

**FIRE IMPACTS ON VEGETATION AND SOIL IN A FOREST
ECOSYSTEM IN WADAKKANCHERRY FOREST RANGE,
THRISSUR FOREST DIVISION, KERALA**

BY

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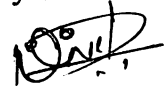
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DECLARATION

I, hereby declare that the thesis entitled “**Fire impacts on vegetation and soil in a forest ecosystem in Wadakkancherry forest range, Thrissur Forest Division, Kerala**” is a bonafide record of research done by me during the course of research and that this thesis has not previously formed the basis for award of any degree, diploma, fellowship or similar title, of any other University or Society.

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Dedicated to

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**All the brave fire fighters who lost their lives
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I. INTRODUCTION

Natural disturbances like fire, wind, flood, drought, have their roles over millennia in shaping the ecosystems and organisms within the biosphere. The ecologists recognized long back the influence of these disturbances in determining the structure and function of ecosystems (Coyle, 2017). Forest fire an extrinsic disturbance factor whether deliberately set or not, has been exploited by farmers and forest dwellers for their own benefits like agriculture, collection of non-wood products and cattle feed etc. (Bond and Keeley, 2005). Fire is being used as a tool in forest management and protection in several parts of the world. Fire not only helps in the distribution of fire prone communities but also aid them in maintaining their structure and function in forest ecosystems. Fire becomes catastrophic when it occurs in combination with any of the following viz. hoof, axe, plough and climate change. All these factors magnify the effects of forest fire as they can alter the timing, intensity and fuel (Chaturvedi, 1999).

The forests around the world are progressively facing more strenuous fire weather conditions, extended fire seasons and large fire events which are influenced by the climate change. This will have its effects on biodiversity, ecosystem services, human well-being, livelihoods and national economies.

Due to the exposure to smoke arising from the landscape fires including forest fires, an annual premature death toll of 2.6 lakhs to 6 lakhs human and wildlife was reported from all over the world. The estimated emission from forest fires was in the range of 2.5 billion to 4.0 billion tons, which added large and increased volume of greenhouse gases to atmosphere (IPCC, 2014).

Global Forest Resource Assessment reported that, 4% of the total tropical forest domain was fire affected out of 98 million hectares of forest area burnt in the year 2015 all over the globe. (FAO, 2020). 35.46% of India's forest cover is susceptible to forest fires. Out of this, 2.81% of forest cover falls under extremely

fire prone category while 7.85% in very highly prone and 11.51% is classified under highly prone (ISFR, 2021). Over the past few years, state of Kerala has been witnessing a decrease in the number of forest fires. Kerala State Forest Department records show that the number dropped to 330 incidents (1,279ha) from 737 reports in 2016-2017 which affected 2,994 ha. The state observed 184 fire incidents in 2019-2020 which affected 375.3 hectares of forest. According to Dhanya *et al.*, (2019), the projected rise in temperature by the end of the 21st century in Kerala will be in the range of 2.1-2.6°C. An increment higher than this can be expected in Kollam, Pathanamthitta, Idukki, Palakkad, Malappuram and Wyanad districts. The thickly forested areas in Kerala like Periyar Tiger Reserve, Silent Valley and forested Areas of Wyanad are predicted to experience severe warming of 2.7°C during the daytime in future. This increased heat will facilitate the conditions for more fire to occur. The uncertainties attached to the climate change projections include the impacts on species distribution, frequency of extreme climate events, outbreaks of more insects, pests and diseases, forest productivity and community livelihood.

A prescribed fire is a type of controlled burning of naturally amassed forest floor or slash, practiced when the forest soil is moderately moist. This is practiced to reduce the level of fuel in the stand which is intended to reduce the severity of an anticipated wild fire. This will also facilitate the germination of certain desired tree species. (Walstad *et al.*, 1990). A forest fire is a wildfire when it becomes out of control. This occurs when there exist a plenty of dry fuel load in the stand and facilitating environmental conditions and topography. Rab (1996) reported that since the spatial distribution of fire severity is heterogeneous in nature even in the case of a prescribed fire, the impact created on various patches by a wildfire will be highly variable.

Fire as a significant ecological event can produce variable effects on forest ecosystems (Keane *et al.*, 2002). It can affect the succession by selecting and regenerating plants, recycling nutrients, maintaining diversity, decreasing biomass,

controlling insects triggering and regulating plant and animal interactions. Along with these, fire also influence the biological and biogeochemical processes associated with the forest ecosystems (Verma and Jayakumar, 2018). The extent and duration of the effects created by fire, will primarily depend upon the fire severity. It is controlled by various environmental factors that facilitates the combustion process. These include amount, nature and moisture of live and dead fuel existing in the stand, temperature of air, humidity, wind speed and topography of the site etc. (Campbell *et al.*, 1994).

Cochrane (2003) pointed out that the fire sensitive ecosystems like tropical rain forests which are converted for agricultural land uses will face catastrophic results later and even transition to different ecosystems can happen. Ecosystems like grasslands, savannah and temperate coniferous forests are adapted to the recurring low intensity surface fires (Coyle, 2017).

Most of the physical, chemical, mineralogical and biological soil properties are affected by the forest fires. The climate and topography of the fire affected area can influence the resilience of the soil system. The changes induced by fire can be temporary or permanent. A notable removal of organic matter, variations in structure and porosity, loss of nutrients due to volatilisation, entrapment of ash in smoke columns are some of the after effects of fire on soil. The recovery of vegetation in the fire affected area can take most of the altered soil properties to pre- fire level. Fire will have long term impacts on soil properties like water holding capacity and bulk density. Another remarkable effect of forest fire on soil is soil erosion. After the fire has happened, the hydrophobicity of soil is increased and this will make the soil system less able to soak up with water (Certini, 2005).

The vegetation are often affected by independent or combined effects of fire related cues. Heat and smoke are the immediate and obvious cues. Stem tissues of seedlings and saplings are directly killed by the forest fires. The soil will be sufficiently heated so as to kill seeds and roots near the soil surface (Kennard *et al.*, 2002). The fire disturbance can influence relative abundance of species that are

able to asexually reproduce, cause shift in the composition of species (Hoffmann, 1998). Various facets of plant growth and development like flowering, seed dispersal, germination, seedling establishment, plant mortality and biomass production are affected by the fire (Walters *et al.*, 2004).

The effects of forest fire on soil macro invertebrates are less studied on contrary to soil and plants. The motility of these organisms in response to fire generally vary according to the size of their body. As a thumb rule, mobility increases with size. Interestingly, within the similar sized animals the ability to burrow through soil differ greatly (Certini, 2005). Quick colonisation by fire-favoured species, instant mortality and habitat alteration followed by fire will determine the changes in the abundance and species composition of soil dwelling macro- invertebrates. The fire intensity and fire duration affects the patterns of survival, colonisation and recovery (Wikars and Schimmel, 2001).

Only a handful of studies are available related to the present study especially in tropics and particularly to India. The changes happening over a time to the soil, vegetation and animals associated with fire affected forest ecosystem are not attended with serious concern. Soil has a big role in determining the composition of upcoming plant community after fire. The vegetation can influence soil in bringing the physico-chemical properties back to their pre-fire level. Macro-invertebrates like earthworm and ants can alter the soil properties. The cumulative effects of these factors and their interactions are hardly recorded and put under research. These combined with the effects of climate change will make understanding on post fire forest ecosystems more complex. More studies in this perspective should be undertaken regularly in the forthcoming days as fire can have long term impacts on forest ecosystems.

The present study attempted to record the changes happening in a fire affected forest ecosystem over a period of six months. This study intended to understand the complex switchovers expected in the soil, vegetation and macro-fauna after a fire which is highly variable in the tropical forests. Understanding the

effects and changes incurred over time will help the forest managers to recommend suitable management practices to be followed in a fire affected forest ecosystems. The data generated from this study will be of benchmark value for the forest department as well as forest ecologists and can later be used to monitor the changes in both vegetation and soil, especially in the context of a changing climate. For researchers, data generated will be useful for comparisons with those obtained from comparable ecosystems and to deduce trends.

The objectives of this study were;

1. To assess the impacts of the forest fire on the vegetation and soil physicochemical and biological properties in the fire burnt areas of Poongode Section of Wadakkancherry Forest Range of Thrissur Forest Division.
2. To compare and contrast the changes in the vegetation and soil between burnt and control areas over a time series.

II. REVIEW OF LITERATURE

The relevant literature on the study entitled “Fire impacts on vegetation and soil in a forest ecosystem in Wadakkanchery forest range in Thrissur Forest Division, Kerala” is briefly reviewed here.

2.1 FOREST FIRE

Forest fire is a common hazard to the forest from ancient history. The FAO (Food and Agriculture Organization) defined ‘fire hazard’ as the chances of initiating a fire due to the presence and activity of active causal agents. The heat, oxygen and fuel are the three important elements for a fire to occur. The forests become littered during summer with dry senescent leaves and twinges. This added fuel in the forest floor with a slightest spark can easily burst out into flames. The wildlands including forest areas are reported to be progressively facing strenuous fire weather conditions, extended fire seasons, large fire events influenced by the climate change resulting in huge losses in terms of loss of biodiversity, human well-being, ecosystem services, national economies and lively hoods. Around 98 million ha of forest area all over the world was affected by forest fire in 2015 alone, which comprises 3% of global forest expanse. The loss of tropical forest domain in the same year according to this report was 4%. (FAO, 2020).

The Inter- Governmental Panel on Climate change on its fifth report has reported an estimated count ranging from 2,60,000 to 6,00,000 untimely deaths of human /wildlife annually around the world. The exposure to smoke from the landscape fires including forest fires are behind these large premature death toll. The annual carbon emissions between 2.5 billion – 4.0 billion tonnes of CO₂ from these large fires can add large volumes of greenhouse gases to the atmosphere (IPPC Report 5). Carbon dioxide, carbon monoxide, methane, hydrocarbons, nitric oxide, nitrous oxide, methyl bromide are the other gases emitted in large quantities by burning of vegetation. This can lead to global warming and depletion of ozone layer. It is observed that the emissions can be transported over hundreds of

kilometres, notably in the case of very intense fires. Ozone is produced typically from its precursors during the transport and the levels of ozone are significantly elevated due to forest fires (Jaffe and Wigder, 2012). Similarly, climate change can also have its impacts on the occurrence of forest fire. It can affect the number of fires that occurs annually, intensity of fire, duration of the fire season and the area affected by the fire. Changes in these properties of fire due to climate change will make the prediction of potential of future fires difficult (IPCC, 2007).

Forest fires are there since the inception of human civilization which implies that both the human and ecosystems have been continuously responding to the perturbations caused by the disaster. It is observed that the fire is not bad for speciation but the rapid rise in the frequency and intensity of fires of various origin have exceeded our potential to adapt to its impacts. In the meanwhile, the impacts of climate change magnify the impacts of fire especially in combination with global warming which reduce significantly the soil moisture content. According to Chaturvedi (1999), fire alone has seldom destroyed a landscape completely. Fire and axe, fire and hoof, fire and plough, fire and sword altogether magnify the impacts of fire. It can have long lasting effects on the structure and species composition of the post fire communities and their capacity to adapt to the future disturbances (Ryan, 2002).

2.1.1. Causes of forest fire

Forest fires can be caused by both natural and anthropogenic factors. Natural causes include lightning, friction between the stems of trees, rolling of stones etc. Dry bamboos, low humidity and high temperature facilitates the conditions for a fire to commence. The intentional or accidental fires from a source of fire like discarded cigarettes, electric spark, engine sparks, naked flame, fire play match sticks, rail roads, electric power lines, unattended camp fires, sparks from chainsaws or any man-made causes of ignitions which comes into contact with the combustible materials within the forest can lead to huge wild fires. Besides this, it

is impossible to ignore the role of climate change in facilitating wildfires. Studies are suggesting that gradual disappearance of fire seasons can be expected due to the prolonged dry periods in some places.

The leading causes for a wildfire to occur vary between places. Land conversion for agriculture and poor forest management along with the persistent hotter and drier weather are the major drivers behind the increased forest fire events. Around 75% of the wild fire over the globe reported in the year 2020 was due to anthropogenic reasons (WWF, 2020). The intentionally made fires by the people residing adjacent to the forest area to induce growth of grass and to collect non- timber forest products from the forest floor are very common. Such fires mostly end up uncontrollable (Saigal, 1989).

2.1.2. Types of forest fires

There are three types of forest fire generally viz. surface fire, ground fire and crown fire. Surface fire is the common type of fire seen in India. It is a quick moving fire, which eats up the small vegetation, surface litter and loose debris. The ground fire is another kind of fire which is not easily predictable as it spreads beneath the surface. It burns up organic matter like duff, musk or peat beneath the surface litter of the forest floor. It is distinct from other types of fires as it has a smouldering edge which seldom having flame and smoke. These are very hard to tackle due to these features. Crown fire is the fastest spreading fire and is highly destructive to trees and wildlife, rarely observed in India. It advances from top to top of trees or shrubs without any link with the surface fire. (Saigal, 1989).

