitative Analysis

For the vegetation analysis, different parameters such as density, frequency, relative density, relative frequency, importance value index (IVI), and diversity index (Shannon and Weiner 1963) were calculated for the species. Vegetation analyses were carried out using Zobel *et al.*, (2000).

$$\text{Density} = \frac{\text{Total no. of species occurred}}{\text{Total no. quadrat studied}} \times \frac{1}{\text{area of quadrat}}$$

$$\text{Relative density} = \frac{\text{Density of individual species}}{\text{Total density of all species}} \times 100\%$$

$$\text{Frequency} = \frac{\text{No. of quadrat in which species occurred}}{\text{Total no. of quadrat studied}} \times 100\%$$

$$\text{Relative frequency} = \frac{\text{Frequency of individual species}}{\text{Total frequency of all species}} \times 100\%$$

$$\text{Average coverage}=\frac{\text{Total coverage of species}}{\text{Total no. of quadrat} \times \text{Area of quadrat}} \times 100\%$$

$$\text{Relative coverage}=\frac{\text{Coverage of individual species}}{\text{total coverage of all species}} \times 100\%$$

$$\text{Simpson's index (D)} = \frac{\Sigma n(n-1)}{N(N-1)}$$

Simpson's index of diversity (Ds) = 1-D

Shannon Weiner index (H) = $-\Sigma P_i (L_n P_i)$

Where,

P_i=Proportion of individual species

3.4.1 Important Value Index (IVI)

The important value index is a measure of how dominant a species is in a given forest area. In this research work, it was calculated by the following formula.

Important value index (IVI) =RD+RF+RC

Where,

RD=Relative density

RF=Relative frequency

RC=Relative coverage

3.4.2 Plant Diversity Index

A plant diversity index is defined as the number of plants and abundance of each plant that lives in a particular location. The plant species diversity was calculated based on the Shannon diversity index and Simpson diversity index. Shannon diversity index was calculated using the general formula.

$$H = -\sum pi \times \ln pi$$

Where,

H = Shannon's diversity index

Pi = Species proportion

Ln = natural logarithm

The Simpson's diversity index was calculated using the following formula;

Ds = 1-D

Ds value ranges between 0 and 1.

Where,

D = Simpson's index

Simpson's index (D) $= \frac{\Sigma n(n-1)}{N(N-1)}$

N = total no. of individual species (all species)

n = no. of individuals of a particular species

3.5 Estimation of Biomass and Carbon Stock

3.5.1 Estimation of Above and Below Ground Biomass

The allometric equation (model) developed by Chave *et al*., (2005) was used for estimating the above-ground tree biomass (AGTB).

The allometric model developed by Chave *et al*., (2005) was

ABG = $0.0509 \times \rho D^2H$……for moist forest stand Where,

AGB = above ground biomass (kg)

ρ = wood density (g/cm^3)

H = height of tree (m)

D = diameter of tree at breast height (cm)

Above ground carbon stock (AGCS) = Biomass x 0.47

Below ground carbon stock (BGCS) = AGCS x 0.2

Total carbon stock = above ground carbon stock + below ground carbon stock

3.5.2 Wood Density

It was measured by the wood density index given by Chave *et al*., (2005). For the name of species and wood density see Appendix III.

3.5.3 Estimation of Carbon Stock

Total tree biomass was obtained by adding the above-ground, and below- ground biomass of the tree layer. When above-ground biomass was multiplied by 0.47 and belowground biomass by 0.2 separately by default carbon fraction (IPCC, 2006), gave total C-stock in kg. Then the area of the total plot was calculated. Then after carbon stock in kg was divided by the total area of the plot. The obtained value in kg/m^2 was multiplied by 10,000, and divided by 1000 giving the C-stock in t/ha. Total carbon stock in the forest was obtained by adding above-ground, and below ground C-stock.

3.6 Regeneration Status of Forest

To estimate the regeneration status of the forest, the density of seedling, sapling, and tree of each species were determined separately following the method described by Zobel *et al.,* (1987). The density was estimated by the following equation;

$$\text{Density (stem/ha)} = \frac{\text{Total no.of individuals in each life form}}{\text{Total number of plots studied} \times \text{size of plot}(\text{m}^2)} \times 10000$$

Density of individual species was calculated by the following equation;

$$\text{Density (stem/ha)} = \frac{\text{Total no. of individual of each species in each life form}}{\text{total number of plots studied} \times \text{size of plot}(\text{m}^2)} \times 10000$$

Total counts of plants were obtained by summation of the number of plants from all sampling plots.

3.7 Bulk Density

At first prepare an uninterrupted flat horizontal in the soil with a spade. Then, hammer the steel ring into the soil. Then, it was exhausted around the ring without disturbing the soil it contains, and carefully it was removed with the soil intact. Then, the soil sample weight was taken and wrapped in aluminum foil and kept inside the hot air oven for 24 hours at 105◦c. After that, the final weight of the soil was taken after drying. Further, the internal diameter of the steel ring was measured and a calculation was carried out.

For calculation,

Soil volume = ring volume

Internal diameter of ring (D) = 2cm

Ring height = 2 cm and 15 cm

Radius of ring (r) =1 cm

Ring volume = $3.14 \times r^2 \times$ ring height

$$\text{Bulk density} = \frac{\text{Dry soil}}{\text{Soil volume}}$$

To estimate the bulk density of a forest, the bulk density of each plot was determined separately. Then, bulk density was estimated by the following equation;

$$\text{Bulk density (g/cm3)} = \frac{\text{Sum of bulk density of each plot}}{\text{Total number of plot studied}}$$

3.8 Statistical Analysis

To assess the impact of fire on tree biomass, linear regression between plant biomass and soil parameters different depth of BF and UBF were conducted using SPSS16.0. One-way ANOVA and Duncan's multiple range test were performed to test the significance of Nitrogen, Phosphorus, Potassium, and soil organic carbon throughout the three soil depths of soil profile between burnt and unburnt forests.

CHAPTER 4: RESULTS

4.1 Vegetation

A total of 69 plant species, under 32 families, were recorded in this study from the unburnt forest, and 52 plant species, under 27 families were recorded from a forest that had experienced a fire. In the unburnt forest, the richest family was Asteraceae with 10 species i.e (*Acmella paniculata, Ageratum conyzoides, Ageratum houstonianum, Anaphalis* sp., *Artimesa vulgaris, Bidens pilosa, Conyza* sp., *Parthenium* sp., *Sonchus* sp., *and Vernonia cinera)* and second richest family was Poaceae with 8 species i.e (*Imperata cylindrical, Thysanolaena latifolia, Cyanodon dactylon, Desmostachya bipinnata, Eragrostis sp., Hyperthelia dissolute, Paspalum* sp., and *Saccharum spontaneum)* followed by Lamiaceae with 6 species i.e (*Tectona grandid, Clerodendron* sp., *Colebrookea oppostitifolia, Hyptis suaveolens, Labiatae* sp*., and Ocimum* sp.) and Fabaceae with 4 species i.e(*Bauhinia* sp*., Senna occidental, Desmodium gangeticum and Trifolium latifolium)*. Where as in burnt forest the richest family was Poaceae with 9 species i.e (*Imperata cylindrical, Cyanodon dactylon, Eragrostis* sp*., Hyperthelia dissolute, Paspalum* sp*., Setaria gluaca, Hyparrhenia hitra, Digitaria sanguinalis and Saccharum spontaneum)* and second richest families were Anacardiaceae i.e (*Buchanania latifolia, Mangifera indica and Semecarpus anacardium)*, Asteraceae i.e (*Ageratum conyzoides*m, *Conyza* sp. and *Galinsoga* sp.) and Fabaceae i.e (*Bauhinia* sp., *Desmodium gangeticum and Flemingia* sp.) with 3 species . Among these recorded species, 35 species were herbs, 20 species were trees and 14 species were shrubs in unburnt forest. Where as in burnt forest, 22 species were herbs followed by 16 species were shrubs and 14 species of trees (Table.1). The number of tree species were higher than that of herbs in an unburnt forest. Besides this the number of herbs, and trees were higher in unburnt forest than in burnt forest where as the number of shrubs were higher in BF than in UBF. Tree species like *Bombax ceiba, Ficus benjamina, Ficus racemosa, Madhuca longifolia, Mallotus philippenis, Phylanthus emblica,* etc were not recorded in burnt forest. Similarly, the shrubs like *Jasmine* sp. *Senna occidental, Smilax* sp. and *Thysanolaena latifolia* and herbs like *Acmella paniculata, Acorus* sp., *Ageratum houstonianum, Anaphalis* sp*., Asplenium* sp., etc were not recorded from the burnt forest. Some of the shrubs and herbs recorded in the burnt forest but absent in UBF were *Asparagus racemosa, Discorea deltoidea, Phyllanthus* sp., *Nyctanthes arbor-tristis, Adiantum* sp., *Digitaria sanguinalis, Eulaliopsis binate, Galinsoga* sp., etc.

Trees

Table 1: Tree species in unburnt and burnt forests.

Scientific name	**Local name**	**Family**	**Unburnt**	**Burnt**
Acacia catechu (Linnaeus f.) Willdenow	Khayer	*Leguminosae*	+	+
Aegle marmelos Linn.	Bel	*Rutaceae*	+	+
Bombax ceiba Linn.	Simal	*Bombacacae*	+	-
Buchanania latifolia Roxb.	Piyari	*Anacardiaceae*	+	+
Dalbergia sissoo Roxb.ex DC	Sissoo	*Leguminosae*	+	+
Ficus benjamina Linn.	_	*Moraceae*	+	-
Ficus racemosa Linn.	-	Moraceae	+	-
Lagesteroemia parvifolia Roxb.	Botdhairo	*Lythraceae*	+	+
Madhuca longifolia (J.Konig ex L.)	Mauwa	*Sapotaceae*	+	-
Mallotus philippensis (Lam.) Muell.-Arg.	Rohini	*Euphorbiaceae*	+	-
Mangifera indica Linn.	Aap	*Anacardiaceae*	+	+
Melia azedarach Linn.	Bakaino	Meliaceae	+	+
Phylanthus emblica Linn.	Aamala	*Euphorbiaceae*	+	-
Psidium guajava L.	Aamba	*Myrtaceae*	+	-
Shorea robusta Gaertn	Sal	*Dipterocapaceae*	+	+
Semecarpus anacardium Linnaeus	*Valayo*	*Anacardiaceae*	-	+
*Syzygium cumini (*Linnaeus) Skeels	Jamuno	*Myrtaceae*	+	-
Tectona grandis L.	-	*Lamiaceae*	+	-
Terminalia bellirica (Gaertn.) Roxb	Barro	*Combretaceae*	+	+
Terminalia chebula Retz.	Harro	*Combretaceae*	+	-
Terminalia tomentosa Roxb.	Saj	*Combretaceae*	+	+
Unknown-1	Seto tilka	-	-	+
Unknown-2	Tilka	-	-	+
		Total	**20**	**14**

Shrubs spp.

Table 2: Shrubs species in unburnt and burnt forests.

Scientific name	**Local name**	**Family**	**Unburnt**	**Burnt**
Asparagus racemosa Willd.	Kurilo	Asparagaceae	-	+
Bauhinia sp.	*Maluka*	Fabaceae	+	+
Berberis aristata DC	*Chutro*	Berberidaceae	+	+
Clerodendrunm sp.	-	Lamiaceae	+	+
Colebrookea oppositifolia Smith	*Dhurseta*	Lamiaceae	+	+
Cycas pectinata Griff.	-	Cycadaceae	+	+
Dioscorea deltoidea Wall. Ex Griseb	*Tarul*	Dioscoreaceae	-	+
Ficus nerifolia Linn.	-	Moraceae	+	+
Fraxinus sp.	-	Oleaceae	+	+
Jasmine sp.	-	Oleaceae	+	-
Lantana camara L.	-	Verbenaceae	+	+
Nyctanthes arbor-tristis Linn.	-	Oleaceae	-	+
Phyllanthus sp.	-	Phyllanthaceae	-	+
Senna occidentalis L.	-	Fabaceae	+	-
Smilax sp.	-	Smilacaceae	+	-
Thysanolaena latifolia Roxb. Ex Hornem.	-	Poaceae	+	-
Unknown-1	Randia	-	-	+
Unknown-2	*Nundheky*	-	-	+
Woodfordia fruticosa (L.) Kurz.	*Dhairo*	Lythraceae	+	+
Zizyphus jujube L.	*Bayer*	Rhamnaceae	+	+
		Total	14	16

Herbs species

Table 3: Herbs species in unburnt and burnt forests.

	Family	**Unburnt**	**Burnt**
Acmella paniculata Wall ex DC.	Asteraceae	+	-
Acorus sp.	Acoraceae	+	-
Adiantum sp.	Pteridaceae	-	+
Ageratum conyzoides L.	Asteraceae	+	+
Ageratum houstonianum Mill.	Asteraceae	+	-
Anaphalis sp.	Asteraceae	+	-
Artimesia vulgaris L.	Asteraceae	+	-
Asplenium sp.	Aspleniaceae	+	-
Bidens pilosa Linn.	Asteraceae	+	-
Centella asiastica L.	Apiaceae	+	-
Conyza sp.	Asteraceae	+	+
*Cyanodon dactylon (*Linn.) Pearsoon	Poaceae	+	+
Cyperus sp.	Cyperaceae	+	+
Desmodium gangeticum (Linn.) Candolle	Fabaceae	+	+
Desmostachya bipinnata (Linn.) Stapf.	Poaceae	+	-
Digitaria sanguinalis L.	Poaceae	-	+
Eragrostis sp.	Poaceae	+	+
Eulaliopsis binate (Retz.)C.E Hubbard	Oxalidaceae	-	+
Euphorbia hitra Linn.	Euphorbiaceae	+	-
Flemingia sp.	Fabaceae	-	+
Galinsoga sp.	Asteraceae	-	+

Hemidesmus indicus (L.) R.Br.	Apocynaceae	+	-
Hyparrhenia hitra L.	Poaceae	-	+
Hyperthelia dissolute Ness ex Steud.	Poaceae	+	+
Hyptis suaveolens L.	Lamiaceae	+	-
*Imperata cylindrical (*Linn.) Raeuschel	Poaceae	+	+
Labiatae sp.	Lamiaceae	+	-
Lygodium sp.	Lygodiaceae	-	+
Ocimum sp.	Lamiaceae	+	-
Oxalis sp.	Oxalidaceae	+	-
Parthenium sp.	Asteraceae	+	-
Paspalum sp.	Poaceae	+	+
Potentilla sp.	Rosaceae	-	+
Reinwardtia indica Dumort.	Linaceae	+	-
Rubia sp.	Rubiaceae	+	-
Saccharum spontaneum Linn.	Poaceae	+	+
Setaria glauca L.	Poaceae	-	+
Sida sp.	Malvaceae	+	+
Solanum incanum L.	Solanaceae	-	+
Sonchus sp.	Asteraceae	+	-
Trifolium latifolium L.	Fabaceae	+	-
Urena lobata L.	Malvaceae	+	+
Unknown(lawase)	-	+	-
*Vernonia cinera (*L.) Less.	Asteraceae	+	-
	Total	35	22

4.2 Important value index (IVI)

In the unburnt forest (UBF) and burnt forest (BF), altogether 35and 22 species of herbs, respectively were recorded. Among them, the herb *Paspalum sp.* had the highest IVI i.e. 38.126 and *Hemidesmus indicus* had the lowest IVI i.e. 0.517 in UBF, and in BF *Eulaliopsis binata* had the highest IVI i.e. 67.885 and *Solanum incanum* had lowest IVI i.e. 1.093. (Table 4). Frequency, relative frequency, Density, relative density, Coverage, and relative coverage are given in Appendix IV.

Table 4: IVI of herbs species in unburnt and burnt forests.