2.1.3. Forest fire and water

Forest fires can cause a cascade of eco-hydrologic effects like impacts on hydrology, variations linked with the geochemical exports and consequent changes to the stream ecology. (Silins, *et al.*, 2014) Nutrient input on forest water hikes after a fire. This will have its effects on water quality. Phosphorous plays a vital

role in the regulation of primary productivity in the lotic ecosystems and to the biogeochemical cycles of other major elements (Kelly *et al.*, 2006). The elevated phosphorous level and greater light availability in the post fire conditions will boost the algal production in the water. This will in turn affects the relative abundance of macroinvertebrates in the forest water (Spence *et al.*, 2003) The forest water once come out will have its impacts on human water uses. The expected increase in the fire severity, extended fire seasons in the forthcoming days will worsen the conditions. (Silins *et al.*, 2014)

2.1.4. Forest fire and climate change

The uncertainties attached to the climate change projections include the impacts on species distribution, frequency of extreme climate events, outbreaks of more insects, pests and diseases, forest productivity and community livelihood. Burning of forests will contribute more CO₂ to the atmosphere which in turn contributes to global warming and climate change. The smoke consisting noxious gases formed as a result of forest fire will later move to human inhabiting areas and may cause respiratory problems. Fire regimes are altered in a global scale by the climate change. The reported increase of CO₂ in the atmosphere before 8000 years ago was mainly driven by the burning of forest land to promote agriculture. (Ruddiman, 2003). Different kinds of forests response to fire in different form. For instance, tropical forests, boreal forests and tropical peatlands will be more dried while the drylands will experience less fire subsequently as the vegetation in the area decreases (Donohue *et al.*, 2013). Climate change makes the predictability of forest fire harder. The effects of climate change like insect outbreaks, spread of invasive flammable species will alter the fire dynamics (Westerling *et al.*, 2011).

2.1.5. Forest fire in India

Forest fires are becoming a major cause of forest degradation in India, especially in the states like Odisha, Chhattisgarh and Madhya Pradesh that are having more dry deciduous forested regions. This is due to the abundant fuel content available combined with low soil moisture conditions prevailing (Chandra and Bhardwaj, 2015).

Forest fire season is generally referred to the period between a winter season and monsoon. India reported 345,989 forest fires from November 2020 to June 2021 which is the highest ever count recorded yet in this period. This is about 2.7 times more than the fire incidents reported during the same period in 2019-2020. During this period, several severe fire incidences were reported from dry deciduous forest patches over the country while the semi- evergreen, evergreen and montane temperate forests were less prone to the forest fire. 35.46% of the country's forest area has been reported to be prone to frequent forest fires. Nearly 10.6% of the country's forest cover is under extremely to very highly fire prone zone. The report also observed that the state of Uttarakhand has reported an increase of 28.3% fire incidents compared to the previous year. The report also suggested that the cause of this increase can be attributed to the impacts of climate change (ISFR, 2021).

Majority of the forest fires in India are reported to be set out purposefully by landless rural people and small scale farmers. The practice of slash and burning shifting cultivation in the North Eastern states including Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura are one of the leading cause of destruction of forest. An estimated forest area of 4.35 million ha was affected by the shifting cultivation practices. With the increase in population the land per person ratio has come down. The fallow phase which was 30 years before is forced to limited to 2 years in many places. It is interesting to see that although 12.5 million hectares of land is classified officially as grazing land or permanent pasture, the lion's share of this area is devoid of grass. This is one of the major reason why the forest areas are being set fire to get new flush of grasses to

meet the requirement in the dry season. Another important reason for the forest fire in the central India is associated with the extraction of tendu leaves, leaves of *Diospyros melanoxylon* which is used to make Bidi, a kind of cigarette. Collection and sale of these leaves is a source of secondary income for tribal dominated area. They set fire to get new flush of leaves. These problems of tendu extracting areas are least addressed as these areas are leased out for the collection of leaves on an annual basis. Practices for collection of mahua flower (*Madhuca indica*), another important non-wood forest product from the northern part of central India often leads to forest fire. These are collected by the local people in this region. This is an important ingredient of a popular beverage. It is else boiled with the seeds of *Shorea robusta* as a seasonal grain substitute. The mahua flower pickers in order to facilitate the collection set fire to small patch around a single tree. This is intended to clean a small area of ground around. The unattended fires during peak collection period, the summer will aggravate the situation and compound the effects. (Chandra and Bhardwaj, 2015).

The Himalayas, youngest and largest folding mountain ranges of the world are the most vulnerable stretches in the world to forest fire. The forests in the Western Himalayas are more prone to the forest fire than the forests in the Eastern Himalayas. The frequency and intensity of the fire events are more in the Western Himalayas. This low susceptibility of Eastern Himalayas can be attributed to the high rain density area it belongs to. But the frequency and intensity of the forest fires has increased overall in Himalayas due to the large scale expansion of Pine forests. According to Bhandari *et al.*, (2000), the pH of the soils burnt in the Himalayan regions was recorded higher value than the unburnt soil. He also concluded that even though the levels of organic carbon and nitrogen falls after fire, gradual recovery of these chemicals can be expected in course of time. In this study conducted in the Pine forest stands of Himalaya, the herbaceous diversity values of the stand seemed increased and it was due to the opening up of the canopy after fire.

2.1.6. Forest fire in Kerala

Majority of state's forest cover falls under less fire prone areas (91.61%) while only 0.26% of forest cover falls under very highly fire prone zones. It is noticeable that no forest area in Kerala belongs to extremely fire prone zone (ISFR, 2021). Over the past few years, Kerala has been witnessing a decrease in the number of forest fires. Kerala State Forest Department records show that the number dropped to 330 incidents (1,279 ha) from 737 reports in 2016-2017 which affected 2,994 ha. The state observed 184 fire incidents in 2019-2020 which affected 375.3 hectares of forest. This reduction was attributed to the adequate summer showers and preventive measures taken by the forest officials. Setting up of fires by culprits involved in forest offences in vengeance against department are quiet common in the state. Most of the forest areas in the state are in proximity to human inhabitations which increases the fire threat. A fire happening in such areas will consequently results in increased reports of human wildlife interactions. Collection of non- wood forest products like honey, black dammar, increased fire incidences due to the eucalyptus plantations raised by the forest department and farmers in the past as part of the social forestry are some of the identified reasons for the fire incidences in the state.

According to a study conducted by Dhanya *et al.* (2019), the monthly mean climatological data when compared with reference to the baseline (1971-2000) simulations, the projected rise in temperature by the end of the 21st century in Kerala will be in the range of 2.1-2.6°C. An increment higher than this can be expected in the districts including Kollam, Pathanamthitta, Idukki, Palakkad, Malappuram and Wyanad districts. The thickly forested areas in Kerala like Periyar Tiger Reserve, Silent Valley National Park and forested areas of Wyanad district are predicted to experience severe warming of 2.7°C during the daytime in future. This increased heat will facilitate the conditions for fire to occur. The uncertainties attached to the climate change projections include the impacts on species distribution, frequency of extreme climate events, forest productivity, community

livelihood and outbreaks of more insects, pests and diseases, and. All these are to be understood in a better way and act accordingly in a state like Kerala to counter the ill effects of climate change.

2.1. EFFECTS OF FOREST FIRE ON SOIL PHYSICOCHEMICAL PROPERTIES

Fire has been shown to affect the physical, chemical and biological properties of soils. These include the soil moisture, bulk density, water holding capacity, soil texture, soil pH, soil electrical conductivity, organic carbon, total nitrogen, total phosphorous, total potassium etc. In a study conducted by Sandeep *et al.*, (2019) at the montane grasslands of Eravikulam national park in Kerala, it was found that major changes in the soil was taking place between 70°C and 110°C, 250°C and 320°C as well as 430°C and 500°C. The peak temperature recorded as a result of fire was 800°C with a mean temperature of 450–600°C. The temperatures above 600°C provide enough energy to alter kaolin to a mixture of independent amorphous alumina and amorphous silica or metakaolins.

2.2.1. Effects of forest fire on soil physical properties

2.2.1.1. Bulk density and soil moisture

Bulk density is the mass of dry soil per unit bulk volume of soil. It is expressed in g/cm^3 and is closely related to porosity, which is the volume of pores in a soil sample divided by the bulk volume of the sample. As a result of forest fire, the bulk density of forest soils increase significantly. This increment is because of collapse of aggregates and clogging of voids by the ash formed and dispersed clay minerals and consequently, soil porosity and permeability decreases (Certini, 2005). A similar study conducted by Kamble (2021) in the Gadchiroli forest circle in central India, observed an increase in bulk density in all the sampling locations after a fire. This may be due to the heating up of entrapped air in the soil particles.

This will release to atmosphere when the density decreases. This results in a reduction in space between soil particles consequently the bulk density will be increased. With decreasing soil moisture bulk density was found increasing in a study conducted by Xue *et al.*, (2014) The study recorded the change in soil moisture in the forest areas of Giangdong province in South China. They compared the soil moisture of the fire affected areas in the 0, one, four and seventh year of incidence. The study found out that a significant decrease in the soil moisture was found out only in the end of first year (9%).

2.2.1.2. Water Holding Capacity

Water holding capacity can have long term effects on soil properties. In a study conducted by Kamble (2021) in various parts of central India, it is evident that the water holding capacity had reduced post fire in majority of the study sites. The study identified that the minimum water holding capacity before the forest fire was 22.68% while the maximum was 37.32%. The average water holding capacity was found to be 29.87%. The former values came down to 21.58%, 34.63% and the average value was found to be 29.91% and this average value seems comparable.

In a study conducted by Verma (2019), in the fire affected tropical dry deciduous forests of Western Ghats, water holding capacity was founded to be lower initially. The study pointed out that the water holding capacity of top layers of the fire affected soil was lower than the control plots. Going down to the layers beneath, there was no significant difference between the fire affected plots and control plots. The water holding capacity displayed a decreasing trend post fire. This property of the soil is one among the most affected after a fire has happened. The combustion can destroy the storage capacity of water in the organic horizons to several centimetres.

2.2.1.3. Soil texture

The soil texture is not usually affected by the fire unless they are subjected to very high temperatures at the A horizon. The textural fractions are having high temperature thresholds, among them the most sensitive textural fraction is clay, which begins changing only if the soil temperatures rise above 400°C. At this temperature the clay hydration and clay lattice structure begin to subside. At temperatures of 700°C to 800°C the complete destruction of internal clay structure can occur (Neary *et al.*, 2005).

According to a study conducted by Ulery and Graham (1993) in five fire affected sites within California the fire reddened soil layers had notably less content of clay than the unburned soil. A greater proportion of sand may be observed due to formation of sand sized aggregates formed in the surface soils during the burning which eventually alter the particle size distribution. Due to this, the texture of the soil can be coarser. In the same study itself, burning increased silt fraction in one of the site by the decomposition of kaolinized sand grains. This resulted in producing finer texture soil.

2.2.2 Effect of forest fire on soil chemical properties

2.2.2.1. Soil pH

According to a study conducted by Tufekcioglu *et al.* (2010), the soil pH between the burned and control sites showed significant difference between them. The burned sites were showing more pH compared to the control plots. High severity fires increase soil pH because of organic acid denaturation and the increase of sodium and potassium oxides, carbonates and hydroxides. With increasing temperature up to 200 °C, Terefe *et al.* (2008) suggested that pH decrease in the beginning but started increasing when the temperature rise to 500 °C. These results may be the consequences of the collective effects of desiccation and heating that positively influence the proton-reducing oxidation reactions (Sertsu and Sánchez 1978).

According to Ubeda *et al.* (2005), the pH returned to pre-fire values just after one year after the fire had happened. This increment is generally due to the combustion of organic matter and production of ash. Burns are expected to cause removal of un-dissociated organic acids present in the litter and soil by combustion. Along with this, the leaching of alkaline metals from the ash into the soil complexes and the related consumption of hydrogen ions in the formation of water could result in a rise in pH after the fire (Granged *et al.*, 2011).

2.2.2.2. Soil electrical conductivity

The combustion of soil organic matter may release soluble salts. This can increase the soil electrical conductivity significantly (Vasquez *et al.*, 1993). The consequences of fire events like destruction of clay minerals, creation of oxides and formation of coarse particles of fire may also decrease the soil electrical conductivity (EC). Since the salts are rapidly leached out and transported by runoff, in all cases, the variations observed in soil electrical conductivity is short lived (Terefe *et al.*, 2008).

Kamble (2021), found in his study in various fire affected areas along the forest areas of Central India, the average soil electrical conductivity fell after the fire. 43.8 $\mu\text{S}/\text{cm}$ was the average soil electrical conductivity before the fire. It reduced to 36.6 $\mu\text{S}/\text{cm}$ after the fire. The values of standard deviation before controlled forest fires were closer than the values after the forest fire. In this particular study the reason assigned for this is was the decrease in many of the extractable soil nutrients

2.2.2.3. Soil organic carbon

The effect of fire on SOM is highly dependent on the type and intensity of the fire, along with soil moisture, soil type, and nature of the burned materials. Therefore, the effect on soil processes and their intensity influenced by fire are highly variable and no generalized tendencies can be suggested. The effects of fire

on soil organic matter can range from slight volatilization of minor components, charring to even complete oxidation, which ultimately depends on fire severity. Considerable consumption of organic matter starts in the 200–250°C range and will complete around 460°C (Giovannini *et al.* 1988).

Generally, the soil organic matter in the fire affected areas are recovered in a quick pace, which is possible either by the natural or artificial introduction of vegetation. This quickness is generally attributed to the high net primary productivity of the secondary succession. According to a study conducted by Johnson and Curtis (2001), there exist a long term positive effect of forest fires on the content of carbon. They studied the observations from 48 different fire affected areas statistically. As a result of statistical analysis of data, they could found out that a significant average increase in carbon of 8% was there in the 'A' horizon of fire affected areas than there 10 years before. They suggested that the above increment may be due to the integration of unburnt residues in the mineral soil which eventually protected them from easy biochemical decomposition or due to the conversion of fresh organic matter into more recalcitrant form.