Name of plants	**IVI**	
	Unburnt	**Burnt**
Acmella paniculata	2.188	-
Acorus sp.	10.016	-
Ageratum conyzoides	11.773	1.099
Ageratum houstonianum	4.490	-
Anaphalis sp.	1.576	-
Artimesia vulgaris	0.771	-
Asplenium sp.	5.818	-
Bidens pilosa	3.510	-
Centella asistica	4.965	-
Conyza sp.	0.700	6.108
Cyanodon dactylon	24.421	6.098
Cyperus sp.	9.167	17.313
Desmodium gangeticum	9.842	20.143
Desmostachya bipinnata	5.387	-
Digitaria sanguinalis	-	26.068
Eragrostis sp.	24.759	2.327
Eulaliopsis binata	-	67.885

Euphorbia hitra	0.805	-
Flemingia sp.	-	5.151
Galinsoga sp.	-	2.105
Hemidesmus indicus	0.517	-
Hyparrhenia hirta	-	39.881
Hyperthelia dissoluta	8.672	4.088
Hyptis suaveolens	2.895	-
Imperata cylindrica	29.859	40.489
Labiatae sp.	1.012	-
Lawase	12.420	-
Lygodium sp.	6.844	2.425
Ocimum sp.	2.480	-
Oxalis sp.	1.916	-
Parthenium sp.	1.542	-
Paspalum sp.	38.126	2.339
Potentilla sp.	-	2.430
Reinwardtia indica	8.932	-
Rubia sp.	1.271	-
Saccharum spontaneum	11.192	27.244
Setaria glauca	-	13.244
Sida sp.	23.601	3.824
Solanum incanum	-	1.093
Sonchus sp.	1.625	-
Trifolium latifolium	12.507	-
Urana lobata	13.125	-
Vernonia cinera	1.274	-

In the UBF and BF, altogether 14 and 16 species of shrubs, respectively were recorded. Among them shrubs *Jasmine sp.* had the highest IVI i.e. 67.60 and *Senna occidentali* had the lowest IVI i.e 1.093 in UBF and *Berberis aristata* had the highest IVI i.e. 81.255 and *Bauhinia sp.* had the lowest IVI i.e 1.784 in BF (Table 5). Frequency, relative frequency, Density, relative density, Coverage, and relative coverage are given in Appendix V.

Table 5: IVI of shrubs species in unburnt and burnt forests.

	IVI	
Name of plants	**Unburnt**	**Burnt**
Asparagus racemosa	62.175	81.255
Bauhinia sp.	2.493	1.784
Berberis aristata	-	5.766
Clerodendrum sp.	3.154	2.685
Colebrookea oppositifolia	14.737	4.190
Cycas pectinata	65.082	29.139
Dioscorea deltoidea	-	6.306
Ficus nerifolia	15.264	26.192
Fraxinus sp.	3.442	1.904
Jasmine sp.	67.607	-
Lantana camara	43.730	5.486
Nundheky	-	2.097
Nyctanthes arbor-tristis	-	10.164
Phyllanthus sp.	-	8.982
Randia		4.575
Senna occidental	1.704	-
Smilax sp.	3.055	-
Thysanolaena latifolia	1.831	-
Woodfordia fruticosa	6.547	63.827
Zizyphus jujube	9.180	45.647

In the UBF and BF, altogether 20 and 14 of Trees species, respectively, were recorded. Among them, trees *Acacia catechu* had the highest IVI i.e. 73.713 and *Buchanania latifolia* had the lowest IVI i.e 0.991 in UBF and *Acacia catechu* had the highest IVI i.e. 48.323 and *Semicarpus anacardium* had the lowest IVI i.e 0.589 in BF (Table 6). Frequency, relative frequency, Density, relative density, Coverage, and relative coverage are given in Appendix V.

Table 6: IVI of tree species in unburnt and burnt forests.

	IVI	
Name of plants	**Unburnt**	**Burnt**
Acacia catechu	73.713	48.323
Aegle marmelos	1.983	-
Azadiracta indica	-	1.001
Bombax ceiba	17.413	
Buchanania latifolia	0.991	1.295
Dalbergia sissoo	23.265	9.653
Ficus benjamina	1.027	-
Ficus racemosa	1.947	-
Lagerstroemia parvifolia	52.400	7.063
Madhuca longifolia	1.134	-
Mallotus philippenis	1.283	-
Mangifera indica	5.455	-
Phylanthus emblica	1.283	-
Semicarpus anacardium	-	0.589
Seto tilka	-	0.471
Shorea robusta	56.706	27.251
Syzygium cumini	1.283	-
Terminalia bellirica	21.187	1.707
Terminalia chebula	3.002	-
Terminalia tomentosa	35.928	2.4649

4.3 Diversity indices

The Shannon Wiener (H) diversity index value of herbs was found higher in BF than UBF and the Shannon Wiener (H) diversity index value of shrubs and trees was higher in UBF than BF. Simpson diversity (D) index value for herbs, and trees was found higher in BF than in UBF and the Simpson diversity (D) index value for shrubs was found higher in UBF than BF (Table 7).

Table 7: Shannon Wiener index (and evenness) and Simpson index of herbs, shrubs, and trees in unburnt and burnt forests.

	Shannon's diversity index (H)	**Simpson's diversity index(D)**	**Forests**
Herbs	2.869	0.079	Unburnt
	2.961	0.126	Burnt
Shrubs	1.914	0.194	Unburnt
	1.546	0.163	Burnt
Trees	1.92	0.185	Unburnt
	1.402	0.342	Burnt

4.4 Regeneration and forest structure of trees:

In the present study, the total density of seedlings, saplings, and trees of all species in UBF were 474.167, 694.167, and 559.167 individuals/ha, respectively whereas in BF seedlings, saplings, and trees were found to be 552.5, 565.83, and 341.667 individuals/ha, respectively (Table 8). The density of seedling, sapling, and trees of *Shorea robusta*, *Melia azedarach* and *Acacia catechu* respectively was found to be higher than other species in UBF. The density of seedlings, saplings, and trees of *Acacia catechu* was found to be higher than other species in BF. In UBF highest density of seedlings, saplings, and trees were recorded for *Shorea robusta* (125 individuals seedling), *Melia azedarach* (406 individuals sapling), *and Acacia catechu* (198 individuals ttree respectively. In BF highest density of seedlings, saplings, and trees were recorded of *Acacia catechu* (377 individuals seedling, 336 individuals sapling, and 220 individuals tree) (Table 8).

Similarly, seedling, sapling, and tree density of co-dominant associated species *Melia azedarach* (117 individuals, 406 individuals, and 0 individual) and *Terminalia tomentosa* (115 individuals, 38 individuals, and 71 individuals) respectively were found in UBF. In BF seedling, sapling, and tree density of co-dominant associated species *Shorea robusta* was 110 stems, 62 stems, and 92 stems respectively and that of Dalbergia *sissoo* was 56 stem seedlings, 102 stem saplings, and 46 stems trees. The tree species found in UBF and BF with their numbers of seedlings, saplings, and trees/ha regeneration status are given in (Table 8).

Table 8: Species-wise regeneration status in unburnt and burnt forests.

S.N	Name of plants	Unburnt			Burnt		
		SD	SP	Trees	SD	SP	Trees
1	*Aegle marmelos*	40	89	2	3	2	-
2	*Acacia catechu*	15	46	198	377	336	220
3	*Lagesteroemia parvifolia*	47	41	121	35	30	30
4	*Terminalia bellirica*	48	53	38	11	4	
5	*Terminalia tomentosa*	115	38	71	25	40	13
6	*Ficus benjamina*	-	-	1	-	-	-
7	*Bombax ceiba*	8	8	26	-	-	-
8	*Buchanania latifolia*	2	26	1	20	49	4
9	*Shorea robusta*	125	46	143	110	62	92
10	*Tectonia grandis*	2	-	-	-	-	-
11	*Syzygium cumini*	8	6	2	-	-	-
12	*Madhuca longifolia*	7	2	1	2	1	-
13	*Terminalia chebula*	3	8	5	-	-	-
14	*Dalbergia sissoo*	5	29	48	56	102	46

15	*Mangifera indica*	20	2	8	3	-	-
16	*Psidium guajava*	2	1	-	-	-	-
17	*Ficus racemosa*	-	-	2	-	-	-
18	*Phylanthus emblica*	-	2	2	2	11	-
19	*Mallotus philippenis*	5	30	2	-	9	-
20	*Melia azedarach*	117	406	-	9	22	-
21	*Azadiracta indica*	-	-	-	3	7	4
22	Seto tilka (Nepali name)	-	-	-	3	2	1
23	Tilka (Nepali name)	-	-	-	4	2	-
	Total in the studied quadrats	**569**	**833**	**671**	**663**	**679**	**410**
	Trees/ha	**474.1667**	**694.1667**	**559.1667**	**552.5**	**565.8333**	**341.6667**

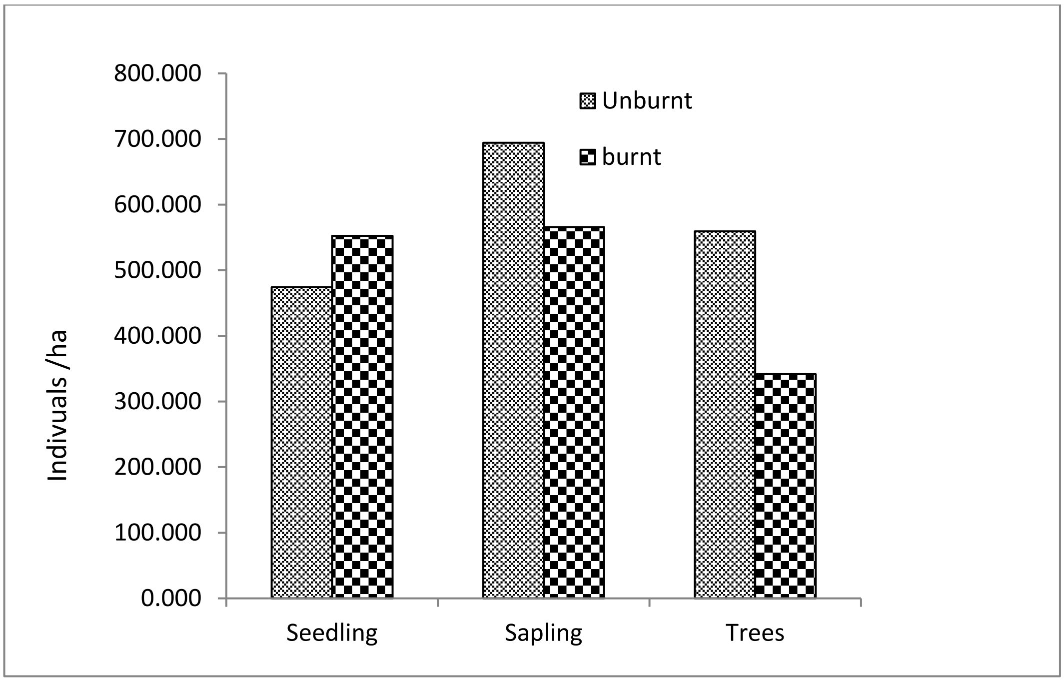


Figure 3: Life form diagram to show the regeneration status of all species in unburnt and burnt forests.

4.5 Density Diameter Relationship

Tree density (per ha) was highest in density class 10-20 followed by 20-30 in both UBF and BF (Figure 4 and Figure 5) This showed that most of the stands were at the intermediate stage of growth and there is a rapid decrease in density with an increase in DBH of trees in both UBF and BF.

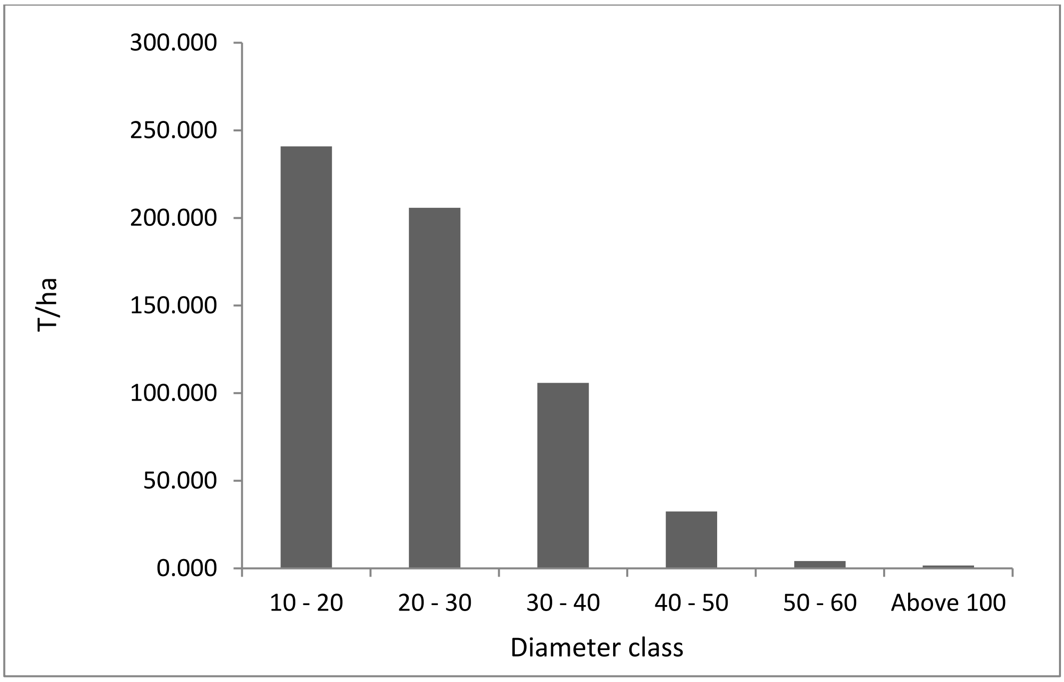


Figure 4: Density diameter relationship of trees >10cm in Unburnt forest.

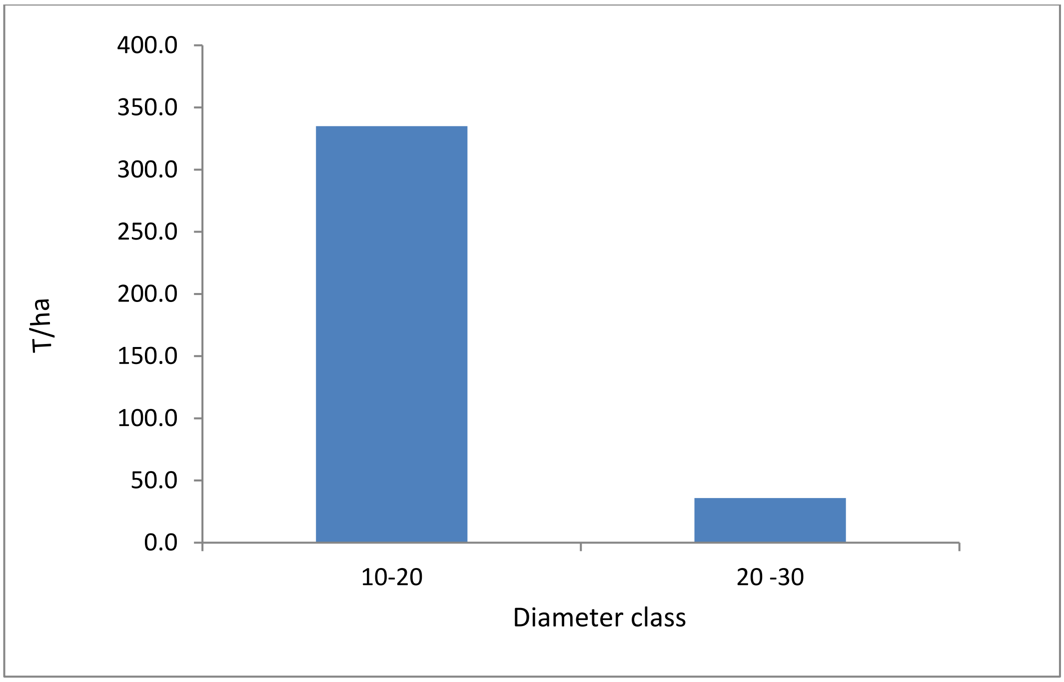


Figure 5: Density diameter relationship of trees >10cm in Burnt forest.

4.6 Biomass and Carbon Stock

Tree biomass

Total biomass in UBF was much higher than at the BF (Table 9). Among plant tree species *Shorea robusta* had the highest biomass in both above and below ground in both forests i.e 72.293 t/ha in above ground and 14.459 t/ha in below ground in UBF and 20.439 t/ha above ground and 4.088 t/ha below ground in BF, *Buchanania latifolia* had the lowest biomass in forest i.e 0.017 t/ha above ground and 0.003 t/ha below ground in UBF and 0.054 t/ha above ground and 0.011 t/ha below ground in BF (Table 9).

Table 9: Species wise above ground and below ground biomass in unburnt and burnt forests.

Name of plants	Above-ground biomass (t/ha) of UBF	Below-ground biomass (t/ha) of UBF	Above-ground biomass (t/ha) of BF	Below-ground biomass (t/ha) of BF
Aegle marmelos	0.241	0.048	-	-
Acacia catechu	27.248	5.450	11.347	2.269

Azadiracta indica		-	0.088	0.018
Bombax ceiba	12.971	2.594	-	-
Buchanania latifolia	0.017	0.003	0.054	0.011
Dalbergia sissoo	14.357	2.871	3.299	0.660
Ficus benjamina	0.965	0.193	-	-
Ficus racemosa	0.549	0.110	-	-
Lagesteroemia parvifolia	26.508	5.302	2.575	0.515
Madhuca longifolia	5.396	1.079	-	-
Mallotus philippenis	0.064	0.013	-	-
Mangifera indica	2.920	0.584	-	-
Phylanthus emblica	0.102	0.020	-	-
Semicarpus anacardium	-	-	0.087	0.017
Shorea robusta	72.293	14.459	20.439	4.088
Syzygium cumini	0.238	0.048	-	-
Terminalia bellirica	9.853	1.971	0.668	0.138
Terminalia chebula	2.304	0.461	-	-
Terminalia tomentosa	43.280	8.656	2.340	0.468
Unknown-1	-	-	0.075	0.015
Total	219.308	43.862	40.972	8.199

The total carbon stock in the living biomass of trees was found to vary significantly between the two community forests. The total carbon stock in trees of UBF and BF was calculated to be 123.690 t/ha, and 23.133 t/ha respectively (Appendix VI). Among the trees, the contribution of *Shorea robusta* was highest for carbon stock at both UBF and BF.

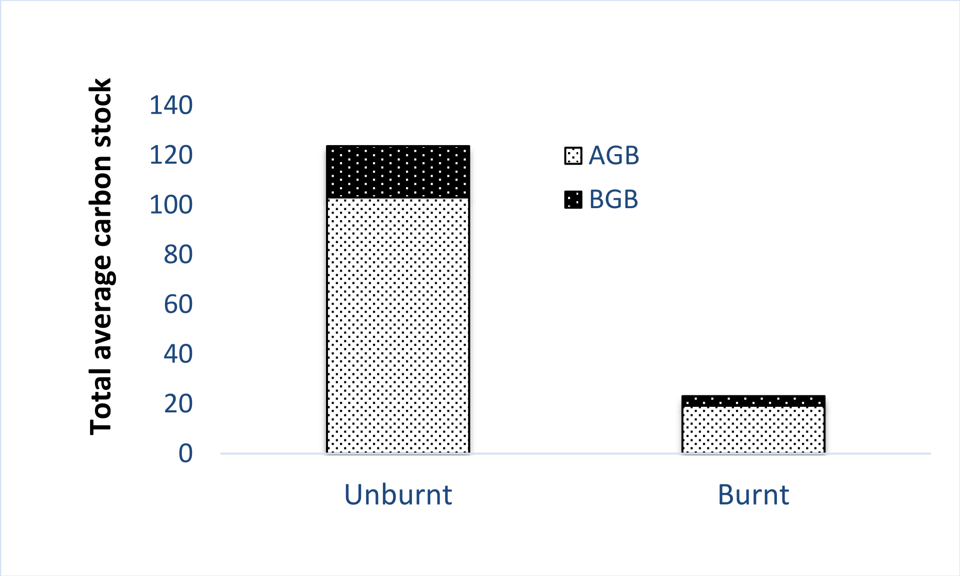


Figure 6: Total average above ground and below ground carbon stock in unburnt and burnt forests.

4.7 Soil parameters:

Potassium:

The mean value of Potassium in sal UBF was found to be 301.86 kg/ha, 293.40 kg/ha and 538.29 kg/ha of 2cm, 15cm and 30cm soil depth respectively and khayer UBF was 264.096 kg/ha, 304.28 kg/ha and 260.74 kg/ha of 2cm, 15cm and 30cm soil depth respectively in (Figure 7).

The mean value of Potassium in sal BF was found to be 302.19 kg/ha, 214.23 kg/ha, and 200.27 kg/ha of 2cm, 15cm, and 30cm soil depth respectively and khayer BF was 219.97 kg/ha, 101.73 kg/ha, and 85.49 kg/ha of 2cm, 15cm, and 30cm soil depth respectively in (Figure 7).

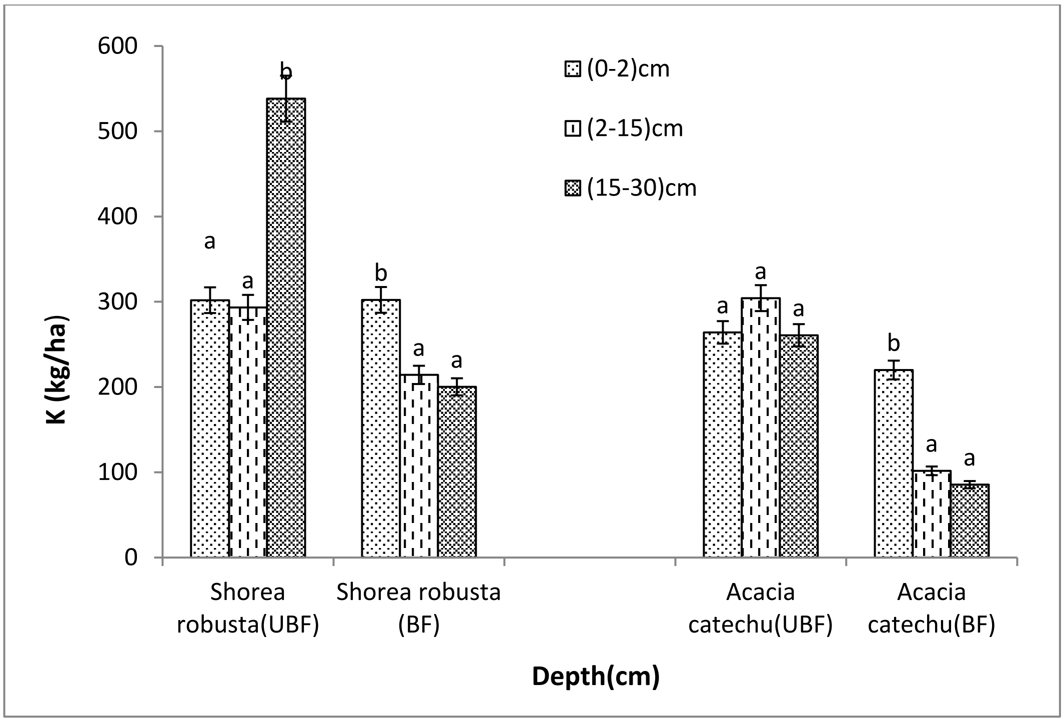


Figure 7: Soil potassium of unburnt and burnt forests at different depth. The different letters above the bar diagram for each forest types denotes significant difference at p=0.05 obtained by Ducan multiple range test followed after one way ANOVA.

Nitrogen:

The mean value of Nitrogen in sal UBF was found to be 0.010 %, 0.011 % and 0.012 % of 2cm, 15cm, and 30cm soil depth respectively and khayer UBF was 0.015 %, 0.014 %, and 0.016 % of 2cm, 15cm, and 30cm soil soil respectively in (Figure 8). The mean value of Nitrogen in sal BF was found to be 0.009%, 0.0092 %, and 0.010 % of 2cm, 15cm, and 30cm soil depth respectively and khayer BF was 0.010 %, 0.008 %, and 0.009 % of 2cm, 15cm, and 30cm soil depth respectively in (Fig. 8)

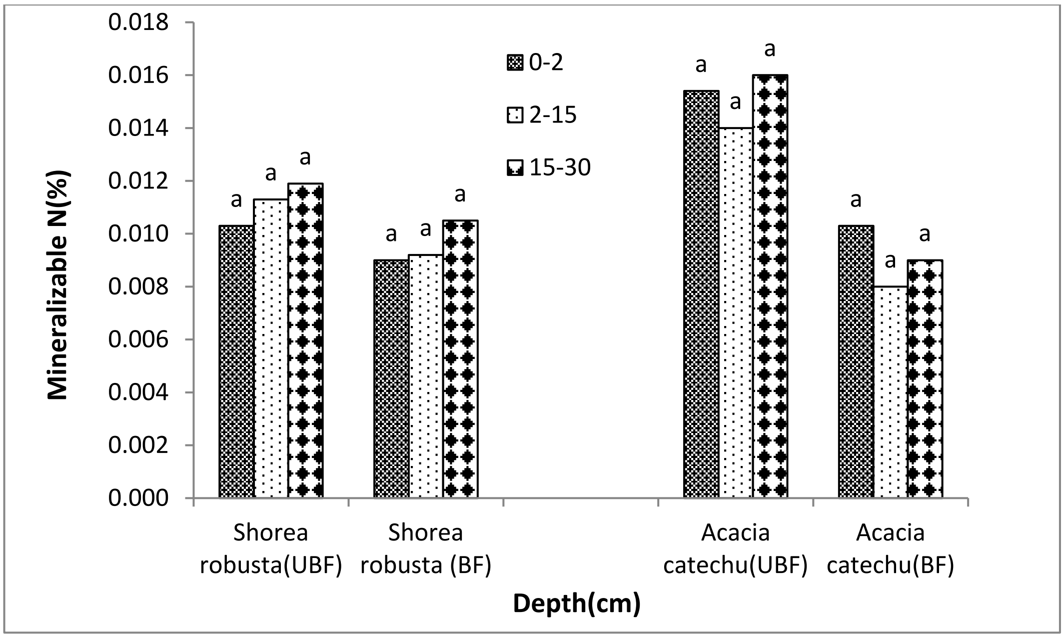


Figure 8: Soil nitrogen content of unburnt and burnt forests at different depth. The same letter above the bar diagram for each forestr types denotes insignificant difference at p=0.05 obtained by Ducan multiple range test followed after one way ANOVA.

Phosphorus:

The mean value of phosphorus in sal UBF was found to be 36.22 kg/ha, 57.07 kg/ha and 23.99 kg/ha at 2cm, 15cm, and 30cm soil respectively, and khayer UBF was 35.86 kg/ha, 48.21 kg/ha, and 38.67 kg/ha at 2cm, 15cm, and 30cm soil depth respectively in (Figure 9).

The mean value of phosphorus in sal BF was found to be 21.81 kg/ha, 23.84 kg/ha, and 55.93 kg/ha at 2cm, 15cm, and 30cm soil depth respectively and khayer BF was 29.80 kg/ha, 29.26 kg/ha, and 25.60 kg/ha at 2cm,15cm, and 30cm soil depth respectively in (Fig. 9)

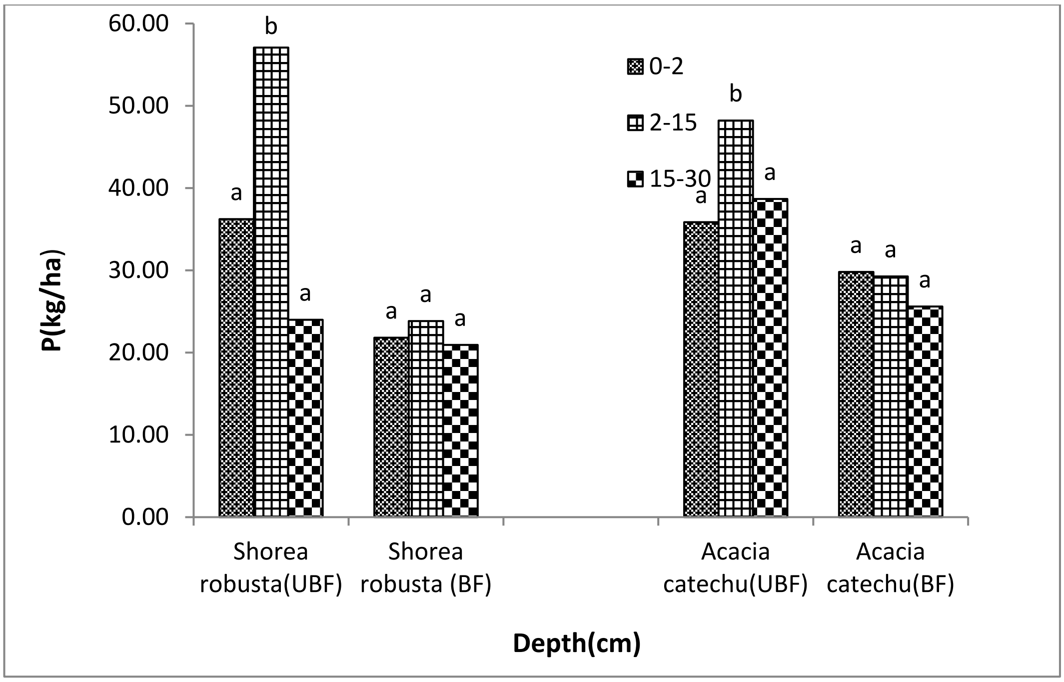


Figure 9: Soil phosphorus of unburnt and burnt forests at different depth. The different letter above the bar diagram for each forestr types denotes significant difference at p=0.05 obtained by Ducan multiple range test followed after one way ANOVA.

Soil organic carbon:

The mean value of SOC in sal UBF was found to be 2.17 %, 0.67 % and 0.53 % of 2cm, 15cm, and 30cm soil depth respectively and at khayer UBF it was 2.18 %, 0.50 % and 0.44 % at 2cm, 15cm, and 30cm soil respectively in (Fig. 10).

The mean value of SOC in sal BF was found to be 0.84 %, 0.63%, and 0.51 % at 2cm, 15cm, and 30cm soil depth respectively and at khayer BF it was 0.88 %, 0.48 %, and 0.34 % of 2cm, 15cm, and 30cm soil depth respectively (Fig. 10)

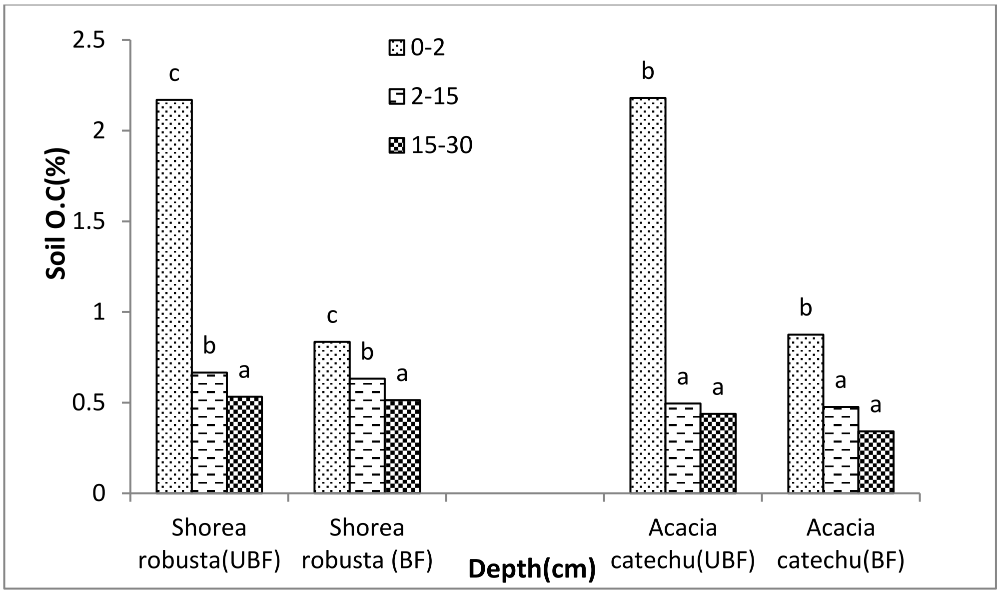


Figure 10: Soil organic carbon of unburnt and burnt forests at different depth. The different letters above the bar diagram for each forestr types denotes significant difference at p=0.05 obtained by Ducan multiple range test followed after one way ANOVA.