2.2.2.4. Total Nitrogen

Most studies conclude that the total nitrogen reduces after a fire event while the amount of plant available forms of nitrogen increases, not every time in line with this statement. This decrease in nitrogen is due to volatilization. The effect of fire on other nutrients are less. This high availability of nutrients will lead to the surge of nitrogen in the soil which is followed by the rapid up come of herbaceous plants and remarkable rise in the storage of nitrogen in plants (Kutiel and Naveh, 1987). A fraction of organic nitrogen mineralises to form ammonium which is a form absorbable by biota. Ammonium adsorb on to the negatively charged mineral and organic surfaces but in due course of time, this will biochemically transformed to nitrate. Nitrate will be leached out soon if it is not taken up by the plants. For these reasons the availability of nitrogen seems to be lower than the pre-fire levels.

(Certini, 2005). Verma *et al.* (2019), in his study stated that the nitrogen levels after two years of the fire event was lower than the control area. But a recovery from the fifth year was observed. Also in case of available nitrogen, this had not happened. In 2 year old burnt patch, the levels of available nitrogen appeared higher than in the 15 year old fire affected patch. They concluded that the variations in bottom layer were similar to the top layer while the middle layer was not significantly different from unburned

2.2.2.5. Total Phosphorous

The removal of organic phosphorous through volatilization unlike nitrogen is minimum. This is because the organic phosphorous mineralises to orthophosphate. This is not leached out of soil but if not taken up promptly, it precipitates as moderately available mineral form later. (Certini, 2005). According to Verma *et al.* (2019), phosphorus recorded in the top layer of soil in the control area was $1.51 \pm 0.32 \mu\text{g/gm}$, in two year old fire affected area is $0.87 \pm 0.05 \mu\text{g/gm}$ and it is $1.78 \pm 0.20 \mu\text{g/gm}$ in fifteen year old fire burnt area, which shows a clear increase gradually. In both the middle layer and bottom layer available phosphorus was lower in two year old fire affected area. A recovery can be seen in fifteenth year of fire incidence.

2.2.2.6. Total Potassium

In a study conducted by Verma *et al.* (2019), in which they tried to analyse the post fire nutrient dynamics happening in the fire affected areas of Mudumalai Tiger Reserve which is situated in the tri-junction of Kerala, Tamilnadu, and Karnataka states over a time series of 15 years. They found out that the change in concentration of extractable potassium in different plots was remarkable. They found that the recently burned plot was showing lower concentration of potassium while the plots which burned 15 years ago showed higher levels of extractable potassium. They found that in all the soil layers of two year old fire affected areas,

the levels of potassium was significantly lower. Conversely the fifteen year old fire affected areas showed a greater recovery of levels of extractable potassium.

2.2. FIRE EFFECTS ON VEGETATION AND PLANT DIVERSITY

The structure, function and the composition of vegetation in any region are influenced by fires. The recurring disturbances like forest fire can influence the relative abundance of the species that are capable to reproduce asexually. Considering the case of the African savannah, the fire events which are occurring over past 8 million years manages it from becoming closed woodlots. This period also testifies the evolution of fire tolerant and fire dependent species in these areas. (Bond and Keeley, 2005). Similarly in a study conducted by Mahesh Sankaran (2005), in the tropical savannahs of South India, *Cymbopogon flexuosus* covered the burnt area in two years after the burning occurred and made the area almost indistinguishable between the control areas. This suggest that the *Cymbopogon flexuosus* individuals were fairly stable against the disturbances caused by the fire which could make up to 63%, the mean live herbaceous cover.

Fire has both direct and indirect effects on the establishment of plant species. Generally the conditions existing in the stand post fire will be having many advantages for the seeds and seedlings. This environment will be characterized by more light, high temperature and good amount of water availability due to the reduced size of leaves which ends up in reduced transpiration rate. The nutrient levels after fire will generally facilitate the new recruits (DeBano *et al.*, 1998). The reduction in the number of granivorous rodents and ants after fire will also facilitate the new recruits. The plants that has obligate dependency on fire will extinct if the fires are suppressed.

After a forest fire, some species are suppressed while some others are promoted. This will eventually make changes in the vegetation structure. This will also alter the successional pattern (Syaufina & Ainuddin, 2011). In a study conducted by Verma *et al.* (2017), in the Mudumalai Tiger Reserve, in the Western

Ghats in order to understand the effect of a single fire event on tree diversity and regeneration status, four forest patches were chosen which were unburned, 2-year-old burn, 5-year-old burn, and 15-year-old burn. Though the number of small sized stem classes was less in the recently burnt plots and the fire affected the overall diversity, the regeneration showed a positive trend. The increased availability of nutrient, reduction in the pathogen population, breaking in seed dormancy and the changes happening in mineral soils could be the reason for the enhanced count of seedlings and saplings. From the fifth year onwards, number of saplings showed an increase. They concluded that the tree diversity could reach to the pre-fire level by the end of fifteen years.

In a comparative study conducted by Sathya and Jayakumar (2017) between the regeneration in the fire affected and control areas of the Sathyamangalam Tiger Reserve, one of the largest tiger reserve in the country, Shannon Weiner and Simpson's Dominance indices were found following a decreasing with increasing fire frequency. They also observed that diversity values for all the fire classes were lower than the control plots. The plots faced more number of fires showed less basal area. The three dominant species in the stand were *Anogeissus latifolia*, *Phyllanthus emblica* and *Tectona grandis*. The former species remained dominant in the tree and sapling stage. *Ziziphus rugosa* and *Terminalia chebula* replaced them in the seedling stage. It was observed that the *Phyllanthus emblica* was dominant in all the three growth forms. It may be due to the longer dormancy of the seeds which are naturally dispersed by the ruminant animals (Mawalagedera *et al.*, 2014). They also concluded by recommending planting the saplings of *Anogeissus latifolia* and *Phyllanthus emblica* to increase the tree cover in high fire frequency areas.

A similar study conducted by Verma and Jayakumar (2015) in the Mudumalai tiger reserve in the state of Tamil Nadu concluded that out of the 45 identified species in the reserve, only five species could be identified from all the fire frequency classes. They recorded 24 species in common to both control and

burned classes. Only 30 species were present in the seedling form while those in the sapling form was just counted 17. They could record 15 species in tree form only. They observed that, with increasing fire frequency, Shannon-Weiner diversity index showed linear decline while Simpson's dominance index showed an incline. This was attributed to the rapid invasion of reserve by fire adapted exotic species immediately after recurring fire events. The study also observed that one or two fire incidences with almost equal intervals in a period of 15 years is good for regeneration and replenishment of nutrients in the soil while the diversity will be in threat if the fire occurs frequently. This promoted fire-resistant species and root sprouters like *Terminalia crenulata* and *Anogeissus latifolia*.

According to Kittur *et al.* (2014), the forest fires behaves differently in different fire zones. He also concluded that the species composition and diversity indices are independent with the intensity of forest fire. Especially in the moist deciduous forests, the entire species composition, diversity indices can be altered and replaced with a new combination next time. It should be noted that changes in the soil faunal communities during the recovery post fire may not be due to the direct impacts of fire on the soil but can also be due to the change in succession or due to the quality or quantity of the organic matter. (Radea *et al.*, 2010). Pyrophytes coppice and will have responses resulting into offspring from seed. Along with these, consideration must be given to the life cycle of the species and the fire severity and fire regime to which the species was subjected. According to Chandler and Dodds (1983), the fire frequency determines the composition of flora of an area by choosing the species which will continue to occupy a site. There are greater chances of removal of some species if fire occurs too often, too early or late in its life cycle. A non-sprouting species can be lost if the fire occurs before the seed is produced.

2.3. EFFECTS OF FOREST FIRE ON SOIL EROSION

The physico-chemical properties of soil altered by the wildfire will eventually affect the soil-water permeability, rainwater intake rate, capacity to support life forms and the resistance to soil erosion and leaching processes. According to Felicia (2017), the runoff and soil loss exhibited remarkable differences between the soil 'collects' as a response to the temporal variation in the erosive response of the micro plots they selected. In the first months they showed a linear response to the runoff while in the later months they started resembling a sigmoid curve where the soil loss tended to decrease over time. They also suggested that nutrient leaching will be evident as most of the nutrients will be deposited along with the ash. The fire also causes a general decrease in the sum of exchangeable bases after fire at all depths. This is because the base cations are very soluble and are removed in the increased soil erosion and leaching.

According to Neary *et al.* (1999), the organic horizon in the soil is a critical component of the forest floor. This protective soil cover can mitigate erosion to a large extent. Volatilization during fire will take away a good amount of nutrients from the forest floor and the remaining part, in a highly soluble form get deposited on the soil surface. The nutrient enhancement due to wildfire has its effect mostly on the topmost layer of the forest floor, ie.0-5cm only. This may get easily eroded in the fire affected area (DeBano and Conrad, 1978). According to a study by Efthimiou (2020), using the Arcmap programme to estimate the average annual soil loss in a fire affected area, the annual average soil loss increased from 69 t/ha/year to 94 t/ha/year post fire. It has come down to 64 t/ha/year after 15 years of the fire incidence.

2.4. EFFECTS OF FOREST FIRE ON MACRO-INVERTEBRATES

Organisms that live on the litter layer and O horizon are referred to the epigeic organisms. These include both micro and macro invertebrates. These

organisms help in converting organic matter that falls to the ground into soil. These are more susceptible to natural disturbances like fire, flood, wind than those in the deeper layers. This may be either due to the inability of the organisms to penetrate deeper when a fire occurs or also can be due to the loss of substrate in the combustion. In case of detritivores, the abundance may reduce only if the severity is more and it leaves less affected if the fire affects superficially leaving the detritus behind on the soil surface. Endogeic organisms are those dwelling deeper layers of soil like ants which are less affected by the fire event most times (Coyle, 2017). This group of animals generally recover to their pre-fire level within a year normally (Neumann and Tolhurst, 1991).

The sensitivity or dependence of the fire affected ecosystem, the frequency and intensity of fires and also the life history characteristics of the soil organisms themselves together will determine the kind of responses to the forest fire. The surface fires can have many direct and indirect effects on soil faunal communities. Normally when the temperature above ground increases, these organisms has a tendency to go deeper to safeguard themselves in comfortable temperature. But in case of a surface fire which remove a good portion of upper organic horizon, conditions for existence of the soil organisms will be hostile. This can be due to the loss of habitats like litter and topsoil besides the shortage of food resources like fungal hyphae (Siepel, 1994). Also the fire impacts on the soil physicochemical properties are also able to influence the soil fauna.

Ilkeda *et al.* (2015), found out that the cocoons of an invasive earthworm species in the fire affected area took more time to hatch out than that of the unburned plots. Davies *et al.* (2010) suggested that although the termite population are less affected by the lighter forest fires even if they are frequent, more intense fire can affect these populations very badly. Abundance of nematode and their biomass were unaffected to some extend by the wildfire, the bacteria feeding nematodes even showed an increment in the number post fire (Butenko *et al.*, 2017). Fauna like mites, nematodes and collembolans have an elevated level of

resilience towards the fire. These are observed to move downwards in times of a fire incidence. Millipedes are more often reported to be affected by the fires and their abundance are strongly reduced (Radea *et al.*, 2010).

The response of the ground beetles may vary to different fire conditions but their thick cuticles may help them to survive most times (Wikars and Schimmel, 2001). The pyrophilic spiders are uncommon compared to the ground beetles. This group of animals may take decades to recover to levels before fire. Still some spider groups (eg: Linyphiidae, Lycosidae) are observed to be more common in the fire affected area (Ryan *et al.*, 2006).

III. MATERIALS AND METHODS

The present study entitled “Fire impacts on vegetation and soil in a forest ecosystem in Wadakkanchery forest range in Thrissur forest division, Kerala” was carried out during 2020-2021 to assess the impacts of forest fire on the vegetation and soil physicochemical and biological properties in the fire burnt areas of Poongode section of Wadakkanchery forest range of Thrissur forest division. Concurrently the study also compared and contrasted the changes in vegetation and soil between burnt and control areas over a time series of 6 months. The details of the study area and the methods of investigation followed are described below.

3.1. STUDY AREA

3.1.1. Name. Location and Extent

The study area, Chembikkunnu (10°43'59.5"N 76°14'12.8"E) is located in the Kottambattoor village, Desamangalam Grama panchayat in Thrissur district of Kerala. The forest plantation where the study being undertaken falls under the purview of Poongode forest section of Wadakkanchery forest range in the Thrissur Forest Division in the state of Kerala. This was earlier managed by the Hindustan Newsprint limited as an industrial plantation. The area borders with 4 adjoining small reserve forests viz. Arattamala RF, Kottanputhurkkunnu RF, Charakkuvalichakunnu RF and Karanchirakkunnu RF.

The plantation covers an area of 475 ha. It comprises of *Acacia mangium*, *Acacia auriculiformes* and *Eucalyptus spp. combined*. It was established in the year 2016. In 3 fire incidents of February 2020, an area of 133.1 ha was burnt. The area has records of previous fire events. A Fire has been recently reported in February 2022. The area is having an average slope of 17% and average elevation of 97m above mean sea level.