Bulk Density

Bulk density in UBF at 2cm, 15cm, and 30cm soil depth is ranged from 0.99 to 1.93 g/cm³, 1.29 to 1.72 g/cm³, and 1.40 to 1.76 g/cm³ respectively and in BF at 2cm, 15cm, and 30cm soil depth it ranged from 1.44 to 1.89 g/cm³, 1.39 to 1.96 g/cm³, and 1.31 to 2.04 g/cm³ respectively. The mean value of bulk density in UBF was found 1.57 g/cm³, 1.52 g/cm³, and 1.56 g/cm³ of 2cm, 15cm and 30cm soil respectively and 1.61 g/cm³, 1.56 g/cm³, and 1.62 g/cm³ of 2cm, 15cm, and 30cm soil respectively in BF (Figure 11).

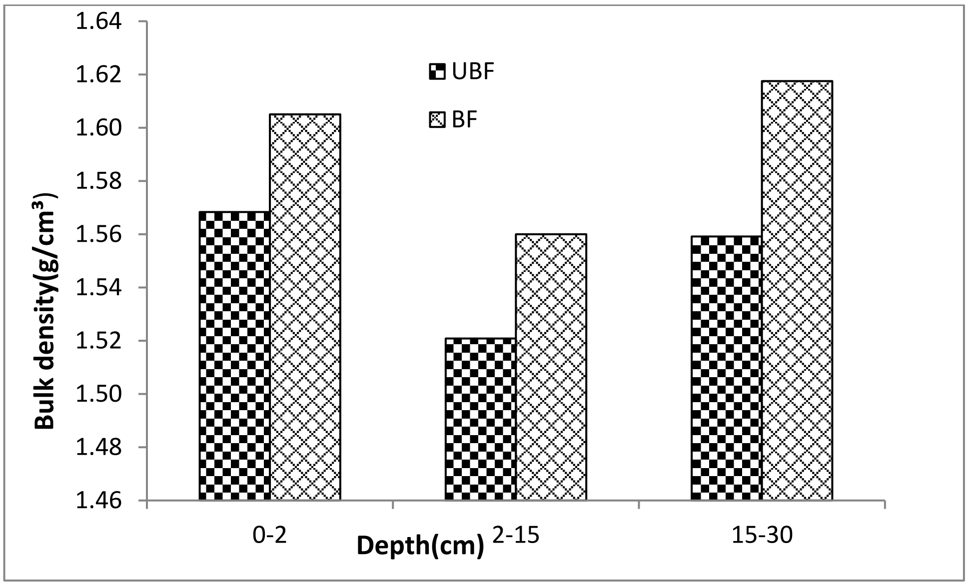
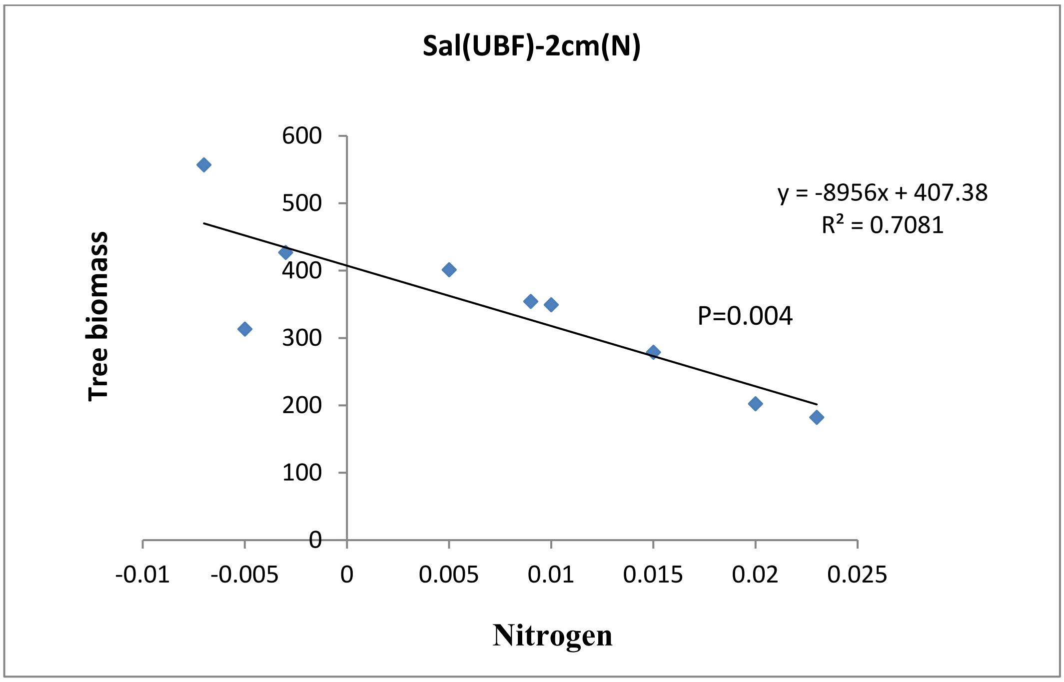


Figure 11: Bulk density of unburnt and burnt forests.

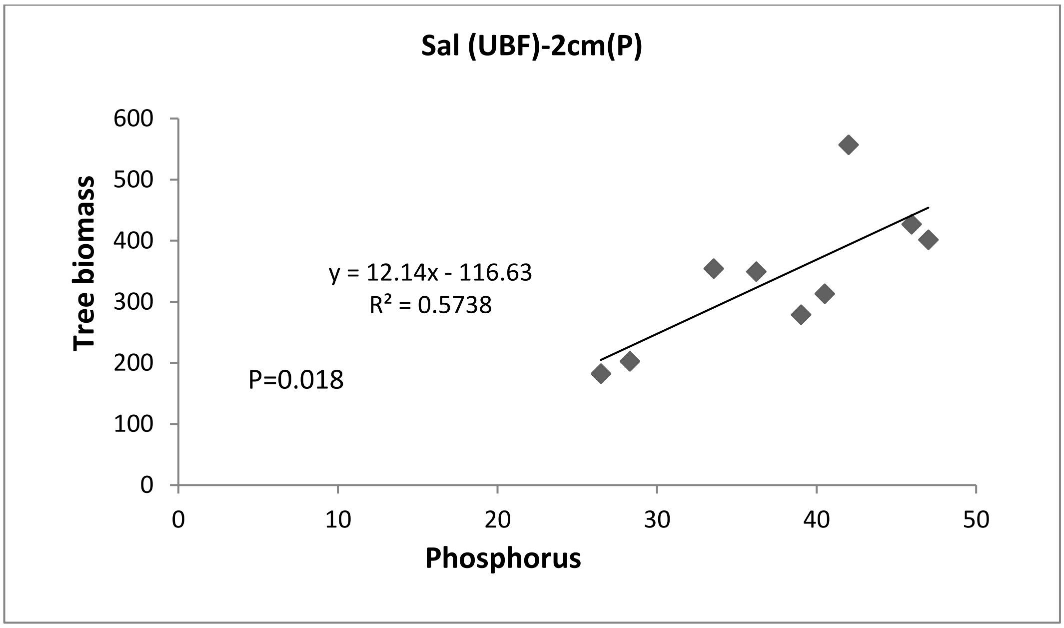
4.8 Relation between tree biomass and soil parameters:

Regression analysis between the biomass and soil parameters (Bulk density (B.D), Nitrogen (N), Phosphorus (P), Potassium (K), and Soil organic carbon (SOC)) was calculated, and only the significant values ($P \leq 0.05$) obtained are presented in the graph below.

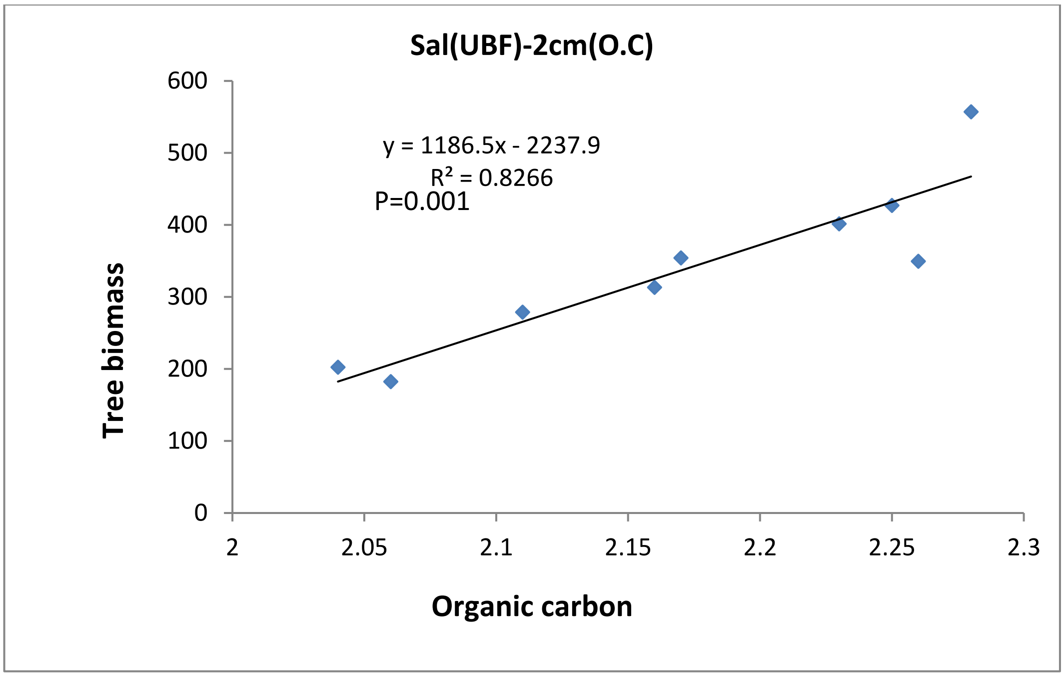
The significant ($P \leq 0.05$) relation between the biomass of Sal unburnt forest (UBF) and soil parameters like N (of 2 cm soil), P (of top 2cm soil), SOC (of 2cm and 30cm soil), K (of 30cm soil), and B.D (of 30cm soil) was observed (fig.12)



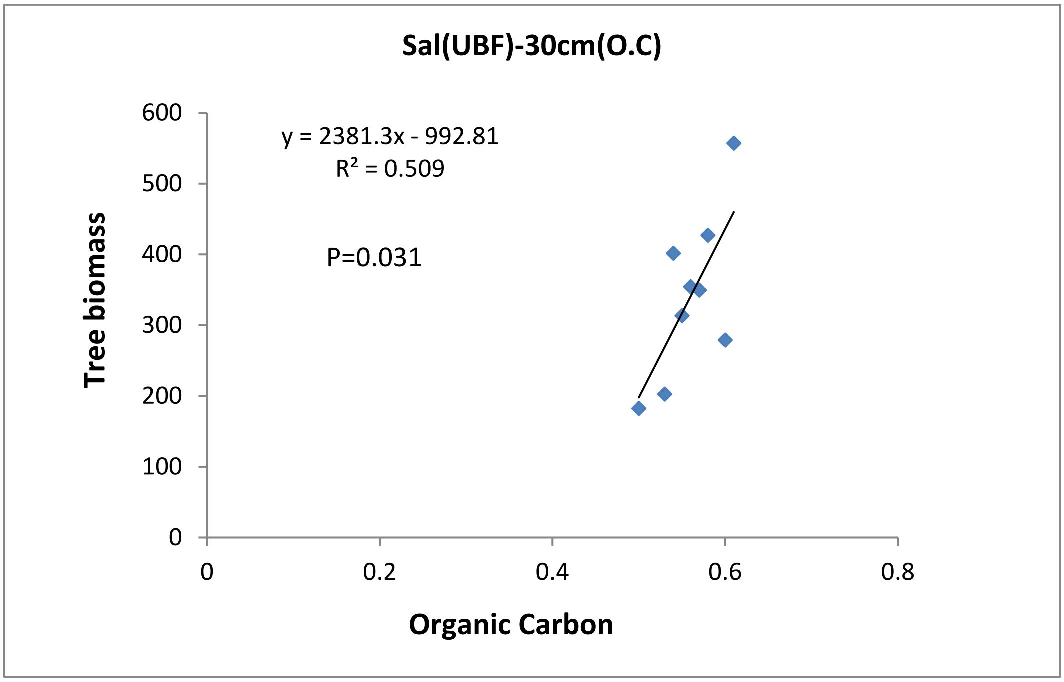
(a)



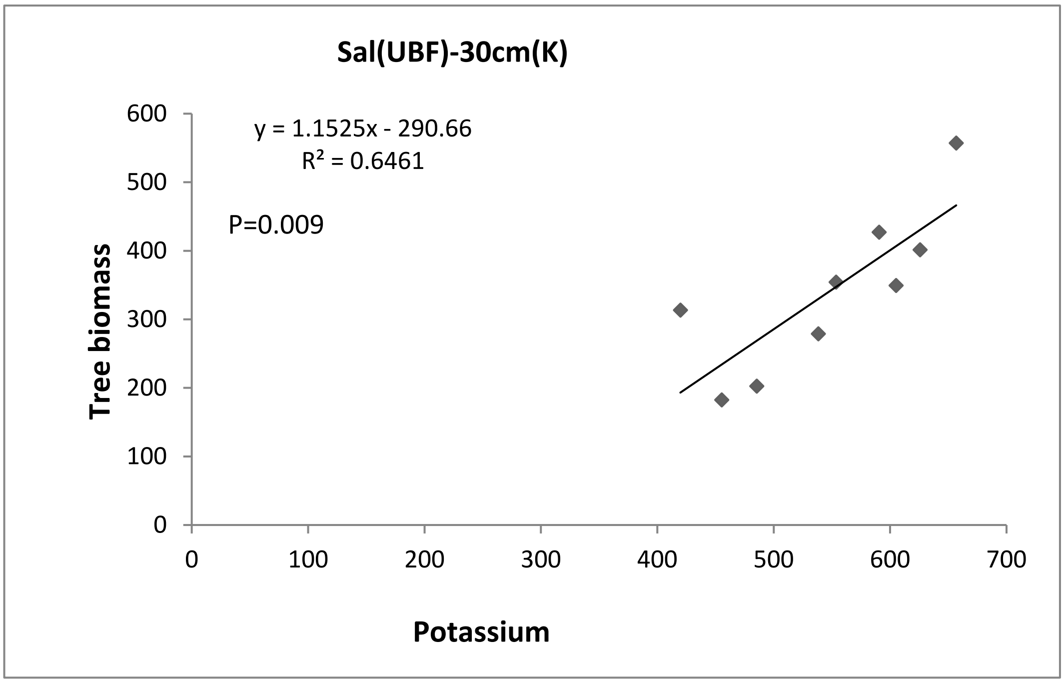
(b)


Sal(UBF)-2cm(O.C)
y = 1186.5x - 2237.9
R² = 0.8266
P=0.001
Tree biomass
Organic carbon
600
500
400
300
200
100
0
2
2.05
2.1
2.15
2.2
2.25
2.3

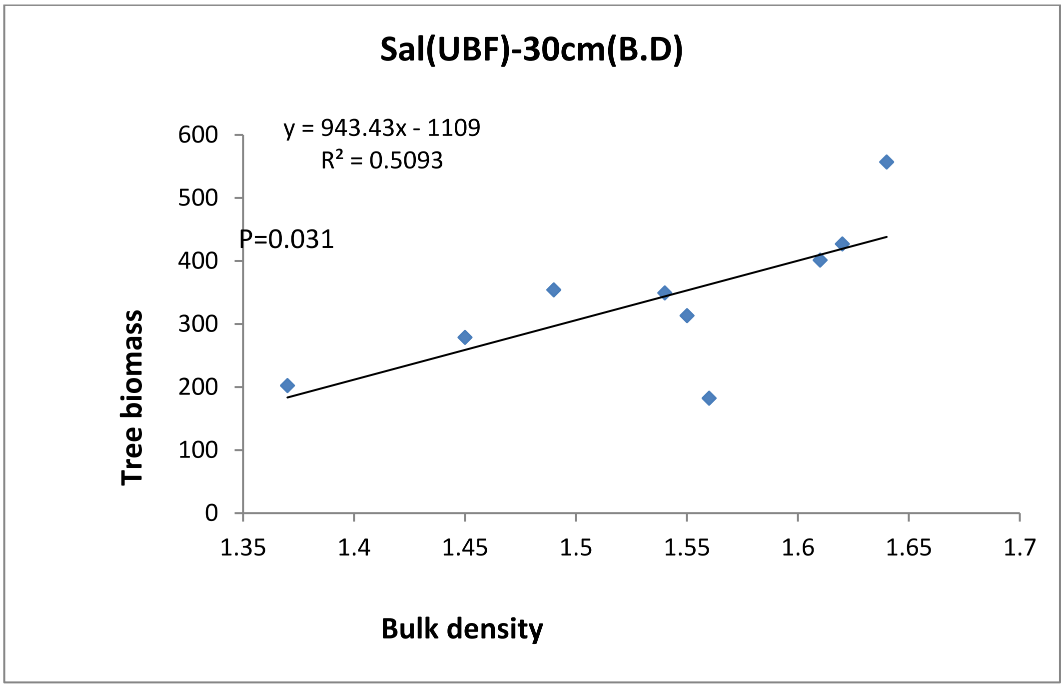
(c)


Sal(UBF)-30cm(O.C)
y = 2381.3x - 992.81
R² = 0.509
P=0.031
Tree biomass
Organic Carbon
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8

(d)



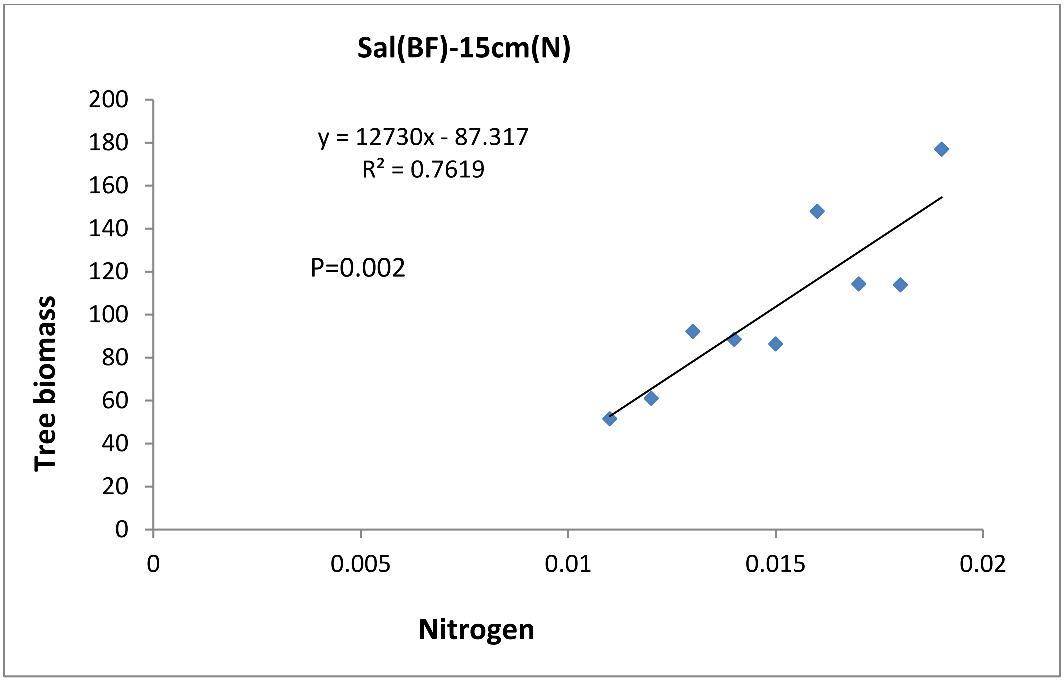
(e)



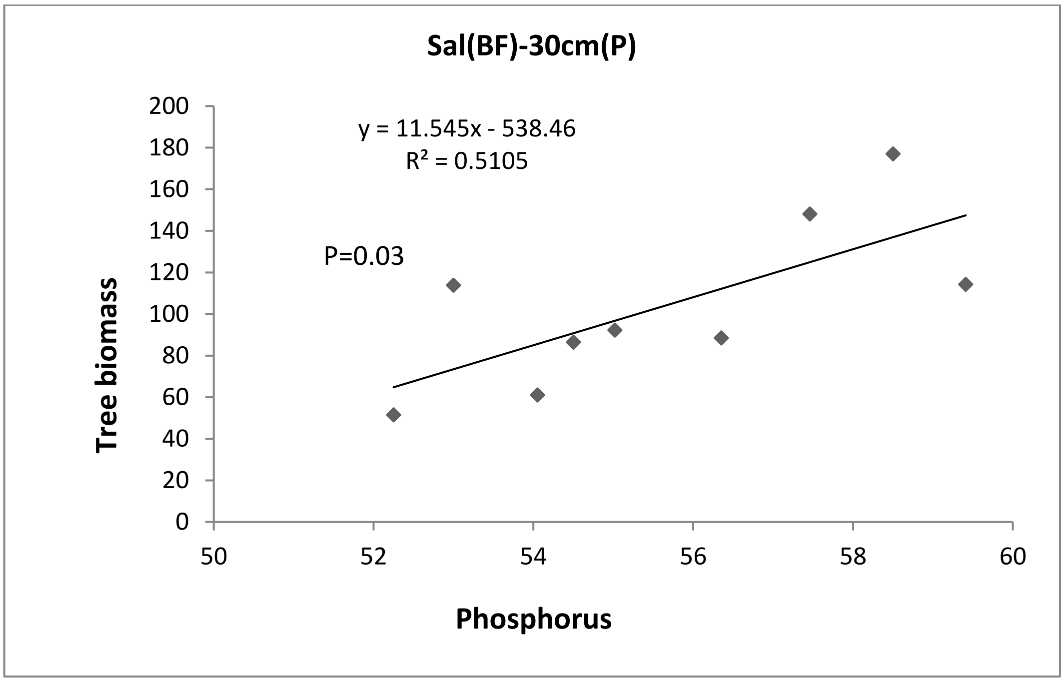
(f)

Figure 12: Regression analysis showing relationship between the biomass of Sal unburnt forest (UBF) and soil parameters like N 2cm (a), P 2cm (b), SOC 2cm(c), SOC 30cm (d), K 30cm (e), and B.D 30cm (f).

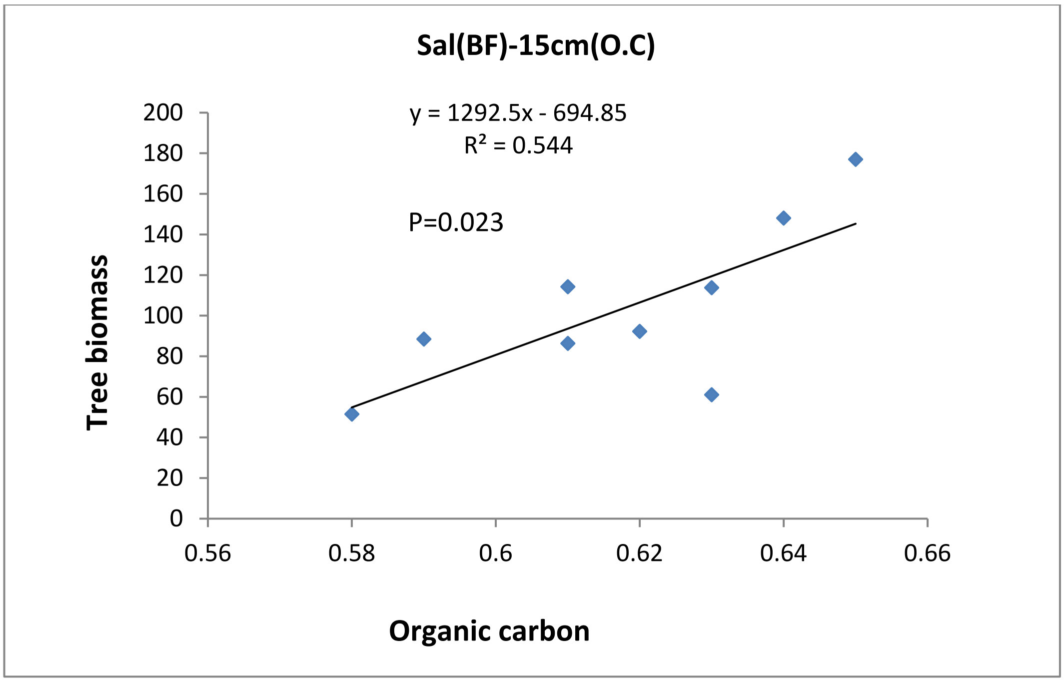
The significant ($P \leq 0.05$) relation between the biomass of Sal burnt forest (BF) and soil parameters like N (of 15 cm soil), P (of 30cm soil), SOC (of 15cm soil), K (of 15cm soil), and B.D (of 15 cm soil) was observed (fig. 13).


Sal(BF)-15cm(N)
y = 12730x - 87.317
R² = 0.7619
P=0.002
Tree biomass
200
180
160
140
120
100
80
60
40
20
0
0
0.005
0.01
0.015
0.02
Nitrogen

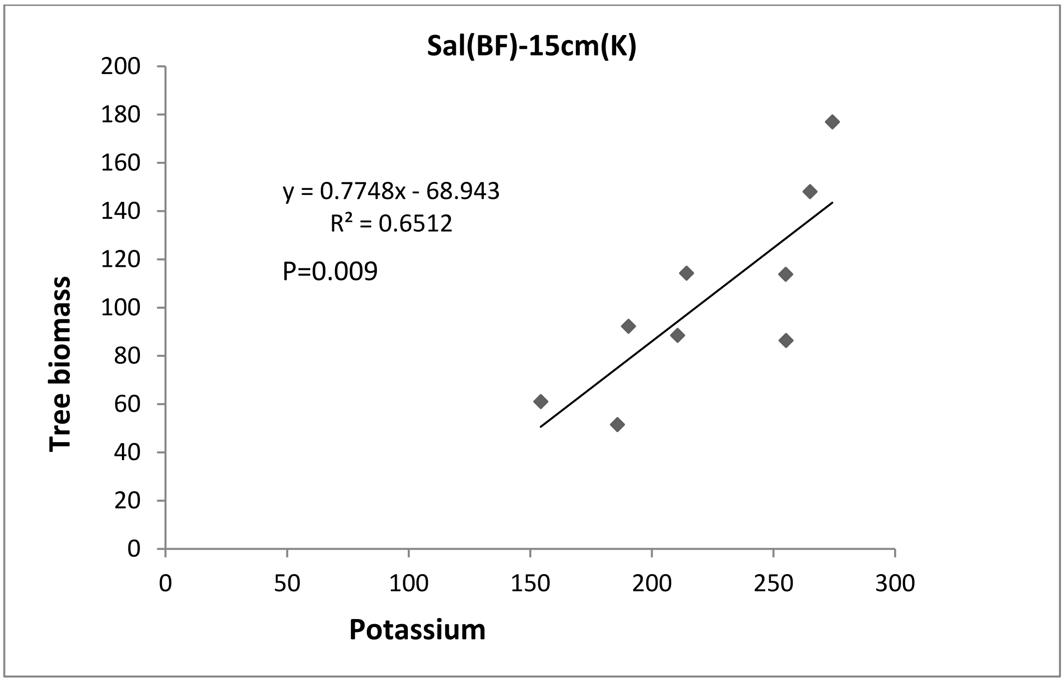
(a)


Sal(BF)-30cm(P)
y = 11.545x - 538.46
R² = 0.5105
P=0.03
Tree biomass
200
180
160
140
120
100
80
60
40
20
0
50
52
54
56
58
60
Phosphorus

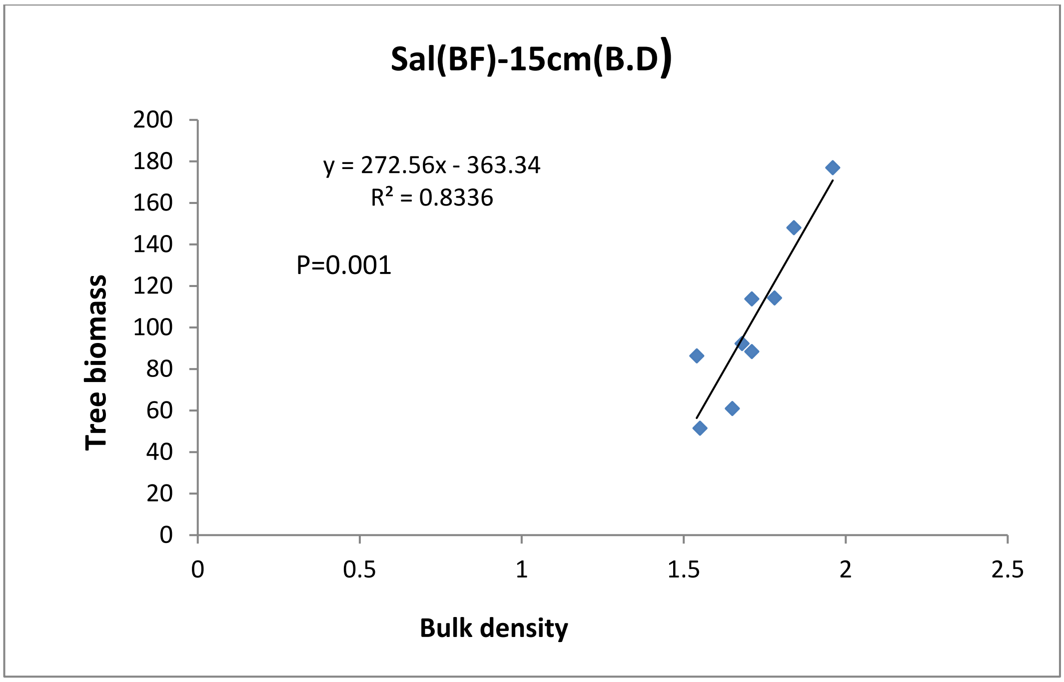
(b)


Sal(BF)-15cm(O.C)
y = 1292.5x - 694.85
R² = 0.544
P=0.023
Tree biomass
Organic carbon
200
180
160
140
120
100
80
60
40
20
0
0.56
0.58
0.6
0.62
0.64
0.66

(c)


Sal(BF)-15cm(K)
y = 0.7748x - 68.943
R² = 0.6512
P=0.009
Tree biomass
Potassium
200
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300