The soil is loamy, lateritic, rocky, shallow and degraded. It has very low humus content. The area has gentle to moderate slope. The temperature of the area ranges between 24°C and 39 °C. The average rainfall received in the area is 2100 mm. The area suffers from dry desiccating winds from the Palghat gap which makes the region highly vulnerable to forest fire. The area is surrounded by human inhabitations, private rubber estates and home gardens and therefore the biotic pressure is very high. Grazing add up to causes of forest fires.

In the Year 2021, in order to prevent another fire incident the forest department has set fire to 14 ha of vegetated land in patches, as part of the fire control programme. Thus the study area could be classified into three categories, viz. control plot, originally burnt area and newly burnt area. This classification was used to compare the changes that happened to the vegetation and soil in the forest ecosystem over a period of six months.

3.1.2. Experimental site

A preliminary survey was conducted to make an overview about the study area regarding the topographical, pedological and vegetational aspects. Twenty eight permanent plots of size 10m x 10m were marked and established randomly in both burnt (0.14 ha) and control area (0.14 ha). The burnt class was further classified into originally burnt area (2020 February) and newly burnt area (Control burnt- January 2021) of 0.07 ha each.

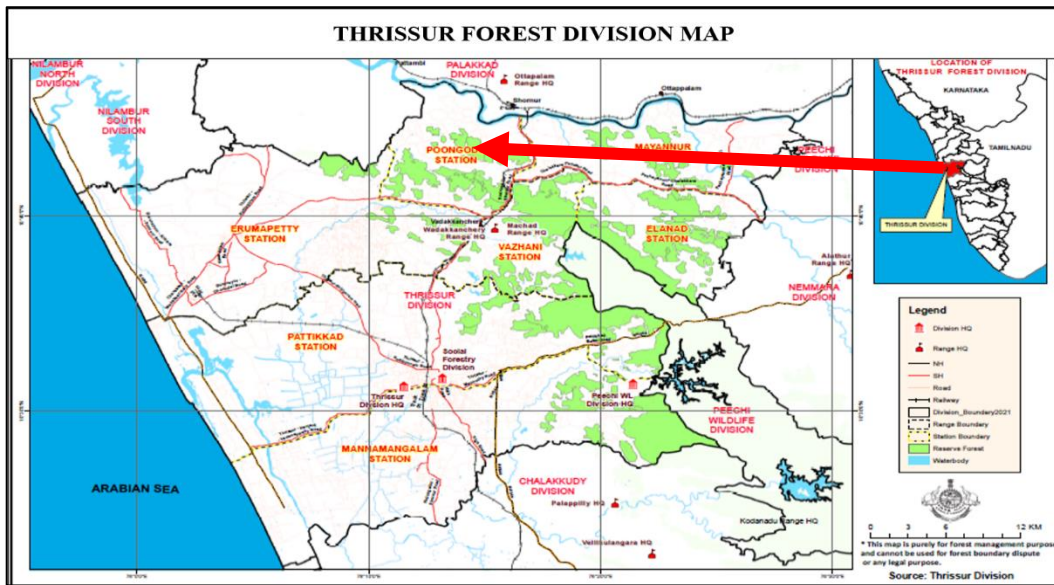


Fig.1: Location of the study area

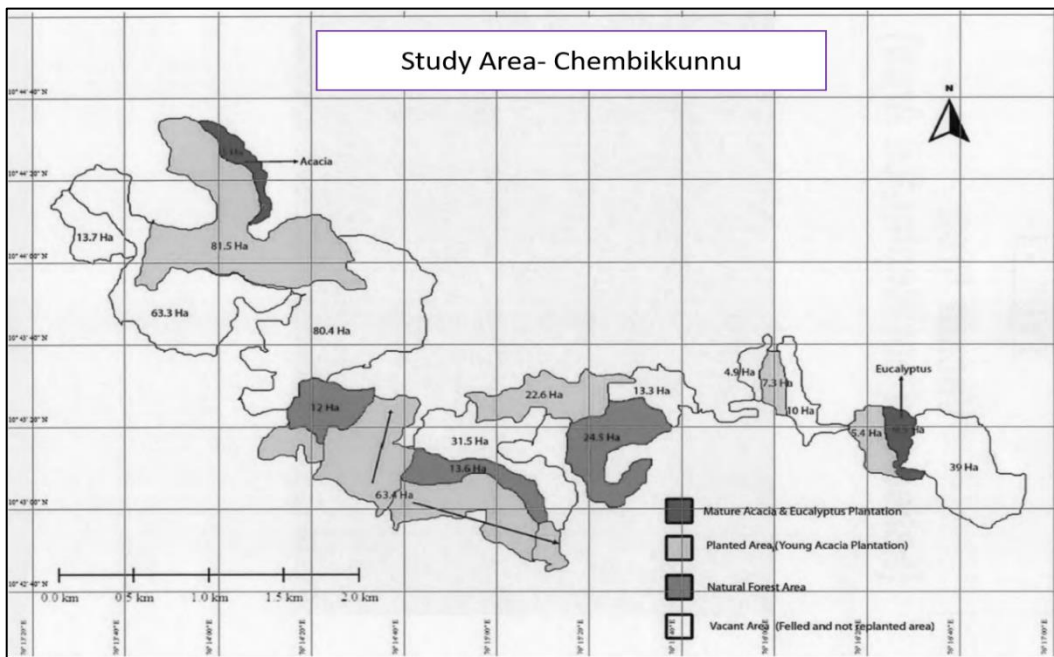


Fig.2: Map of the study area- Chembikkunnu

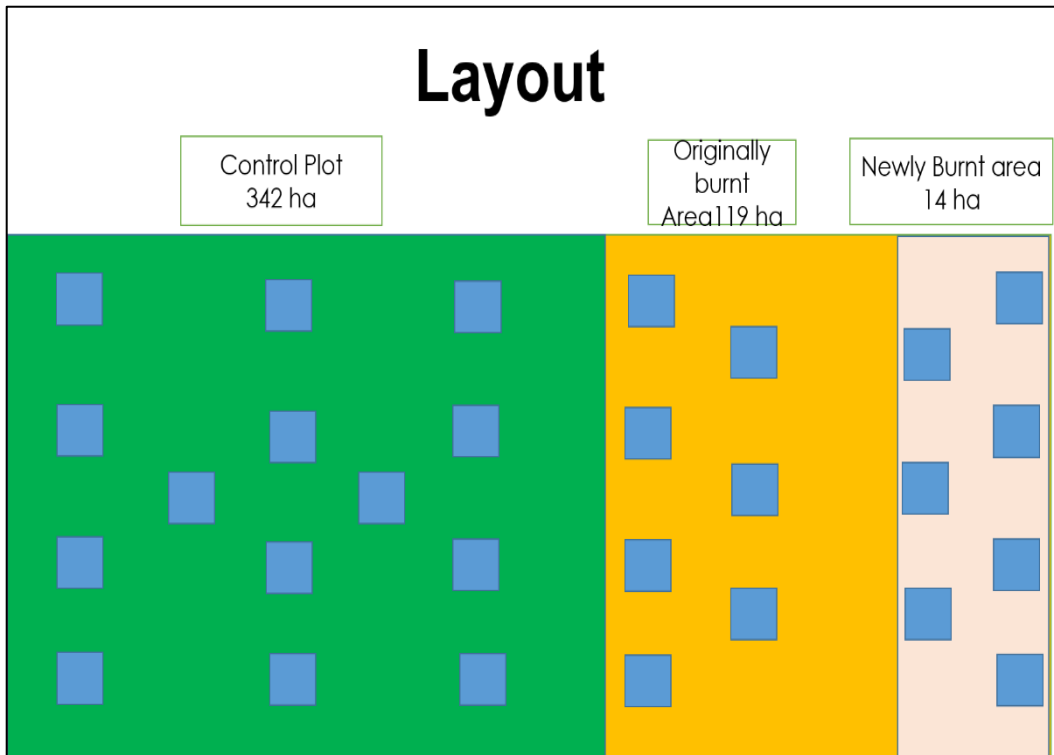


Fig.3: Layout of the study area

3.2. PHYSICAL AND CHEMICAL PROPERTIES OF SOIL

From each 10m x 10m plot, soil samples (one sample each) was collected from two soil depths (0-15 cm and 15-30cm) for the analysis of various physical and chemical properties. This was done twice, before the monsoon (immediately after the ‘control fire’) and after the monsoon. The soil samples collected from the study site were packed, sealed in plastic bags and brought to the laboratory. A share from each soil sample were air-dried for one week. The air-dried samples were sieved using 2mm sieve and stored in polybags for the analysis of soil physico-chemical properties.

3.2.1 Soil physical properties

The methods for estimation of physical properties of soil like Soil moisture content, Bulk Density, Water Holding Capacity, Soil texture are discussed below.

3.2.1.1 Soil moisture (Gravimetric method)

In a moisture can, a known weight of soil sample was collected. It was then dried in an oven at 105°C till constant weight was obtained. The quantity of the moisture lost was determined gravimetrically and expressed on oven dry basis.

$$\text{Moisture \% in the soil (Dry basis)} = \frac{\text{Weight of moisture in the sample} \times 100}{\text{Weight of dry soil sample}}$$

$$\text{Moisture \% in the soil (Wet basis)} = \frac{\text{Weight of moisture in the sample} \times 100}{\text{Weight of wet soil sample}}$$

3.2.1.2. Bulk Density

The Bulk Density of the soil was estimated using core-sampler method. A known volume of soil was collected using a metal ring that can be pressed into the soil (intact core). The soil collected was transferred into an air tight container and the weight of the soil (both wet and dry) was estimated.

$$\text{Bulk density (Apparent Specific Gravity)} = \frac{\text{Weight of Soil}}{\text{Volume of Soil with pore space}}$$

3.2.1.3. Water holding Capacity

Using Keen-Raczkowski Box, the single value constant Maximum Water Holding Capacity was determined gravimetrically by allowing a known quantity of soil to fully saturate and equilibrate with water. From the water held in the soil, the Maximum water holding capacity was determined.

Weighed the box after placing suitable filter paper at the perforated base in a physical balance. Ensured even packing of the box with soil by gently tapping till the box was nearly full and filled it smartly by adding soil. Levelled it off and weighed the box with soil. Left overnight the box with soil in a small tray containing water to a depth of half inch. Weighed it after the period.

Above the edge of the box, the soil was found expanded. Removed raised soil with the help of a sharp blade or scalpel to a porcelain box and weighed it immediately. Weighed the box with residual wet soil. Dried the residual wet soil and expanded soil in an oven at 105°C and weighed to a constant weight. The calculations are as follows.

Calculation

$$\text{Maximum water holding capacity (\%)} = \frac{(c-b) \times 100}{(b-a)}$$

Where,

Weight of the box + filter paper = **a** g

Weight of box + Air dried soil = **b** g

Weight of box + Wet saturated soil = **c** g

3.2.1.4. Soil Texture- International Pipette Method

Soil texture is defined as the relative proportion of various sized particles (sand, silt, clay) in soil. Determination of relative proportion of these particles (size < 2mm) is known as mechanical analysis or particle size analysis of the soil. Soil texture is a basic property which cannot be altered easily. It helps in understanding weathering & profile development, water retention, CEC, workability, erodibility of soil etc. Following are the two important steps involved.

Dispersion and fractionation of soil sample

Under natural conditions soil particles exist as aggregates or floccules and are cemented together by organic matter, CaCO₃ etc. To determine particle size distribution, soil particles should be dispersed completely by inactivating or removing cementing agents. Organic matter was removed by treating the soil with 30 % H₂O₂ which acted as oxidising agent and oxidized organic matter to CO₂ and H₂O. CaCO₃ was removed by treating soil with dil. HCL. But while doing so, HCl saturated soil with H⁺ ions, which also kept soil flocculated. So in order to

disperse soil completely, it was treated with NaOH. The completely dispersed soil particles are called mechanical separates.

Coarse sand particles were separated by sieving the dispersed soil suspension. Fine sand particles were separated by decantation. Fractionation of clay and silt is based on their settling velocities which is governed by Stoke's law of sedimentation (Robinson, 1922).

3.2.2. Soil chemical properties

Soil chemical properties like soil pH, electrical conductivity, soil organic carbon, Total Nitrogen, Total Potassium and Total Phosphorus were estimated using the standard analytical methods that are discussed below

3.2.2.1. Soil pH

The soil pH is meant to measure acidity or alkalinity of soil and it gives the measure of activity of H⁺ ions in the soil solution. The aqueous suspension method was used to determine the soil pH (Chang and Jackson, 1958). With the help of a pH meter, soil pH was obtained potentiometrically in 1:2.5 soil/water suspensions. For this, in a 50 ml beaker, 10 gm of an air dried soil sample was taken, into which 25ml distilled water was added and repeatedly stirred for 20-30 minutes. The pH meter was used for obtaining the value of pH of the soil solution.

$$\text{pH} = -\log(\text{H}^+)$$

3.2.2.2. Electrical Conductivity

The determination of the electrical conductivity of the soil was done by calibrating electrical conductivity meter in 1:2.5 soil/water suspensions (Chang

and Jackson, 1958). Conductivity is measured in the supernatant of the soil water suspension prepared for estimation of soil pH.

3.2.2.3. Soil organic Carbon

Soil Organic Carbon (C) was estimated by the Walkley and Black method (Walkley and Black, 1934). The soil samples were dried and fine ground using mortar and pestle so as to pass through 0.5mm sieve. The 0.5 g sieved soil samples were transferred into a conical flask of 500ml in to which 10 ml, 1N $K_2Cr_2O_7$ (Potassium Dichromate) was mixed thoroughly. 20 ml of concentrated H_2SO_4 was added to the conical flask, swirled 2-3 times and kept for 30 minutes for oxidation. 200 ml distilled water was added with 4-5 drops of ferroin indicator. It was titrated against 0.5 N Ferrous Ammonium Sulphate solution until dull green colour changed to chocolate dull red colour. A blank was also run simultaneously and readings were noted.

Calculation

$$\text{Soil organic carbon \%} = \frac{(BV-TV) \times 10 \times \text{Amount of 1 N } K_2Cr_2O_7 \text{ used} \times 100}{BV \times \text{weight of sample in gm}}$$

Where,

BV – Blank value

TV – Titre Value

3.2.2.4. Total Nitrogen

Total nitrogen was estimated by semi macro-Kjeldahl method. Of the total nitrogen in the soil, 90-95% is existing as organic pool and rest in mineral form. In the estimation of total N, the organic Nitrogen is converted to ammoniacal nitrogen by digesting with con. H_2SO_4 in the presence of salts and catalysts. The ammonia was subsequently liberated from its sulphate by distillation with alkali. The

liberated ammonia was collected in boric acid and estimated by titration with standard acid, 0.01N HCl (Jackson, 1973).

Calculation

$$\% \text{ of N in the sample} = (T.V - B.V) \times 0.01 \times 0.014 \times \text{dilution factor} \times 100/W$$

Where,

T.V = sample titration value

B.V = blank titration value

W = Weight of the sample.

0.014g N = 1ml of 1N HCl

Di – acid digestion

Di- Acid digestion was carried out using a 9:4 mixture of HNO₃: HClO₄. It was a prerequisite in making the soil samples suitable for the determination of P, K Ca, Mg, S Fe etc. For the sample high in oil or fat, pre-digestion using 25ml HNO₃ is recommended to avoid explosion.

3.2.2.5. Total Potassium

Total Potassium in the soil was extracted by di-acid digestion (9:4 mixture of HNO₃:HClO₄). The extracted potassium was estimated using the flame photometer method.

Calculation

Weight of the soil sample = Wg

Volume of digested sample made up to = V1 ml

Reading for the sample from the instrument = R

Total potassium (ppm) = (R/W) x V1

Total potassium in the soil = g

3.2.2.6. Total Phosphorous

Total phosphorous in the soil was extracted by di-acid digestion (9:4 mixture of HNO₃:HClO₄). The extracted P is estimated using spectrophotometer.

Calculation

Weight of the soil taken = 1 gm

Volume of acid extract made up = 100 ml

Volume of acid extract pipetted = 10 ml

Final volume made up for colour development = 25 ml

Sample concentration of P from graph = X ppm

Phosphorous content in ppm = $(X \times 100 \times 25) / (1 \times 10)$

3.3. ANALYSIS OF VEGETATION

Total enumeration of all the regeneration in the permanent plots (10m x 10m) established were carried out for six months on monthly basis from January – July (2021-Except May). Plants were identified using published resources like KFRI's Flowering plants of Kerala Version 2.0 (Sasidharan, 2012), Flora of Peninsular India by IISc's Centre for Ecological Sciences (2019) and also by consulting plant taxonomists and dendrologists. Those plants having height less than 50cm is designated as seedlings. Saplings are those plants having height between 50cm-150 cm and collar girth from 1 to 10 cm (Verma *et al.*, 2017). Various indices like Shannon Diversity Index (Shannon and Weiner, 1963), Margalef Richness Index (Margalef, 1958), Pielou's Evenness Index (Pielou, 1969), Simpson Index (Simpson, 1949), and Sorenson Similarity Index (Sorensen, 1948) were calculated for the observed data in order to understand the plant species diversity.

a) Shannon-Wiener diversity index

Shannon Diversity Index or Shannon-Wiener Index is a method to measure the diversity of species in a community. The higher the value of H, the higher will be the diversity of species in a particular community. The lower the value of H, the lower will be the diversity of species in a particular community. When H=0, such a community is having a single species.

$$\text{Shannon-Wiener diversity index} = \sum [p_i \times \ln(p_i)]$$

p_i = proportion of total sample represented by species 'i'.

b) Simpson's index

Simpson's Index (D) measures the likelihood that two individuals arbitrarily selected from a sample will belong to the same species (or some listing other than species). With this index, 0 represents infinite diversity and 1, no diversity. That is, the bigger the value of D, lower will be the diversity.

$$= \frac{\sum_i n_i (n_i - 1)}{N(N - 1)}$$

n_i - Number of individuals of the species

N – Total number of individuals:

c) Pielou's evenness index

Pielou's evenness index is an index that measures diversity along with species richness. While species richness is the number of various species in a given area, evenness is the sum of individuals of each species in an area. A calculated value of Pielou's evenness ranges from 0 (no evenness) to 1 (complete evenness).

$$\text{Pielou's Evenness Index} = \frac{H}{\ln(N)}$$

Where,

H – Shannon- Weiner Index

N – Total number of species in the sample

d) Sorensen similarity index

The Sorensen index which is also known as Sorensen's similarity coefficient, is a statistic used for comparing the similarity of two samples which was developed by botanist Thorvald Sorensen.

$$Cs = \frac{2a}{2a+b+c}$$

a=Number of species in both sites

b= Number of species in second site only

c= Number of species in first site only

e) Margalef's diversity index

Margalef's diversity index is a species richness index which was developed by Spanish ecologist Ramon Margalef Lopez.

$$\text{Margalef Richness Index} = (S - 1) / \ln N$$

S = total number of species

N = total number of individuals in the sample

ln = natural logarithm

3.4. STUDY OF MACRO-INVERTEBRATES

Soil samples of 20x20x20 cm dimensions were collected in polythene bags, labelled and transported to the laboratory. Collected samples were placed in trays and hand sorted the large macro-invertebrates such as earthworms, spiders, centipedes etc. The remaining soil was placed in the Berlese Tullgren Funnel (Bano and Roy, 2016) for the extraction of smaller macro invertebrates for a period of 3

days. It is an efficient and economic equipment for the extraction of macro invertebrates. It is an equipment with a large funnel with a wired mesh in the flat basal portion and an incandescent lamp above the funnel. At the base of the funnel a collecting tube with 70% alcohol is kept. The temperature of the soil samples will increase under the continuous heat produced by the lamp for 72 hours. As a result the macro-invertebrates in the soil sample surface would go down to the funnel to escape from heat and eventually will fall into the collecting tubes through the wire mesh. Photographs of extracted organisms were taken using macro photographic technique. The extracted invertebrates were preserved in appropriate media and identified at the family level or order level with the help of experts. Soft bodied organisms were preserved in 70% alcohol and hard bodied organisms in dry preservation and earthworms in 5% formaldehyde solution.

3.5. Estimation of soil erosion - Erosion pin method

This is a widely-used method to estimate the soil erosion (Hadley and Lusby, 1967). Here metallic pins were driven into the soil and the top of the pin will act as a datum from which the changes in the soil surface level can be measured. The pins are also called spikes, pegs. It can be of any materials like wood, nails, stakes or rods that won't easily get decay and is readily and economically available. Steel rods were used. To give a firm datum the pin was having an optimal length of 30cm and this varied with soil as loose soil needs more length than shallow soil. The desirable diameter of the rod was about 5mm. The pins were randomly laid out in rectangular grids with spacing appropriate to the area under study. Five pins each in the upper slope, mid slope and lower slope of selected areas in control area, originally burnt area and control burnt area were established. The readings were taken every month. The length of pin exposed were measured. This gave an idea of accretion or scouring happened around the pin.

$$\text{Volume of soil loss} = \text{Average soil loss} \times \text{Area}$$

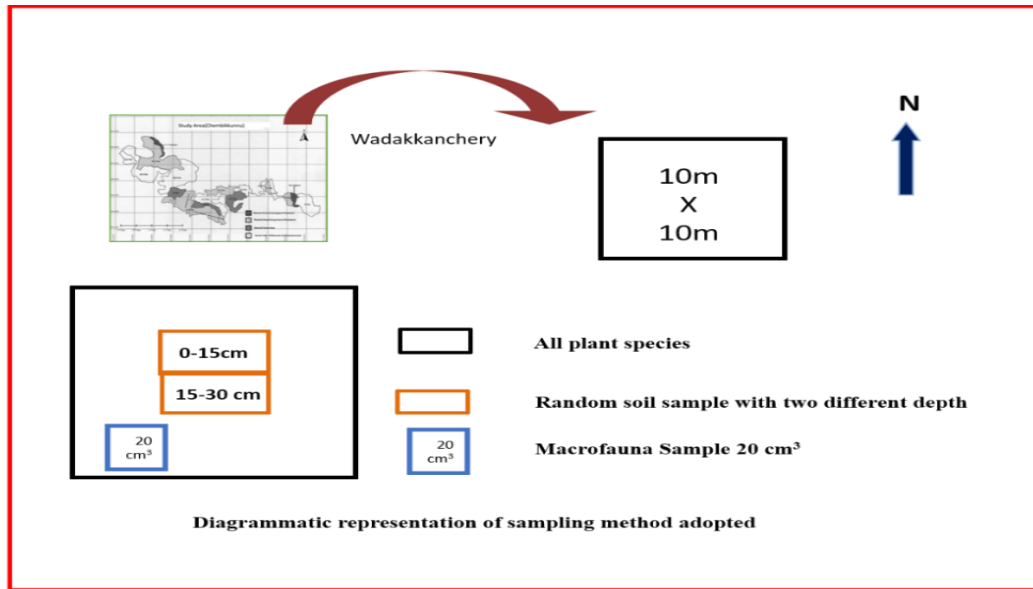


Fig.4: Diagrammatic representation of sampling method adopted.

9

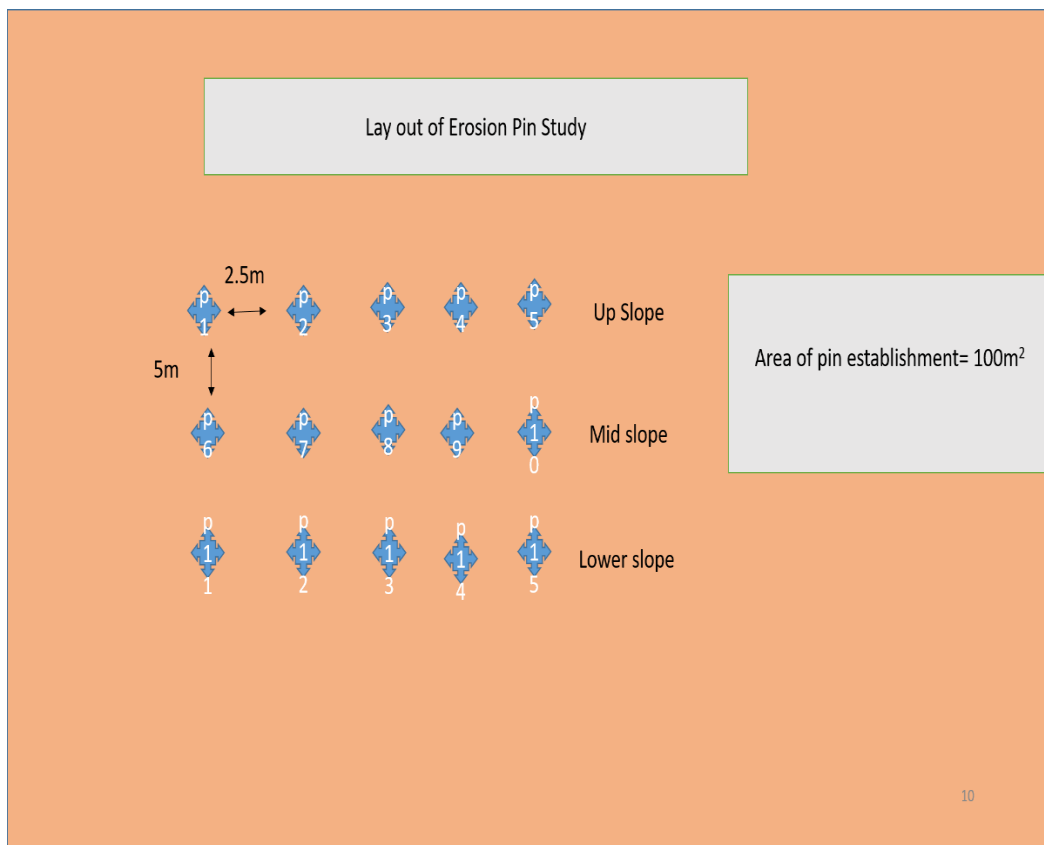


Fig.5: Layout of erosion pin study

Photoplate no. 1



Fig (i)



Fig (ii)



Fig (iii)

Fig I - Study area

Fig ii - Marking the plots

Fig iii- Marked plots

3.6. STATISTICAL ANALYSIS

The experimental data associated with three fire classes were subjected to statistical analysis. One way anova test was used to determine the influence of fire on soil properties among three plots. LSD test (CD- test) was executed for the post-hoc analysis of the above test. Paired t-test was conducted to analyse the effect of monsoon on soil properties. Software used for the analysis includes R (version 4.3.1), Microsoft Excel (Office 2019).