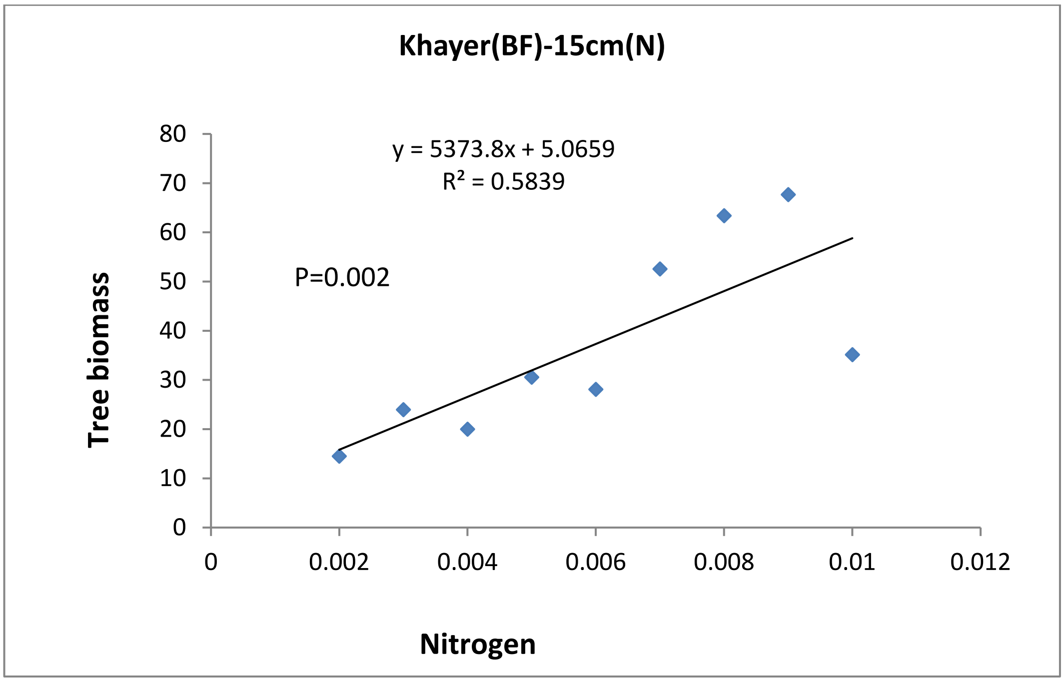
(d)



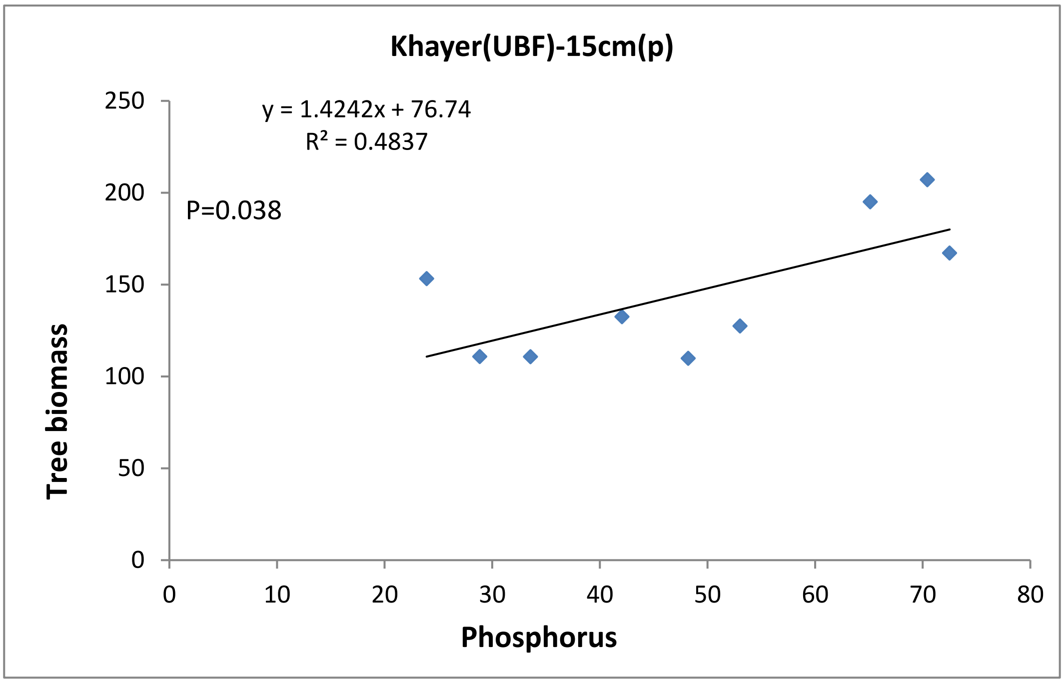
(e)

Figure 13: Regression analysis showing relationship between the biomass of Sal burnt forest (BF) and soil parameters like N 15cm (a), P 30cm (b), SOC 15cm(c), K 15cm (d) and B.D 15cm (e).

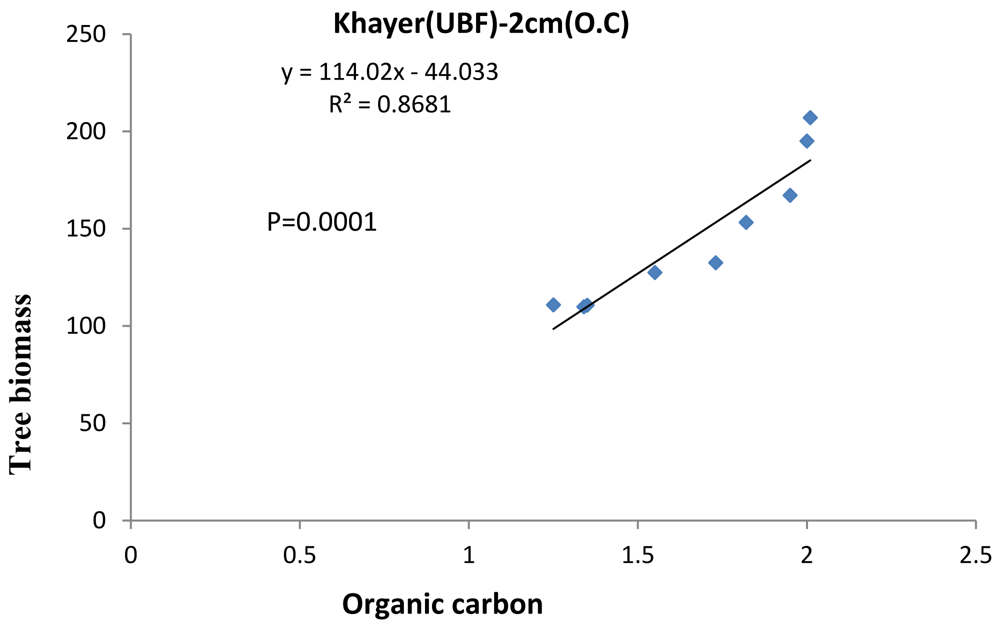
The significant (P≤0.05) relation between the biomass of Khayer unburnt forest (UBF) and soil parameters like N (of 15 cm soil), P (of 15cm soil), SOC (of 2cm, 15cm, and 30cm soil) and K (of 30cm soil) was observed (fig. 14).



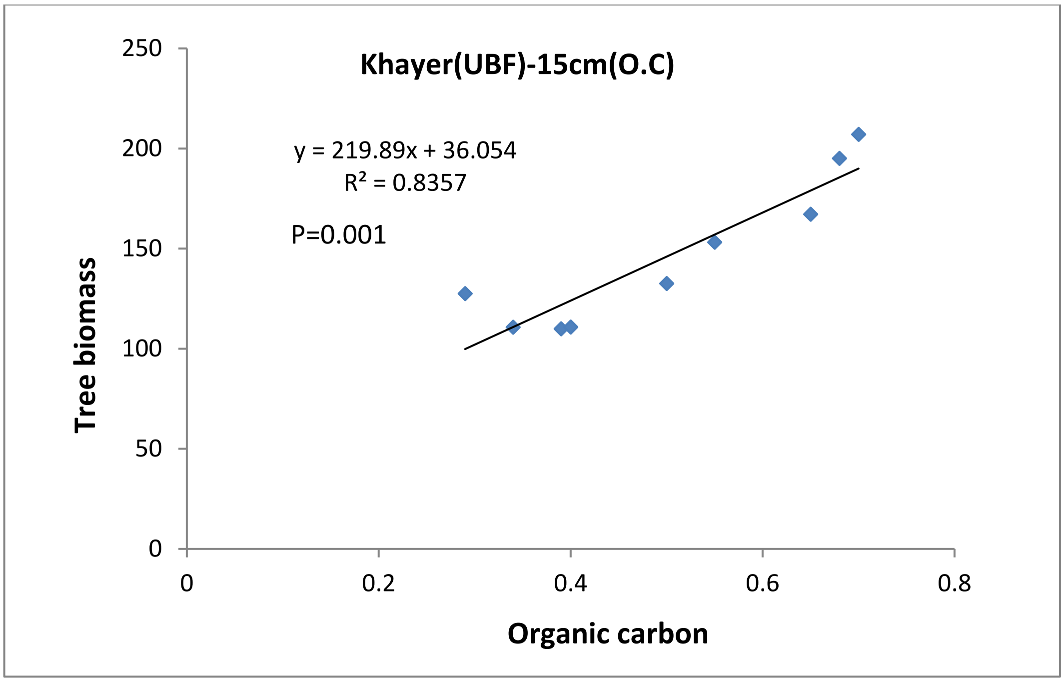
(a)


Khayer(UBF)-15cm(p)
y = 1.4242x + 76.74
R² = 0.4837
P=0.038
Tree biomass
Phosphorus
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80

(b)


Khayer(UBF)-2cm(O.C)
y = 114.02x - 44.033
R² = 0.8681
P=0.0001
Tree biomass
Organic carbon
0
50
100
150
200
250
0
0.5
1
1.5
2
2.5

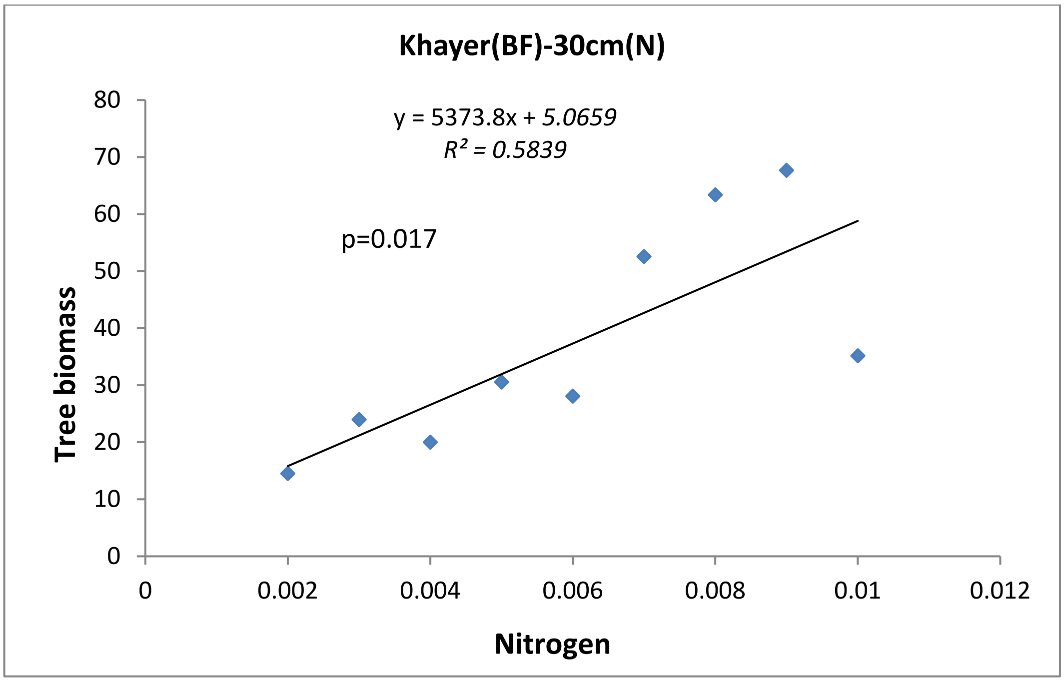
(c)



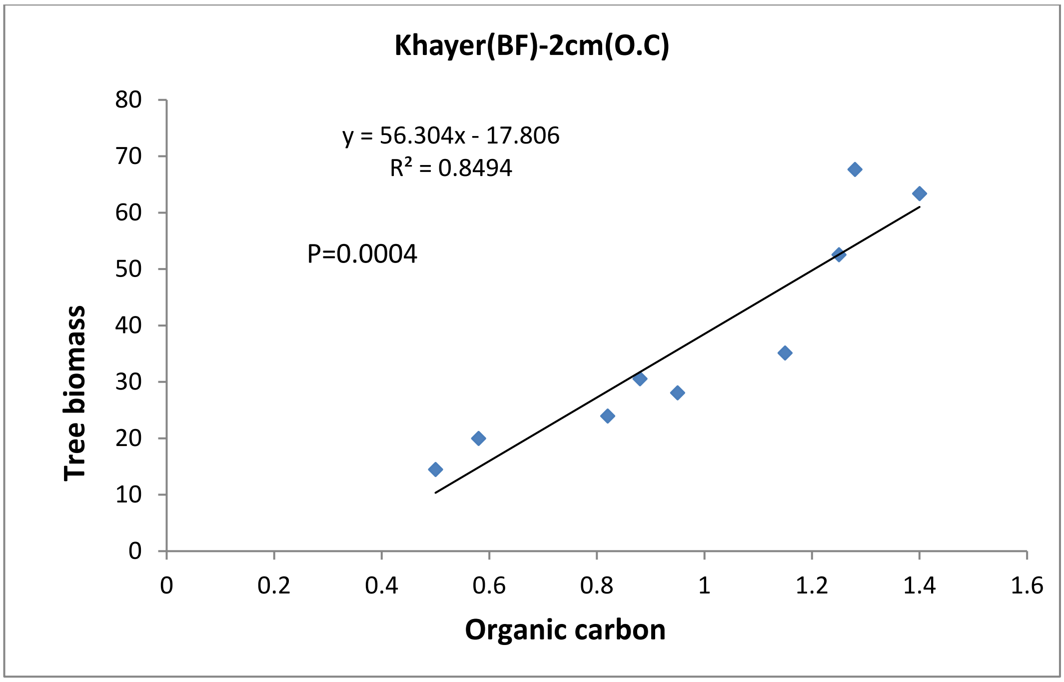
(d)

Figure 14: Regression analysis showing relationship between the biomass of Khayer unburnt forest (UBF) and soil parameters like N 15cm (a), P 15cm (b), SOC 2cm(c), SOC 15cm (d), SOC 30cm (e), and K 15cm (f).

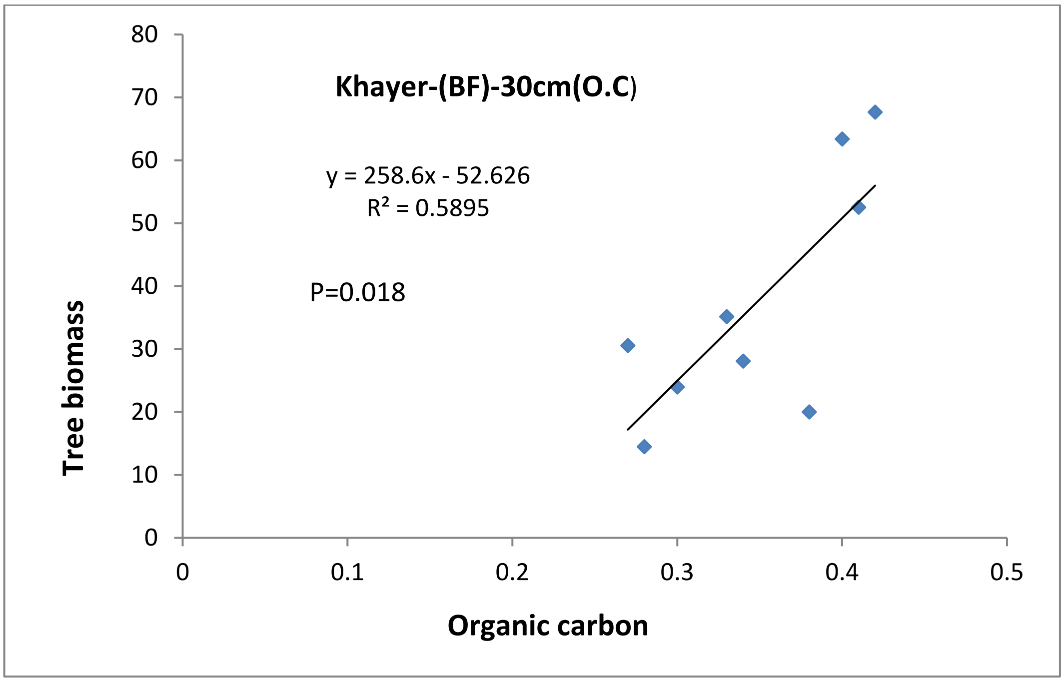
The significant ($P \leq 0.05$) relation between the biomass of Khayer burnt forest (BF) and soil parameters like N (of 30cm soil) and SOC (of 2cm and 30cm soil) was observed (fig.15).