IV. RESULTS

The current study was conducted during 2021-2022 to understand and assess the impacts of the forest fire on the vegetation and soil physicochemical and biological properties in the fire burnt areas of Poongode section of Wadakkancherry forest range of Thrissur Forest Division in Kerala. It was also intended to compare and contrast the changes in the vegetation and soil between burnt and control areas over a time series of six months. For the convenience of representation, control plots, originally burnt plot (one year old burnt plot) and newly burnt plots were designated as CP, OBP and NBP respectively.

4.1 SOIL STUDIES

4.1.1 Physical properties of soil

4.1.1.1 *Soil Moisture Content*

4.1.1.1.1 *Dry Basis*

In the pre-monsoon conditions, the soil moisture content of the soil layer (0-15cm) was found to be higher in the CP-10 (38.5 %), OBP-6(12.1%) and NBP-5(11.85 %) while the moisture content was found lower at CP-1(9.6%), OBP-4 (5.2%) and NBP-7 (5.04%) (Table 2). The soil moisture content of the soil layer (15-30cm) was found higher in the CP-10(28.8%), OBP- 3(16%) and NBP-5(9.4%) while it was observed to be lower at CP-1(8%), OBP-1(4.8%) and NBP-2 (3.7%) (Table 3).

In the post monsoon conditions, the soil moisture content of the soil layer (0-15cm) was found to be higher in the CP-4(31.9 %), OBP-3(30.2%) and NBP-6(24.1%) while the values were found lower at CP-3(17.64%), OBP-1(13.9%) and NBP-3 (11.6%) (Table 2). The soil moisture content of the soil layer (15-30cm) was found to be higher in the CP-4 (28.2%), OBP-3(28.5%) and NBP- 5(21.7%) while moisture content was lower at CP-13(15.7%), OBP-1(15.47%) and NBP-3(10.6%) (Table 3).

Fire had significant effects on soil moisture at 0-15 cm (p value - 0.002457) (Table 1) and 15-30 cm depth (p value - 0.002148) (Table 1). The effects of fire were found to be non-significant during post monsoon conditions 0-15 cm (pvalue-0.2792) (Table 1) and 15-30 cm (p value-0.3278) (Table 1). Paired t-test executed to compare the plots from both the depths of 0-15cm and 15-30 cm in pre-monsoon and post-monsoon conditions revealed that the monsoon had significant effects on soil moisture since the probability value is less than 0.05 (Table 30)

Table 1. Soil moisture content at two depths in two seasons

Depth (cm)	Treatments/Plots	Pre-monsoon (%)		Post-monsoon (%)	
		Mean	Mean±SE	Mean	Mean±SE
0-15	CP	17.39 ^a	17.39±7.83	22.27 ^a	22.27±4.12
	OBP	8.80 ^b	8.80±2.72	20.28 ^a	20.28±4.98
	NBP	8.28 ^b	8.28±2.89	19.04 ^a	19.04±4.54
15-30	CP	15.27 ^a	15.27±5.87	19.55 ^a	19.55±3.52
	OBP	9.81 ^b	9.8±4.53	20.28 ^a	20.28±4.99
	NBP	6.62 ^b	6.62±2.35	17.18 ^a	17.18±4.12

Table 2. Soil moisture content in the depth of 0-15cm (Dry basis)

Sl No	Pre-monsoon (%)			Post-monsoon (%)		
	CP	OBP	NBP	CP	OBP	NBP
1	7.99	4.82	4.60	20.19	15.47	19.62
2	8.93	5.48	3.73	17.92	25.00	12.87
3	9.89	16.00	9.17	16.00	28.53	10.62
4	19.33	6.83	5.04	28.20	16.55	19.33
5	18.48	8.93	9.40	22.24	15.74	21.65
6	13.89	11.35	5.93	16.55	21.06	19.90
7	19.90	15.20	8.45	17.92	19.61	16.28

Table 2 continued...

8	21.06	*	*	19.33	*	*
9	11.35	*	*	17.92	*	*
10	28.86	*	*	23.76	*	*
11	9.89	*	*	19.04	*	*
12	14.41	*	*	22.24	*	*
13	17.37	*	*	15.74	*	*
14	12.35	*	*	16.55	*	*

* Seven plots each were sampled from OBP and NBP.

Table 3. Soil moisture content in the depth of 15-30 cm (Dry basis)

SI NO	Pre-monsoon (%)			Post monsoon (%)		
	CP	OBP	NBP	CP	OBP	NBP
1	9.65	6.60	11.35	22.24	13.89	21.95
2	10.86	5.93	6.60	19.61	21.06	14.16
3	10.38	8.93	5.93	17.64	30.20	11.61
4	22.85	5.26	9.64	31.92	18.48	20.48
5	21.36	11.85	11.85	24.06	14.67	21.95
6	14.94	12.10	7.52	19.04	19.33	24.06
7	20.19	10.86	5.04	22.85	16.00	19.05
8	21.95	*	*	20.48	*	*
9	11.11	*	*	21.06	*	*
10	38.50	*	*	30.20	*	*
11	10.62	*	*	21.65	*	*
12	14.94	*	*	21.95	*	*
13	21.65	*	*	20.19	*	*
14	14.42	*	*	18.76	*	*

4.1.1.1 Soil Moisture Content

4.1.1.1.2. Wet Basis

In the pre-monsoon conditions, the soil moisture content of the soil layer (0-15cm) was found higher in the CP-10(27.8 %), OBP-6(10.8%) and NBP-5(10.6 %) while the values were found lower at CP-1(8.8%), OBP-4 (5%) and NBP-7 (4.8%) (Table 5). The soil moisture content of the soil layer (15-30cm) was found higher in the CP-10(22.4%), OBP- 3(13.8%) and NBP-5(8.6%) while lower values were observed at CP-1(7.4%), OBP-1(4.6%) and NBP-2 (3.6%) (Table 6).

In the post monsoon conditions, the soil moisture content of the soil layer (0-15cm) was found higher in the CP-4(24.2%), OBP-3(23.2%) and NBP-6(19.4%) while the values were found lower at CP-3(15%), OBP-1(12.2%) and NBP-3 (10.4%) (Table 5). Moisture of the soil layer (15-30cm) was found to be higher in the CP-10(19.2%), OBP-3(22.2%) and NBP- 5(17.8%) while the lower values were observed at CP-13(13.6%), OBP-1(13.4%) and NBP-3(9.6%) (Table 6).

Fire had significant effects on soil moisture (wet basis) at 0-15 cm (p value - 0.001114) (Table 4) and 15-30 cm depth (p value - 0.001419) (Table 4). The effects of fire on soil moisture (wet basis) were found to be non-significant during post monsoon conditions 0-15 cm (p value-0.1795) (Table 4) and 15-30 cm (p value-0.3142) (Table 4). Paired t-test executed to compare the plots from both the depths of 0-15cm and 15-30 cm pre-monsoon and post-monsoon conditions revealed that the monsoon had significant effects on soil moisture since the probability value is less than 0.05 (Table 30).

Table 4. Soil moisture content at two depths in two seasons (Wet basis)

Depth	Treatments/Plots	Pre-monsoon (%)		Post-monsoon (%)	
		Mean	Mean \pm SE	Mean	Mean \pm SE
0-15cm	CP	14.49 ^a	14.49 \pm 5.30	18.13 ^a	18.13 \pm 2.64
	OBP	8.03 ^b	8.03 \pm 2.45	15.89 ^a	15.89 \pm 3.73
	NBP	7.60 ^b	7.60 \pm 2.29	15.89 ^a	15.89 \pm 3.29

Table 4 continued...

15-30cm	CP	13.04 ^a	13.04±4.30	16.29 ^a	16.29±2.39
	OBP	8.80 ^b	8.80±3.72	16.74 ^a	16.74±3.38
	NBP	6.17 ^b	6.17±2.06	14.57 ^a	14.57±3.04

Table 5. Soil moisture content in the depth of 0-15 cm (Wet basis).

Sl No.	Pre-monsoon (%)			Post-monsoon (%)		
	CP	OBP	NBP	CP	OBP	NBP
1	7.41	4.61	4.49	16.84	13.41	16.48
2	8.22	5.27	3.68	15.24	20.04	11.41
3	9.06	13.86	8.41	13.86	22.24	9.61
4	16.27	6.41	4.81	22.07	14.26	16.21
5	15.64	8.21	8.62	18.25	13.67	17.82
6	12.23	10.20	5.63	14.24	17.48	16.64
7	16.62	13.29	7.84	15.23	16.41	14.04
8	17.41	*	*	16.25	*	*
9	10.27	*	*	15.26	*	*
10	22.49	*	*	19.27	*	*
11	9.08	*	*	16.09	*	*
12	12.68	*	*	18.21	*	*
13	14.86	*	*	13.62	*	*
14	11.04	*	*	14.21	*	*

* Seven plots each were sampled from OBP and NBP.

Table 6. Soil moisture content in the depth of 15-30 cm (Wet basis).

Sl No.	Pre-monsoon (%)			Post-monsoon (%)		
	CP	OBP	NBP	CP	OBP	NBP
1	8.81	6.24	10.21	18.24	12.25	18.04
2	9.82	5.64	6.29	16.42	17.44	12.44
3	9.41	8.24	5.60	15.12	23.27	10.49
4	18.61	5.01	8.81	24.21	15.66	17.14
5	17.63	10.61	10.61	19.44	12.84	18.02
6	13.00	10.79	7.01	16.02	16.14	19.30
7	16.81	9.84	4.81	18.51	13.81	16.02
8	18.14	*	*	17.01	*	*
9	10.04	*	*	17.44	*	*
10	27.71	*	*	23.29	*	*
11	9.52	*	*	17.84	*	*
12	13.04	*	*	18.04	*	*
13	17.74	*	*	16.70	*	*
14	12.66	*	*	15.75	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.1.2 Bulk density

4.1.1.2.1 Bulk density (Dry Basis)

In the pre-monsoon conditions, the soil bulk density (BD) was found highest in the CP-2(0.95 cm⁻³), OBP-3 (0.98 cm⁻³) and NBP-1(1.0 cm⁻³) while the values were found lowest at CP-10 and CP-12 (0.82 cm⁻³), OBP-7(0.83 cm⁻³) and NBP-7 (0.89 cm⁻³). In the post monsoon conditions, the soil bulk density was found highest in the CP-7(1.02 cm⁻³), OBP-4(1.16 cm⁻³) and NBP-4(1.15 cm⁻³) while the values were found lowest at CP-9(0.71 cm⁻³), OBP-1(0.72 cm⁻³) and NBP-5 (0.78 cm⁻³) (Table 8).

The one way anova test executed for the pre-monsoon samples revealed that fire had significant effects on soil bulk density (p value - 0.002104) (Table 7) and the same test performed for the post-monsoon samples revealed that effects of fire were non-significant at 5% level of significance (p value-0.9785) (Table 7). Paired t-test executed to compare the plots of pre-monsoon and post-monsoon conditions revealed that the monsoon had no significant effects on bulk density since the probability value is greater than 0.05 (Table 30).

Table 7. Soil bulk density in different seasons (Dry basis).

Treatments/Plots	Pre-monsoon (gcm ⁻³)		Post-monsoon(gcm ⁻³)	
	Mean	Mean±SE	Mean	Mean±SE
CP	0.86 ^b	0.86±0.04	0.91 ^a	0.91±0.10
OBP	0.90 ^{ab}	0.90±0.05	0.90 ^a	0.90±0.15
NBP	0.94 ^a	0.94±0.04	0.90 ^a	0.90±0.13

Table 8. Soil bulk density (Dry basis).

Sl.No	Pre-monsoon(gcm ⁻³)			Post Monsoon(gcm ⁻³)		
	CP	OBP	NBP	CP	OBP	NBP
1	0.84	0.86	1	0.76	0.72	0.79
2	0.95	0.95	0.9	0.99	1.04	0.82
3	0.88	0.98	0.93	0.91	0.81	0.83
4	0.83	0.91	0.96	0.99	1.16	1.15
5	0.89	0.85	0.98	0.98	0.89	0.78
6	0.84	0.89	0.91	0.94	0.78	0.98
7	0.84	0.83	0.89	1.02	0.88	0.91
8	0.88	*	*	0.86	*	*
9	0.82	*	*	0.71	*	*

Table 8 continued...

10	0.81	*	*	0.75	*	*
11	0.85	*	*	1	*	*
12	0.89	*	*	0.94	*	*
13	0.81	*	*	0.82	*	*
14	0.89	*	*	0.99	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.1.2.2 Bulk density (Wet basis)

In the pre-monsoon conditions, the soil bulk density (BD) was found highest in the CP-2(1.0 cm⁻³), OBP-3 (1.0 cm⁻³) and NBP-1(1.01 cm⁻³) while the values were found lowest at CP-9(0.85 cm⁻³), OBP-7(0.86 cm⁻³) and NBP-7 (0.89 cm⁻³). In the post monsoon conditions, the soil bulk density was found highest in the CP-4(1.2 cm⁻³), OBP-4(1.32 cm⁻³) and NBP-4(1.15 cm⁻³) while the values were found lowest at CP-9(0.86 cm⁻³), OBP-1(0.88 cm⁻³) and NBP-1 and NBP-5(0.76 cm⁻³) (Table 10).

The one way anova test executed for the pre-monsoon samples revealed that fire had no effects on soil bulk density (wet basis), since the p value is greater than 0.05(p value - 0.06066) (Table 9). and the same test performed for the post-monsoon samples revealed that three plots were found to be significant at 5% level of significance (p value-0.005491) (Table 9). Paired t-test executed to compare the plots of pre-monsoon and post-monsoon conditions revealed that the monsoon had significant effects on soil bulk density since the probability value is less than 0.05 (Table 30).

Table 9. Soil bulk density in different seasons (Wet basis)

Treatments/Plots	Pre-monsoon(gcm^{-3})		Post monsoon(gcm^{-3})	
	Mean	Mean \pm SE	Mean	Mean \pm SE
CP	0.91 ^a	0.91 \pm 0.04	1.09 ^a	1.09 \pm 0.11
OBP	0.93 ^a	0.93 \pm 0.05	1.06 ^a	1.06 \pm 0.15
NBP	0.96 ^a	0.96 \pm 0.04	0.88 ^b	0.88 \pm 0.14

Table 10. Soil bulk density (Wet basis).

SI NO	Pre-monsoon(gcm^{-3})			Post Monsoon(gcm^{-3})		
	CP	OBP	NBP	CP	OBP	NBP
1	0.88	0.90	1.01	0.93	0.88	0.76
2	1.00	0.97	0.92	1.19	1.19	0.82
3	0.92	1.00	0.94	1.10	0.97	0.81
4	0.87	0.94	0.98	1.21	1.32	1.15
5	0.92	0.87	0.99	1.12	1.06	0.76
6	0.87	0.93	0.93	1.12	0.93	0.95
7	0.90	0.86	0.89	1.17	1.03	0.87
8	0.91	*	*	1.03	*	*
9	0.85	*	*	0.86	*	*
10	0.86	*	*	0.95	*	*
11	0.91	*	*	1.17	*	*
12	0.92	*	*	1.12	*	*
13	0.86	*	*	1.03	*	*
14	0.94	*	*	1.15	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.1.3 Water Holding Capacity

In the pre-monsoon conditions, the water holding capacity of the soil layer (0-15cm) was found to be highest in the CP-5(35.5 %), OBP-6(36.9%) and NBP-7(43.9 %) while the WHC was lowest at CP-6(27.5%), OBP-1 (28.4%) and NBP-4 (29.1%) (Table 12). The water holding capacity of the soil layer (15-30cm) was found highest in the CP-2(32.6%), OBP- 7(26.3%) and NBP-2(25.8%) while it was low at CP-10(22.2%), OBP-5(8.73%) and NBP-7 (18.9%) (Table 13).

In the post monsoon conditions, the water holding capacity of the soil layer (0-15cm was found highest in the CP-5(47.8 %), OBP-2(43.3%) and NBP-3(55.74%) while the values were found lowest at CP-8(35.4%), OBP-7(34.7%) and NBP-4 (34.7%) (Table 12). The water holding capacity of the soil layer (15-30cm) was found to be highest in the CP-7 (31.8%), OBP-1(28%) and NBP- 3(23.8%) while the lower values were observed at CP-10(20.03%), OBP-5(14.3%) and NBP-4(14.2%) (Table 13).

Fire had significant effects on soil water holding capacity at 0-15 cm (p value - 0.005491) (Table 11) and 15-30 cm depth (p value - 0.003808) (Table 11). The effects of fire on soil water holding capacity remained significant during post monsoon conditions at depth of 0-15 cm (p value - 0.005491) (Table 11) and 15-30 cm (p value- 0.005664) (Table 11). Paired t-test was executed to compare the water holding capacity of plots from both the depths of 0-15cm and 15-30 cm in pre-monsoon and post-monsoon conditions. This revealed that the monsoon had significant effects on soil moisture (P-value<0.05) (Table 30).

Table 11. Water holding capacity in different seasons

Depth	Treatments/Plots	Pre-monsoon (%)		Post-monsoon (%)	
		Mean	Mean±SE	Mean	Mean±SE

Table 11 continued...

0-15cm	CP	31.89 ^b	31.89±2.45	41.52 ^b	41.52±3.96
	OBP	32.89 ^b	32.89±3.96	39.17 ^b	39.17±3.18
	NBP	39.23 ^a	39.23±5.29	46.87 ^a	46.87±6.58
15-30cm	CP	27.81 ^a	27.81±2.70	26.81 ^a	26.81±3.37
	OBP	21.81 ^b	21.81±5.99	23.70 ^{ab}	23.7±4.47
	NBP	23.47 ^b	23.47±2.61	20.80 ^b	20.80±3.51

Table 12. Soil water holding capacity (0-15cm)

SI NO	Pre- monsoon (%)			Post-monsoon (%)		
	CP	OBP	NBP	CP	OBP	NBP
1	34.69	28.39	43.78	40.80	40.86	47.81
2	35.30	36.84	36.94	47.69	43.37	47.39
3	31.20	36.35	41.17	42.51	37.40	55.74
4	31.63	29.04	29.09	40.43	37.79	34.67
5	35.49	29.09	42.26	47.82	42.62	49.10
6	27.56	36.94	37.33	40.49	37.42	43.06
7	32.19	33.53	43.98	44.70	34.67	50.30
8	33.48	*	*	35.41	*	*
9	31.74	*	*	40.74	*	*
10	30.63	*	*	42.12	*	*
11	28.81	*	*	46.24	*	*
12	29.46	*	*	38.12	*	*
13	30.32	*	*	37.68	*	*
14	33.89	*	*	36.49	*	*

* Seven plots each were sampled from OBP and NBP.

Table 13. Soil Water holding capacity (15-30cm)

SI NO	Pre-monsoon (%)			Post-monsoon (%)		
	CP	OBP	NBP	CP	OBP	NBP
1	28.06	23.65	24.59	29.16	27.99	17.91
2	32.60	23.53	25.78	29.82	24.02	23.16
3	26.86	26.04	25.40	31.43	23.64	23.78
4	29.65	22.35	20.67	25.29	27.05	14.18
5	26.47	8.73	24.61	24.81	14.28	21.21
6	28.38	22.03	24.31	30.99	23.95	22.47
7	24.24	26.28	18.90	31.79	24.96	22.84
8	30.10	*	*	25.44	*	*
9	29.04	*	*	24.59	*	*
10	22.23	*	*	20.03	*	*
11	26.14	*	*	27.10	*	*
12	29.22	*	*	25.12	*	*
13	30.34	*	*	25.04	*	*
14	25.99	*	*	24.70	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.1.4 Soil Texture

In the soil samples collected during pre-monsoon conditions from the control plots, the average proportion of sand, silt and clay was found to be 65.92%, 20.28% and 13.78% respectively. The average proportion of sand, silt and clay in the samples collected from originally burnt area were 67.14%, 17.42% and 15.42% while it was found to be 65.42%, 18.86% and 16% respectively in the samples collected from newly burnt plots (Table 15).

The average proportion of sand, silt and clay was found to be 65.6%, 19.8% and 14.64% respectively in post monsoon samples. While the proportion of sand, silt and clay in the samples collected from originally burnt area were 64.3%,

20.85% and 14.85%, it was found to be 65.42%, 18.86% and 16% respectively in the samples collected from newly burnt plots (Table 16).

The one way anova test executed for the pre-monsoon samples revealed that fire had no significant impacts in the amount of sand (p value - 0.7991) (Table 14) in the fire affected classes of plots and the same test performed for the post-monsoon samples also gave similar output (p value-0.6677) (Table 14). Paired t-test executed revealed that the monsoon had significant impacts on the sand fraction, since the probability value is less than 0.05 (Table 30).

The one way anova test executed for the pre-monsoon samples revealed that there were no significant difference in the amount of silt in three plots (p value - 0.2285) (Table 14). The same test was performed for the post-monsoon samples also. This also revealed that fire had no significant effects in the silt fraction of the soil (p value-0.554) (Table 14). Paired t-test executed found out that the monsoon had no effects in the silt fraction (Table 30).

The one way anova test executed for the pre-monsoon samples revealed that fire had no significant effects in the amount of clay in three plots (p value - 0.2004) (Table 14). The same test was performed for the post-monsoon samples. This also gave a similar result (p value-0.9835) (Table 14). Paired t-test executed revealed that monsoon had no effect on clay fraction (Table 30).

Table 14. Soil texture in two seasons

Plot	Pre-monsoon (%)			Post-Monsoon (%)		
	Sand	Silt	Clay	Sand	Silt	Clay
CP	65.93 ^a ±5. 25	20.29 ^a ±3. 69	13.79 ^a ±3. 31	65.57 ^a ±5. 32	19.79 ^a ±3. 91	14.64 ^a ±3. 56
OB P	67.14 ^a ±4. 81	17.43 ^a ±3. 91	15.43 ^a ±2. 23	64.29 ^a ±6.13	20.86 ^a ±4. 14	14.86 ^a ±2. 85
NB P	65.43 ^a ±4. 47	18.86 ^a ±2. 73	16.00 ^a ±2. 08	63.43 ^a ±4.31	21.71 ^a ±3. 59	14.57 ^a ±2. 15

Table 15. Soil texture of control plot.

	Sand	Silt	Clay	Textural class	Sand	Silt	Clay	Textural class
1	64	18	18	Sandy loam	66	15	19	Sandy loam
2	71	20	9	Sandy loam	70	19	11	Sandy loam
3	72	16	12	Sandy loam	73	17	10	Sandy loam
4	63	20	17	Sandy loam	66	17	17	Sandy loam
5	64	21	15	Sandy loam	62	19	19	Sandy loam
6	73	14	13	Sandy loam	69	15	16	Sandy loam
7	61	27	12	Sandy loam	64	23	13	Sandy loam
8	68	21	11	Sandy loam	66	20	14	Sandy loam
9	61	22	17	Sandy loam	61	23	16	Sandy loam
10	76	15	9	Loamy sand	74	14	12	Sandy loam
11	63	21	16	Sandy loam	62	21	17	Sandy loam
12	65	25	10	Sandy loam	67	24	9	Sandy loam
13	58	24	18	Sandy loam	53	27	20	Sandy loam
14	64	20	16	Sandy loam	65	23	12	Sandy loam
Mean	65.92	20.28	13.78		67.14	17.42	15.42	

Table 16. Soil texture of originally burnt plots

	Silt	Clay	Textural class	Sand	Silt	Clay	Textural class
66	17	17	Sandy Loam	62	22	16	Sandy Loam
70	18	12	Sandy Loam	59	23	18	Sandy Loam
75	12	13	Sandy Loam	76	13	11	Sandy Loam
67	17	16	Sandy Loam	66	18	16	Sandy Loam
69	14	17	Sandy Loam	62	25	13	Sandy Loam
62	20	18	Sandy Loam	58	24	18	Sandy Loam
61	24	15	Sandy Loam	67	21	12	Sandy Loam
67.14	17.42	15.42		64.28	20.85	14.85	

Table 17. Soil texture of newly burnt plots

Sand nbp	Silt	Clay	Textural class	Sand	Silt	Clay	Textural class
60	21	19	Sandy Loam	61	22	17	Sandy Loam
70	16	14	Sandy Loam	67	19	14	Sandy Loam
71	17	14	Sandy Loam	70	17	11	Sandy Loam
68	18	14	Sandy Loam	65	22	13	Sandy Loam
66	16	18	Sandy Loam	61	24	15	Sandy Loam
61	22	17	Sandy Loam	57	28	15	Sandy Loam
62	22	16	Sandy Loam	63	20	17	Sandy Loam
65.42	18.85	16		63.42	21.71	14.57	

4.1.2 Chemical properties of soil

4.1.2.1 Soil pH

In the pre-monsoon conditions, the soil pH was found to be highest in the CP-11(7.2), OBP-3 (6.68) and NBP-6(7.19) while pH was lower at CP-4(6.06), OBP-7(6.14) and NBP-2 (6.57). In the post monsoon conditions, the soil pH was found highest in the CP-6(5.75), OBP-1(5.36) and NBP-1(5.69) while the values were found lowest at CP-7(5.08), OBP-4(4.83) and NBP-4(4.65) (Table 18).

Fire had significant effects on soil pH (p value - 0.004115) (Table 17) but in the post monsoon conditions the effects of fire on soil pH appeared insignificant (p value - 0.2196) (Table 17) and 15-30 cm (p value- 0.005664) (Table 17). Paired t-test was executed to compare the soil pH of pre-monsoon and post-monsoon conditions. This revealed that the monsoon had highly significant effects on soil pH (P- Value<0.05) (Table 31).

Table 18. Mean table of soil pH in two seasons.

Treatment	Pre- monsoon	Post- Monsoon
CP	6.44 ^b ±0.27	5.30 ^a ±0.19
NB	6.85 ^a ±0.22	5.28 ^a ±0.37
OB	6.43 ^b ±0.22	5.11 ^a ±0.17

Table 19. Soil pH in two seasons.

Sl No	Pre-Monsoon			Post- Monsoon		
	CP	OBP	NBP	CP	OBP	NBP
1	6.28	6.43	6.67	5.04	5.36	5.69
2	6.38	6.59	6.57	5.43	5.11	5.38
3	6.13	6.68	6.68	5.2	5.21	5
4	6.06	6.33	6.89	5.19	4.83	4.65
5	6.81	6.66	7.05	5.26	5.07	5.41

Table 19 continued...

6	6.21	6.18	7.19	5.75	5.22	5.19
7	6.64	6.14	6.91	5.08	4.98	5.67
8	6.73	*	*	5.52	*	*
9	6.5	*	*	5.28	*	*
10	6.59	*	*	5.4	*	*
11	7.02	*	*	5.34	*	*
12	6.31	*	*	5.42	*	*
13	6.19	*	*	5.16	*	*
14	6.24	*	*	5.24	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.2.2 Soil electrical conductivity

In the pre-monsoon conditions, the soil electrical conductivity (EC) was found highest in the CP-8(530), OBP-3 (376) and NBP-1(375) while the values were found lowest at CP-2(122.4), OBP-7(197.9) and NBP-5 (205). In the post monsoon conditions, the soil electrical conductivity (EC) was found highest in the CP-6(254.1), OBP-2(140.5) and NBP-6(265) while the values were found lowest at CP-2(91.35), OBP-3(84.7) and NBP-3(127.43) (Table 20).