(a)



(b)



(c)

Figure 15: Regression analysis showing relationship between the biomass of Khayer burnt forest (BF) and soil parameters like N 30cm (a), SOC 2cm (b), and SOC 30cm (c).

CHAPTER 5: DISCUSSION

5.1 Plant biodiversity

Total plant species diversity in the unburnt forest (UBF) was found to be higher than in the burnt forest (BF). However, the diversity of herbs, shrubs, and trees was higher in a non-fire forest (UBF) than in a burnt forest (BF). The species diversity of shrubs and trees was higher in UBF than in BF but the species diversity of herbs was higher in burnt forest than in UBF. Huston (1994) also reported disturbances can reduce plant species diversity by removing disturbance-sensitive species, increase species diversity by opening up growing space and resources for use by colonizing species, maintain species richness by reducing or preventing competitive exclusion, and modify spatial heterogeneity in plant community composition. David and Peter (2008) conducted a study on how fire frequency and tree canopy structure influence plant species diversity in a forest-grassland ecotone and reported a general increase in species richness with fire frequency but noted that grass species richness tended to decrease at fire frequencies greater than five fires per decade. Similarly, in this study, the mean species richness of herbaceous plants (including grasses) decreased in fire forest more than in non-fire forest.

Species richness of trees was higher in the unburnt forest than burnt forest. This study is consistent with the findings of Michael *et al.,* (2007) who observed that at high fire frequency a significantly lower number of woody species were found in the floodplain vegetation of the Okavango Delta, Botswana. David and Peter (2008) also reported that woody plant species richness was higher in plots protected from fire and declined with increasing fire frequency. The coverage of herbaceous plants was higher in burnt forest than unburnt forest. Afolayan *et al.,* (1978) also observed that in late dry-season fires generally increase grass production in Kainji Lake National Park Nigeria.

The percentage cover of shrubs and trees decreased in burnt forest than unburnt forest. This implies that in this study, the cover of woody species (shrubs and trees) was generally greater in UBF than in BF. This is consistent with the findings of Booysen and Tainton (1984) who postulated that the generally accepted trend of the structural response of vegetation to fire frequency is that the more frequent the fire, the larger the herbaceous component, and the less frequent the fire, the more abundant the woody constituent.

Among all tree species IVI of *Acacia catechu* was found highest in both community forests (i.e. 73.71 in UBF and 48.32 in BF). High IVI of a species indicates its dominance and ecological success, its good power of regeneration and greater ecological amplitude (Samee and Kangaroo, 2011). The regeneration of *Shorea robusta* was higher in unburnt forest and *Acacia catechu* was higher in burnt forest. Hence, it indicates that *Shorea robusta,* and *Acacia catechu* were most important and dominant species in both forests.

5.2 Regeneration

Forest fire effects on patterns of species diversity and regeneration in tropical and subtropical forests (Jhariya et al., 2012). The presence of good regeneration potential shows suitability of a species to the environment. The density values of seedlings and saplings were considered as regeneration potential of the species (Joshi, 1990).

In the present study, the total density of seedlings, saplings, and trees of all species in UBF were 474.167 individuals/ha, 694.167 individuals/ha, and 559.167 individuals/ha, respectively whereas in BF seedling, sapling and tree were found to be 552.5 individuals/ha, 565.83 individuals/ha and 341.667 individuals/ha, respectively. The density of seedlings was higher in BF than in UBF. It suggested that increased plant available nutrients could be the reason for an enhanced number of seedlings. This study is consistent with the findings of Schimmel et al., (1996) observed that fire consumption of thick organic layers provides a better substrate for seed germination, and seedling survival, which is particularly important in providing colonization opportunities for small-seeded species. According to Kodandapani (2001) fire enhances the productivity of ecosystems by releasing chemicals and nutrients locked up in old herbages which ultimately helped the regeneration of seedlings after forest fire. Barro and Conard, (1991) also observed that fire eliminates leaves or the whole stem that can stimulate surviving buds to produce new shoots.

The density of saplings and trees was significantly higher in UBF than in BF in the present study. Pinard et al., 1999; Balch et al., (2013) also reported that fire indirectly affects regeneration patterns by killing trees with thin bark. Fire with short intervals can change stand structure by significantly reducing sapling density, and also through moderate reductions in the density of mid-story trees (Hutchinson et al., 2012). Results suggest that fire supports the regeneration of *Acacia catechu and Shorea robusta.* The regeneration of Sal and Khayer occur through fertile seeds, sprouting from root suckers (Gautam et al. 2006).

5.3 Biomass and carbon stock

Carbon sequestration is a biological process, in which photosynthetic organisms especially plants, plays a vital role to balance atmospheric CO2. However, the capacity of capturing and storing carbon varies according to the nature of the plants. The observations of Negi et al., (2003) revealed that the wood, which constitutes maximum portion of total biomass, stored maximum amount of carbon. While comparing the different life forms, it was observed that the maximum carbon is stored in the order of conifers > deciduous > evergreen > bamboos. Thus, it can be said that the conifers can store largest amount of carbon and was more efficient in carbon sequestration (Negi et al., 2003).

Both above-ground and below-ground biomass is a significant quantitative characteristic of forest ecosystems. The tree biomass changes due to numerous factors in forest ecosystems such as stand age, species composition, size class of trees, forest type, site conditions, rainfall pattern, edaphic factors, and elevation (Peichl and Arain, 2006; Terakunpisut et al., 2007; Gairola et al., 2011; Cao et al., 2012; Zhao et al., 2014). Results suggest that the total biomass of trees was higher in UBF than in BF. Xanthopoulos et al., (2012) reported that the loss of forest biomass due to burning is affected by fire intensity as well as by the structure and flammability of different forest types and associated fuels.

It was observed that the total carbon stock of trees was higher in unburnt forest than burnt forest. Highest carbon stock in unburnt forest could be because of the higher value of height and DBH of *Shorea robusta, Lagesteroemia parviflora, Acacia catechu*, etc. in this forest than burnt forest. In burnt forest, fungal infection appears in the wound caused by fire ultimately stunted growth occur in *S. robusta* species. Similar results were observed by Bakshi (1957) in Kashmir, he reported older *S. robusta* trees were resistant to fire but younger trees become unhealthy due to fungi infection in the wound from fire. Due to wildfire carbon stock change in forests depend on combustion in the short-term and in the long-term by redeployment among biomass components and their subsequent differential rates of decomposition and regeneration (Keith et al., 2014). Seasonal losses of carbon by wildfires are identified as high concentrations of trace gases in the troposphere (Watson et al., 1990; Cahoon et al., 1992). There was significant difference of total carbon stocks (AGC+BGC) in *S. robusta* forest of burnt and unburnt forest were observed in the present study. Similar results were obtained in *Pinus roxburghii* forest of Langtang National Park, Central Nepal (Aryal et al., 2017) in deciduous forest, Champadevi Community Forest of Central Nepal (Panthi, 2011) and sub-tropical forest of Garhwal Himalaya (Kumar, 2010).

The total biomass of unburnt forest (263.17 t/ha) was found significantly higher than in burnt forest (49.171 t/ ha). Among plant tree species *Shorea robusta* have the highest carbon in both above and below ground in both forests i.e 72.293 t/ha in above ground and 14.459 t/ha in below ground in UBF and 20.439 t/ha in above ground and 4.088 t/ha in below ground in BF. Chiriacò et al., (2013) found, that a part of living biomass (including understory, leaves, and small branches) is destroyed and causes direct emissions of GHGs and another fraction is transferred to the dead organic matter pool will later decay, releasing indirect emissions. Tree density (per ha) was highest in density class 10-20 followed by 20-30 in both UBF and BF. This showed that most of the stands were at an intermediate stage of growth and there is a rapid decrease in density with an increase in DBH of trees in both UBF and BF.

5.4 Soil parameters:

Results suggest that available mean phosphorus decreases in a burnt forest as compare to an unburnt forest. After fire losses of phosphorus by volatilization or leaching are small. Fire changes the organic pool of soil P to orthophosphate (Cade-Menun et al., 2000); the sole form of available P.

The organic carbon decreases in BF as compared to UBF. Orioli and Curvetto, (1978) described that fire decreases Organic Carbon as a consequence of the pyrolysis of organic materials by heat. The impact of fire on soil organic matter includes charring, volatilization, and oxidation (Giovannini et al., 1988). Substantial loss of organic matter occurs at 200-460°C (Giovannini et al., 1988). Fire destroys Organic Carbon by partially burning it (Simard et al., 2001).

The change in concentration of extractable potassium was very significant. In all soil depths, potassium was lower in BF but was significantly high in UBF. Kutiel and Naveh, (1987) suggest that after fire total amount of potassium decreases but their plant existing forms increase.

In both sal and khayer unburnt forest % of mineralizable Nitrogen was significantly higher than in sal and khayer burnt forest. According to Murphy et al., (2006), the effects of fire are the increase in the soil solution concentrations and leakage of mineral forms of nitrogen but the total nitrogen decreases (Knight, 1966). In this study, the % of mineralizable Nitrogen concentration was significantly lower in burnt forest than in unburnt forest, which is also reported by Neff et al. (2005). According to Driscoll et al., (1999), forest floor layers are a major reservoir of soil N, and their removal during forest fires can cause substantial decreases in Nitrogen. It is suggested that the increase of available nitrogen, particularly NH4 +, is generally short-term, and quick immobilization could reduce it after 6 months (Adams and Attiwill 1986).

Results suggest that bulk density increases in the burnt forest in the collected samples. Bulk density increases in burnt forest due to the collapse of aggregates and blockage of soil spaces by ash and detached clay minerals which reduced soil permeability and porosity (Certini, 2005).

CHAPTER 6: CONCLUSION

- From the study, it can be concluded that fire has a varying degree of impact on tree species diversity, regeneration, biomass, and soil properties.
- Fire affects these properties very differently ranging from beneficial to harmful impacts on tree species, regeneration, biomass, and soil properties.
- A total of 69 plant species, under 32 families, were recorded in this study from the unburnt forest, and 52 plant species, under 27 families were recorded from the forest that had experienced a fire.
- *Acacia catechu, Shorea robusta, Lagesteroemia parvifolia, and Berberis aristata* were the most dominant species. The diversity decreased and dominance increased after the fire.
- The number of seedlings increased immediately after the fire but saplings and trees decreased. The density of seedlings, saplings, and trees of *Shorea robusta*, *Melia azedarach,* and *Acacia catechu* respectively were found to be higher than other species in UBF. The density of seedlings, saplings, and trees of *Acacia catechu* was found to be higher than other species in BF.
- Total biomass in UBF was much higher than at the BF. Among plant tree species *Shorea robusta* had the highest biomass in both above and below ground in both forests.
- Soil organic carbon decreases in burnt forest. The % of mineralizable N, available P, and extractable K decreased at BF (i.e SCF) but the bulk density increased at the BF (at SCF).

CHAPTER 7: RECOMMENDATION

From the present study following recommendations are made

1. Though fire is harmful to plants and animals and causes wide-range of environmental damage, it is recommended to practice control fire at some portion of the forest to reduce bush cover, to enhance the quality of forage to animals and to reduce disease causing-pests for the management of community forest.
2. BCF need to divide the forest into blocks by constructing a fire line and practice control fire at some blocks only and the rest block should be left without fire to maintain biodiversity.
3. Forest fire should be strictly prohibited at some blocks to maintain species diversity and regeneration of the forest. During silviculture practices, due importance should be given to all species specially to maintain biodiversity in both forest.

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APPENDICES

APPENDIX I

Data sheet used in field sampling

Date: District:

Locality: Altitude:

Slope: Latitude:

Longitude: Plot no:

Quadrat no: Quadrat size:

Canopy cover (%): Disturbance (1- 3): Aspect:

Name of recorder: Forest type:

S.N	Plant species	Local name	Seedling	Sapling	Trees
1					
2					
3					
.					
.					

S.N	Plant species	Local name	No. of plant spp.	Coverage (%)	Remarks
1					
2					
3					
.					

APPENDIX II

Geographical position of plots with different variables measured in these plots.

Where, plot no. 1-3; for UBF and 31 -60; for BF (Alt- altimeter, CC-canopy cover).

Plot No	Alt(m)	Latitude	Longitude	Slope(°)	CC (%)	Aspect(°)	Disturbance
1	270	27°52’3”	82°35’56’’	10	55	150SE	1
2	280	27°51’39”	82°36’39’’	15	50	246SW	1.5
3	270	27°51’44”	82°36’44’’	10	60	156NE	2
4	290	27°52’4”	82°35’49’’	18	55	266W	1.5
5	310	27°52’3”	82°35’56’’	5	50	135SE	1
6	270	27°51’44”	82°36’45’’	8	45	172S	1
7	310	27°51’38”	82°36’36’’	5	60	246SW	1
8	270	27°51’48”	82°36’42’’	12	65	124SE	2
9	320	27°52’5”	82°35’59’’	15	58	245E	0.5
10	280	27°51’39”	82°35’39’’	13	65	246SW	2
11	282	27°51’35”	82°36’35’’	9	40	240NE	2.5
12	285	27°51’38”	82°36’38’’	16	58	90E	1.5
13	290	27°51’25”	82°36’11’’	15	45	273W	1.5
14	280	27°51’30”	82°36’31’’	10	55	280W	2
15	285	27°51’39”	82°36’39’’	17	60	245SE	2
16	275	27°51’31”	82°36’33’’	14	65	277W	1.5
17	270	27°51’30”	82°36’35’’	15	45	251W	2
18	290	27°51’30”	82°36’34’’	17	70	289NW	1
19	320	27°51’35”	82°36’40’’	13	65	240NE	0.5

20	300	27°52’4”	82°35’48’’	15	70	250W	1.5
21	270	27°51’32”	82°36’38’’	13	65	301NW	2
22	270	27°52’14”	82°36’3’’	10	75	280NW	1.5
23	300	27°52’4”	82°35’48’’	17	60	258W	1
24	310	27°51’32”	82°36’37’’	15	55	326NW	1
25	300	27°52’12”	82°36’4’’	13	50	345N	1.5
26	290	27°51’31”	82°36’33’’	10	70	277W	0.5
27	280	27°52’2”	82°35’52’’	9	65	275NW	1.5
28	285	27°52’1”	82°35’50’’	15	55	130SE	2
29	280	27°51’49”	82°35’11’’	10	60	270N	1
30	270	27°51’30”	82°36’37’’	15	75	150NE	1.5
31	360	27°52’12”	82°36’4’’	20	30	345N	2.5
32	385	27°52’5”	82°36’2’’	15	35	340N	2
33	385	27°52’8”	82°36’4’’	20	30	330NW	2
34	335	27°52’10”	82°36’3’’	25	40	335NS	1.5
35	380	27°52’14”	82°36’3’’	25	45	303NW	2
36	370	27°52’14”	82°36’2’’	20	50	347N	2.5
37	380	27°52’16	82°36’5’’	15	45	340NE	2.5
38	370	27°52’15”	82°36’1’’	30	35	354N	2.5
39	365	27°52’14”	82°36’9’’	30	35	350N	2
40	370	27°52’18”	82°35’57’’	25	50	325N	1.5
41	365	27°52’15”	82°36’0’’	27	45	328NW	2
42	370	27°52’16”	82°36’1’’	25	35	343N	2.5
43	360	27°52’6”	82°35’59’’	35	40	320NW	2

44	365	27°52’15”	82°35’57’’	30	30	250W	2
45	350	27°52’16”	82°35’59’’	28	25	251W	2.5
46	310	27°52’2”	82°35’55’’	20	35	285E	2.5
47	300	27°52’0”	82°35’53’’	15	40	280NE	2
48	290	27°52’7”	82°35’54’’	25	30	265W	2
49	280	27°52’12”	82°36’4’’	18	34	270SW	2.5
50	285	27°51’25”	82°36’11’’	15	20	275SE	2.5
51	300	27°52’5”	82°35’51’’	22	15	290NW	2.5
52	290	27°52’5”	82°35’58’’	18	25	142SE	2
53	280	27°52’6”	82°35’57’’	22	30	275W	2.5
54	280	27°53’4”	82°36’56’’	15	25	130SE	2
55	310	27°52’3”	82°35’55’’	20	30	125SE	2
56	315	27°52’2”	82°35’52’’	13	35	127SE	2
57	270	27°52’5”	82°35’57’’	18	45	140SE	2.5
58	270	27°52’5”	82°35’58’’	15	35	150SE	2
59	280	27°52’3”	82°35’55’’	20	40	240SW	1.5
60	290	27°52’6”	82°35’47’’	15	45	252W	2

APPENDIX III

Wood density of tree species used to estimate carbon stock using equation Chave *et al*., (2005).

Name of species	**Wood density (g/cm^3)**
Aegle marmelos	0.75
Acacia catechu	0.88
Lagesteroemia parvifolia	0.85
Terminalia bellirica	0.72
Terminalia tomentosa	0.76
Ficus benjamina	0.65
Bombax ceiba	0.36
Buchanania latifolia	0.45
Shorea robusta	0.88
Syzygium cumini	0.77
Madhuca longifolia	0.74
Terminalia chebula	0.96
Dalbergia sissoo	0.78
Mangifera indica	0.59
Ficus racemosa	0.39
Phylanthus emblica	0.67
Mallotus philippenis	0.64
Azadiracta indica	0.69
Semicarpus anacardium	0.64

Source: Sharma and Pukkala (1990); MPFS (1989)

APPENDIX IV

Frequency, Density, Coverage and their relative values of herbs, shrubs and trees in unburnt forest and burnt forest.

Herbs

In unburnt forest

Plants Name	Total no. of individuals in 30 plots	F	RF (%)	D	RD (%)	C	R.C (%)	IVI
Acmella paniculata	10	10.00	1.16	0.33	0.271	1.23	0.75	2.19
Acorus sp.	111	36.67	4.26	3.70	3.011	4.48	2.74	10.02
Ageratum conyzoides	133	30.00	3.49	4.43	3.607	7.65	4.68	11.77
Ageratum houstonianum	46	16.67	1.94	1.53	1.248	2.13	1.30	4.49
Anaphalis sp.	10	6.67	0.78	0.33	0.271	0.87	0.53	1.58
Artimesia vulgaris	7	3.33	0.39	0.23	0.19	0.32	0.19	0.77
Asplenium sp.	95	10.00	1.16	3.17	2.577	3.40	2.08	5.82
Bidens pilosa	58	6.67	0.78	1.93	1.573	1.90	1.16	3.51
Centella asistica	50	16.67	1.94	1.67	1.356	2.73	1.67	4.97
Conyza sp.	4	3.33	0.39	0.13	0.108	0.33	0.20	0.70

Cyanodon dactylon	276	73.33	8.53	9.20	7.486	13.75	8.41	24.42
Cyperus sp.	95	30.00	3.49	3.17	2.577	5.07	3.10	9.17
Desmodium gangeticum	52	36.67	4.26	1.73	1.41	6.82	4.17	9.84
Desmostachya bipinnata	37	16.67	1.94	1.23	1.004	4.00	2.45	5.39
Eragrostis sp.	337	56.67	6.59	11.23	9.14	14.77	9.03	24.76
Euphorbia hitra	6	3.33	0.39	0.20	0.163	0.42	0.25	0.81
Hemidesmus indicus	1	3.33	0.39	0.03	0.027	0.17	0.10	0.52
Hyperthelia dissolute	119	23.33	2.71	3.97	3.228	4.47	2.73	8.67
Hyptis suaveolens	18	13.33	1.55	0.60	0.488	1.40	0.86	2.89
Imperata cylindrical	463	73.33	8.53	15.43	12.56	14.35	8.77	29.86
Labiatae sp.	8	3.33	0.39	0.27	0.217	0.67	0.41	1.01
Lawase	124	40.00	4.65	4.13	3.363	7.21	4.41	12.42
Lygodium sp.	67	26.67	3.10	2.23	1.817	3.15	1.93	6.84
Ocimum sp.	14	6.67	0.78	0.47	0.38	2.17	1.32	2.48
Oxalis sp.	12	6.67	0.78	0.40	0.325	1.33	0.82	1.92
Parthenium sp.	8	6.67	0.78	0.27	0.217	0.90	0.55	1.54
Paspalum sp.	642	83.33	9.69	21.40	17.41	18.03	11.02	38.13
Reinwardtia indica	91	26.67	3.10	3.03	2.468	5.50	3.36	8.93
Rubia sp.	7	6.67	0.78	0.23	0.19	0.50	0.31	1.27
Saccharum spontaneum	133	30.00	3.49	4.43	3.607	6.70	4.10	11.19

Sida sp.	247	80.00	9.30	8.23	6.699	12.43	7.60	23.60
Sonchus sp.	5	10.00	1.16	0.17	0.136	0.53	0.33	1.62
Trifolium latifolium	202	33.33	3.88	6.73	5.479	5.16	3.15	12.51
Urana lobata	190	23.33	2.71	6.33	5.153	8.60	5.26	13.13
Vernonia cinera	9	6.67	0.78	0.30	0.244	0.42	0.25	1.27

In burnt forest

Plants Name	Total no. of individuals in 30 plots	F	RF (%)	D	RD (%)	C	R.C (%)	IVI
Adiantum sp.	7	3.33	0.56	0.23	0.39	1.00	0.74	1.69
Ageratum conyzoides	3	3.33	0.56	0.10	0.17	0.50	0.37	1.10
Conyza sp.	41	10.00	1.69	1.37	2.27	2.92	2.14	6.11
Cynodon dactylon	37	16.67	2.82	1.23	2.05	1.67	1.23	6.10
Cyperus sp.	110	36.67	6.21	3.67	6.09	6.82	5.01	17.31
Desmodium gangeticum	123	43.33	7.34	4.10	6.81	8.15	5.99	20.14
Digitaria sanguinalis	174	50.00	8.47	5.80	9.63	10.83	7.96	26.07
Eragrostis sp.	11	6.67	1.13	0.37	0.61	0.80	0.59	2.33
Eulaliopsis binate	426	93.33	15.82	14.20	23.58	38.76	28.49	67.88

Flemingia sp.	19	16.67	2.82	0.63	1.05	1.73	1.27	5.15
Galinsoga sp.	7	6.67	1.13	0.23	0.39	0.80	0.59	2.11
Hyparrhenia hirta	257	76.67	12.99	8.57	14.22	17.23	12.66	39.88
Hyperthelia dissolute	14	13.33	2.26	0.47	0.77	1.43	1.05	4.09
Imperata cylindrical	267	80.00	13.56	8.90	14.78	16.53	12.15	40.49
Lygodium sp.	11	6.67	1.13	0.37	0.61	0.93	0.69	2.42
Paspalum sp.	9	6.67	1.13	0.30	0.50	0.97	0.71	2.34
Potentilla sp.	8	6.67	1.13	0.27	0.44	1.17	0.86	2.43
Saccharum spontaneum	160	56.67	9.60	5.33	8.85	11.95	8.78	27.24
Setaria glauca	58	30.00	5.08	1.93	3.21	6.73	4.95	13.24
Sida sp.	11	13.33	2.26	0.37	0.61	1.30	0.96	3.82
Solanum incanum	4	3.33	0.56	0.13	0.22	0.42	0.31	1.09
Urana lobata	50	10.00	1.69	1.67	2.77	3.40	2.50	6.96

Shrubs

In unburnt forest

Name of plants	**Total no. of individuals in 30 plots**	**F**	**RF (%)**	**D**	**RD (%)**	**C**	**RC (%)**	**IVI**
Berberis aristata	177	70.00	17.36	147.50	21.69	19.67	23.13	62.17
Smilax sp.	6	6.67	1.65	5.00	0.74	0.57	0.67	3.05
Cycas pectinata	142	93.33	23.14	118.33	17.40	20.87	24.54	65.08
Colebrookea oppositifolia	26	26.67	6.61	21.67	3.19	4.20	4.94	14.74
Woodfordia fruticosa	14	10.00	2.48	11.67	1.72	2.00	2.35	6.55
Zizyphus jujuba	14	16.67	4.13	11.67	1.72	2.83	3.33	9.18
Ficus nerifolia	38	23.33	5.79	31.67	4.66	4.10	4.82	15.26
Clerodendrum sp.	11	3.33	0.83	9.17	1.35	0.83	0.98	3.15
Fraxinus sp.	5	6.67	1.65	4.17	0.61	1.00	1.18	3.44
Bauhinia sp.	4	3.33	0.83	3.33	0.49	1.00	1.18	2.49
Thysanolaena latifolia	5	3.33	0.83	4.17	0.61	0.33	0.39	1.83
Lantana camara	128	56.67	14.05	106.67	15.69	11.90	13.99	43.73
Senna occidentali	3	3.33	0.83	2.50	0.37	0.43	0.51	1.70
Jasmine sp.	243	80.00	19.83	202.50	29.78	15.30	17.99	67.61

In burnt forest

Name of plants	**Total no. of individuals in 30 piots**	**F**	**RF (%)**	**D**	**RD (%)**	**C**	**RC (%)**	**IVI**
Asparagus racemosa	12	6.67	1.85	10.00	2.37	1.33	1.54	5.77
Bauhinia sp.	2	3.33	0.93	1.67	0.40	0.40	0.46	1.78
Berberis aristata	134	90.00	25.00	111.67	26.48	25.73	29.77	81.25
Clerodendron sp.	5	3.33	0.93	4.17	0.99	0.67	0.77	2.69
Colebrookea oppositifolia	5	6.67	1.85	4.17	0.99	1.17	1.35	4.19
Cycas pectinata	44	33.33	9.26	36.67	8.70	9.67	11.18	29.14
Dioscorea deltoidea	12	10.00	2.78	10.00	2.37	1.00	1.16	6.31
Ficus nerifolia	57	26.67	7.41	47.50	11.26	6.50	7.52	26.19
Fraxinus sp.	3	3.33	0.93	2.50	0.59	0.33	0.39	1.90
Lantana camara	10	3.33	0.93	8.33	1.98	2.23	2.58	5.49
Nundheky	3	3.33	0.93	2.50	0.59	0.50	0.58	2.10
Nyctanthes arbor-tristis	12	16.67	4.63	10.00	2.37	2.73	3.16	10.16
Phyllanthus sp.	15	13.33	3.70	12.50	2.96	2.00	2.31	8.98
Randia	5	6.67	1.85	4.17	0.99	1.50	1.74	4.58
Woodfordia fruticosa	111	76.67	21.30	92.50	21.94	17.80	20.59	63.83
Zizyphus jujuba	76	56.67	15.74	63.33	15.02	12.87	14.89	45.65

Trees

In unburnt forest

Name of plants	Total no. of individuals in 30 plots	F	RF (%)	D	RD (%)	C	RC (%)	IVI
Acacia catechu	198	93.33	19.58	2640.00	29.51	22.97	24.62	73.71
Aegle marmelos	2	6.67	1.40	26.67	0.30	0.27	0.29	1.98
Bombax ceiba	26	40.00	8.39	346.67	3.87	4.80	5.15	17.41
Buchanania latifolia	1	3.33	0.70	13.33	0.15	0.13	0.14	0.99
Dalbergia sissoo	48	40.00	8.39	640.00	7.15	7.20	7.72	23.26
Ficus benjamina	1	3.33	0.70	13.33	0.15	0.17	0.18	1.03
Ficus racemosa	2	6.67	1.40	26.67	0.30	0.23	0.25	1.95
Lagerstroemia parvifolia	121	80.00	16.78	1613.33	18.03	16.40	17.58	52.40
Madhuca longifolia	1	3.33	0.70	13.33	0.15	0.27	0.29	1.13
Mallotus philippenis	2	3.33	0.70	26.67	0.30	0.27	0.29	1.28
Mangifera indica	8	13.33	2.80	106.67	1.19	1.37	1.47	5.45
Phylanthus emblica	2	3.33	0.70	26.67	0.30	0.27	0.29	1.28
Shorea robusta	143	66.67	13.99	1906.67	21.31	19.97	21.41	56.71
Syzygium cumini	2	3.33	0.70	26.67	0.30	0.27	0.29	1.28
Terminalia bellirica	38	43.33	9.09	506.67	5.66	6.00	6.43	21.19
Terminalia chebula	5	6.67	1.40	66.67	0.75	0.80	0.86	3.00
Terminalia tomentosa	71	60.00	12.59	946.67	10.58	11.90	12.76	35.93

In burnt forest

Name of plants	Total no. of individuals in 30 plots	F	RF (%)	D	RD (%)	C	RC (%)	IVI
Acacia catechu	220	86.67	33.77	2933.33	52.63	27.37	48.32	134.72
Azadiracta indica	4	10.00	3.90	53.33	0.96	0.57	1.00	5.85
Buchanania latifolia	4	10.00	3.90	53.33	0.96	0.73	1.29	6.15
Dalbergia sissoo	46	40.00	15.58	613.33	11.00	5.47	9.65	36.24
Lagerstroemia parvifolia	30	46.67	18.18	400.00	7.18	4.00	7.06	32.42
Semicarpus anacardium	4	10.00	3.90	53.33	0.96	0.33	0.59	5.44
Seto tilka	1	3.33	1.30	13.33	0.24	0.27	0.47	2.01
Shorea robusta	92	33.33	12.99	1226.67	22.01	15.43	27.25	62.25
Terminalia bellirica	4	3.33	1.30	53.33	0.96	0.97	1.71	3.96
Terminalia tomentosa	13	13.33	5.19	173.33	3.11	1.50	2.65	10.95

APPENDIX V: Species wise above ground and below ground carbon stock in unburnt and burnt forests.

Trees species	**Above- ground carbon stock (t/ha)of UBF**	**Below-ground carbon stock(t/ha) of UBF**	**Above- ground carbon stock (t/ha) of BF**	**Below-ground carbon stock(t/ha) of BF**
Aegle marmelos	0.113	0.023	-	-
Acacia catechu	12.807	2.561	5.333	1.067
Azadiracta indica	-	-	0.041	0.008
Bombax ceiba	6.097	1.219	-	-
Buchanania latifolia	0.008	0.002	0.025	0.005
Dalbergia sissoo	6.748	1.350	1.550	0.310
Ficus benjamina	0.454	0.091	-	-
Ficus racemose	0.258	0.052	-	-
Lagesteroemia parvifolia	12.459	2.492	1.210	0.242

Madhuca longifolia	2.536	0.507	-	-
Mallotus philippenis	0.030	0.006	-	-
Mangifera indica	1.372	0.274	-	-
Phylanthus emblica	0.048	0.010	-	-
Semicarpus anacardium	-	-	0.041	0.008
Shorea robusta	33.978	6.796	9.606	1.921
Syzygium cumini	0.112	0.022	-	-
Terminalia bellirica	4.631	0.926	0.324	0.065
Terminalia chebula	1.083	0.217	-	-
Terminalia tomentosa	20.342	4.068	1.100	0.220
Unknown-1	-	-	0.050	0.007
Total	**103.075**	**20.615**	**19.280**	**3.853**

APPENDIX VI

PHOTO PLATES

Photos of Bakena community (unburnt) forest

Photos of Sundabri community (burnt) forest