Fire had no significant effects on soil electrical conductivity (p value - 0.9784) (Table 19). In the post monsoon conditions, the effects of fire on soil electrical conductivity was found to be significant. (p value - 0.2196) (Table 19). Paired t-test was executed to compare the soil electrical conductivity of pre-monsoon and post-monsoon conditions. This revealed that the monsoon had highly significant effects on soil electrical conductivity (P- Value<0.05) (Table 31).

Table 20. Mean table of soil electrical conductivity in two seasons

Treatment	Pre- monsoon (mS/m)	Post- Monsoon (mS/m)
CP	295.36 ^a ±116.75	161.14 ^a ±44.43
NB	293.96 ^a ±57.96	170.65 ^a ±47.74
OB	286.51 ^a ±56.61	116.47 ^b ±19.44

Table 21. Soil electrical conductivity in two seasons

Sl no	Pre-monsoon (mS/m)			Post-monsoon (mS/m)		
	CP	OBP	NBP	CP	OBP	NBP
1	211.3	255	375	190.32	125.5	151.8
2	122.4	322	270	91.35	140.5	180.2
3	178	376	264	110.26	84.7	127.43
4	332.5	277.4	351	203.97	106.92	166.5
5	257.2	266	205	181.36	128.73	122.4
6	188.4	311.3	318	254.1	127.7	265
7	326.8	197.9	274.7	141.38	101.22	181.2
8	530	*	*	149.1	*	*
9	405	*	*	162.79	*	*
10	200	*	*	128.63	*	*
11	289.4	*	*	123.19	*	*
12	473.5	*	*	212	*	*
13	273	*	*	134.59	*	*
14	347.6	*	*	173	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.2.3 Soil Organic Carbon

In the pre-monsoon conditions, soil organic carbon(C%) in the control plots, originally burnt plots and newly burnt plots were found in the range from 0.69% in CP-9 to 2.58 in CP-14, 0.66% in OBP-2 to 2.91% in OBP 3 and 1.86% in NBP-

3,4 to 2.94 in NBP-1 respectively. In the post monsoon conditions, soil organic carbon (C) (%) in the control plots, originally burnt plots and newly burnt plots was found in the range from 1.38 in CP-3 to 1.77 in CP-2, 1.05 in OBP-3 to 1.89 in OBP-6 and 1.05 in NBP-3 to 2.28 in NBP-4 respectively (Table 22).

Fire had significant effects on soil organic carbon (p value - 0.003694) (Table 21). In the post monsoon conditions, the effects of fire on soil organic carbon was found to be non-significant. (p value-0.06206) (Table 21). Paired t-test was executed to compare the soil amount of soil organic carbon of pre-monsoon and post-monsoon conditions. This revealed that the monsoon had less effect on soil organic carbon (P- Value<0.05) (Table 31).

Table 22. Mean table of soil organic carbon in two seasons

Treatment	Pre- monsoon (%)	Post- Monsoon (%)
CP	1.48 ^b ±0.60	1.56 ^{ab} ±0.12
NB	2.58 ^a ±0.49	1.8 ^a ±0.44
OB	1.75 ^b ±0.80	1.46 ^b ±0.27

Table 23. Soil organic carbon in different plots in 2 seasons

Sl No	Pre- monsoon (%)			Post-monsoon (%)		
	CP	OBP	NBP	CP	OBP	NBP
1	2.34	1.86	2.94	1.59	1.41	1.68
2	1.68	0.66	1.86	1.77	1.41	2.1
3	1.02	2.91	1.86	1.38	1.05	1.05
4	1.92	1.62	2.91	1.74	1.53	2.28
5	2.25	1.74	2.85	1.56	1.26	2.1
6	0.81	0.93	2.88	1.41	1.89	1.98
7	1.41	2.55	2.73	1.5	1.65	1.41
8	1.32	*	*	1.56	*	*
9	0.69	*	*	1.65	*	*

Table 23 continued...

10	1.2	*	*	1.44	*	*
11	1.5	*	*	1.56	*	*
12	0.87	*	*	1.44	*	*
13	1.11	*	*	1.68	*	*
14	2.58	*	*	1.5	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.2.4 Total Nitrogen

In the pre-monsoon conditions, soil total nitrogen (N%) recorded in the control plots, originally burnt plots and newly burnt plots were in the range from 0.7% in Cp-10 to 1.6% in the CP-4, 0.95% in OBP-3 to 1.8% in the OBP-5 and 1.14% in NBP-6 to 1.56% in the NBP-1. In the post monsoon conditions, total nitrogen (%) registered in the control plots, originally burnt plots and newly burnt plots were in the range from 0.64% in Cp-8 to 1.6% in the CP-9, 0.67% in OBP-6 to 1.3% in the OBP-5 and 0.91% in NBP-6 to 1.15% in the NBP-2 (Table 31).

The one way anova test executed for the pre-monsoon samples revealed that three plots were found to be non-significant at 5% level of significance (p value - 0.6451) and the same test performed for the post-monsoon samples revealed that three plots were found to be significant at 5% level of significance since the probability value is less than 0.05 (p value-0.04213). Since the probability value is less than 0.05, the three plots are found to be significant (Table 23).

Fire had no significant effects on total nitrogen in the soil (p value - 0.6451) (Table 23). In the post monsoon conditions, the effects of fire on total nitrogen in soil was found to be significant. (p value-0.04213) (Table 23). Paired t-test was executed to compare the amount of total nitrogen in the soil of pre-monsoon and post-monsoon conditions. This revealed that the monsoon had high effect on total soil nitrogen (P- Value<0.05) (Table 31).

Table 24. Total soil nitrogen (%) in two seasons

Treatment	Pre- monsoon (%)	Post- Monsoon (%)
CP	1.3 ^a ±0.35	1.2 ^a ±0.27
NB	1.3 ^a ±0.13	1.04 ^{ab} ±0.086
OB	1.4 ^a ±0.31	0.93 ^b ±0.22

Table 25. Total soil nitrogen in different plots in two seasons (Tonnes/ha)

Sl No	CP	OBP	NBP	CP	OBP	NBP
1	3.069	4.743	4.464	2.79	2.79	3.069
2	4.185	4.464	3.906	3.627	3.069	3.348
3	3.348	2.79	3.906	3.348	1.953	2.79
4	4.464	3.906	3.627	4.185	2.511	2.79
5	3.627	5.301	4.185	3.348	3.627	3.069
6	4.464	4.185	3.069	3.627	1.953	2.511
7	3.627	3.069	3.627	3.348	2.232	2.79
8	2.232	*	*	1.674	*	*
9	5.58	*	*	4.743	*	*
10	1.953	*	*	2.511	*	*
11	2.79	*	*	2.511	*	*

Table 25 continued...

12	3.627	*	*	3.627	*	*
13	4.464	*	*	3.906	*	*
14	3.348	*	*	3.069	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.2.5 Total Phosphorous

In the pre-monsoon conditions, soil total phosphorous (P %) registered in the control plots, originally burnt plots and newly burnt plots were in the range from 0.31% in Cp-3 to 0.6% in the CP-13, 0.57% in OBP-3,5 to 0.7% in the OBP-1 and 0.36% in NBP-4 to 0.71% in the NBP-1. In the post monsoon conditions, soil total phosphorous (P%) registered in the control plots, originally burnt plots and newly burnt plots were in the range from 0.44% in Cp-2 to 0.75% in the CP-8, 0.58% in OBP-1 to 0.7% in the OBP-6 and 0.6% in NBP-3,4 to 1.01% in the NBP-5 (Table 26).

Fire had significant effects on total phosphorous in the soil (p value - 0.0003873) (Table 25). In the post monsoon conditions also, the effects of fire on total phosphorous in soil was found to be significant (p value-0.001105)(Table 25). Paired t-test was executed to compare the amount of total phosphorous in the soil of pre-monsoon and post-monsoon conditions. This revealed that the monsoon had very high impact on total soil phosphorous (P-value<0.05) (Table 31)

Table 26. Total soil phosphorus (ugm/gm) in two seasons

Treatment	Pre- monsoon	Post- Monsoon (ugm/gm)
CP	44 ^b ±7.6	5.8 ^b ±1

Table 26 continued...

NB	$57^a \pm 13$	$8.1^a \pm 1.7$
OB	$61^a \pm 4.6$	$6.5^b \pm 0.5$

Table 27. Total phosphorus (Tonnes/ha) in different plots in two seasons.

SI NO	Pre-monsoon			Post Monsoon		
	CP	OBP	NBP	CP	OBP	NBP
1	0.15	0.18	0.20	0.02	0.01	0.04
2	0.11	0.19	0.13	0.02	0.02	0.03
3	0.09	0.16	0.16	0.02	0.05	0.03
4	0.11	0.17	0.1	0.02	0.02	0.03
5	0.13	0.16	0.16	0.02	0.02	0.04
6	0.12	0.16	0.17	0.04	0.02	0.03
7	0.14	0.17	0.2	0.03	0.02	0.03
8	0.14	*	*	0.04	*	*
9	0.14	*	*	0.03	*	*
10	0.17	*	*	0.02	*	*
11	0.13	*	*	0.02	*	*
12	0.11	*	*	0.03	*	*
13	0.12	*	*	0.02	*	*
14	0.10	*	*	0.02	*	*

* Seven plots each were sampled from OBP and NBP.

4.1.2.6 Total Potassium

In the pre-monsoon conditions, soil total potassium (K%) registered in the control plots, originally burnt plots and newly burnt plots were in the range from 97.3 in Cp-6 to 151 in the CP-10, 59.6 in OBP-5 to 198 in the OBP-3 and 86.2 in NBP-4 to 136 in the NBP-3. In the post monsoon conditions, soil total potassium (K%) registered in the control plots, originally burnt plots and newly burnt plots were in the range from 6.2 in Cp-3 to 14.5 in the CP-6, 4.2 in OBP-1 to 17.7 in the OBP-3 and 9.3 in NBP-3 to 13.1 in the NBP-5 (Table 28).

The one way anova test executed for the pre-monsoon samples revealed that three plots were non-significant at 5% level of significance since the probability value was greater than 0.05 (p value- 0.4042) and the same test performed for the post-monsoon samples revealed that three plots were non-significant at 5% level of significance since the probability value is less than 0.05 (p value-0.3172) (Table 27).

Fire had no significant effects on total potassium in the soil (p value - 0.4042) (Table 27). In the post monsoon conditions also, the effects of fire on total potassium in soil was found to be significant (p value-0.3172) (Table 27). Paired t-test was executed to compare the amount of total potassium in the soil of pre monsoon and post-monsoon conditions. This revealed that the monsoon had very high impact on total soil potassium (P-value<0.05) (Table 31)

Table 28. Mean table of total potassium in soil in two seasons (ppm)

Treatment	Pre- monsoon	Post- Monsoon
CP	124.06 ^a ±16.57	10.28 ^a ±2.32
NB	107.80 ^a ±20.43	11.13 ^a ±1.68
OB	126.51 ^a ±49.46	8.80 ^a ±4.43

Table 29. Total potassium in different plots in 2 seasons (Tonnes/ha)

Sl No	CP	OBP	NBP	CP	OBP	NBP
1	0.38	0.33	0.31	0.03	0.02	0.04
2	0.34	0.24	0.37	0.03	0.01	0.03
3	0.29	0.55	0.38	0.02	0.02	0.03
4	0.41	0.40	0.24	0.03	0.05	0.03
5	0.33	0.17	0.29	0.02	0.03	0.04
6	0.27	0.49	0.25	0.04	0.02	0.04
7	0.36	0.28	0.27	0.04	0.02	0.03
8	0.30	*	*	0.04	*	*
9	0.31	*	*	0.03	*	*
10	0.42	*	*	0.03	*	*
11	0.39	*	*	0.03	*	*
12	0.38	*	*	0.03	*	*
13	0.32	*	*	0.03	*	*
14	0.34	*	*	0.02	*	*

Table 30. Physical properties in 2 seasons (Paired t test)

Physical Properties	Conditions	Mean values	t-stat	P value
Soil moisture (0-15cm) Dry basis	Pre-monsoon	12.80	-6.905	<0.001
	Post-monsoon	20.96		
Soil moisture (0-15cm) Wet basis	Pre-monsoon	10.99	-7.106	<0.001
	Post-monsoon	17.22		
Soil moisture (15-30 cm) Dry basis	Pre-monsoon	11.74	-9.451	<0.001
	Post-monsoon	20.93		
Soil moisture (15-30 cm) Wet basis	Pre-monsoon	10.26	-9.244	<0.001
	Post-monsoon	17.22		
Soil bulk density- Wet density	Pre-monsoon	0.92	-3.450	0.002
	Post-monsoon	1.03		

Table 30 continued...

Soil bulk density- Dry density	Pre-monsoon	0.89	-0.511	0.613
	Post-monsoon	0.90		
Water holding capacity (0-15cm)	Pre-monsoon	33.97	-9.732	<0.001
	Post-monsoon	42.27		
Water holding capacity (15-30cm)	Pre-monsoon	25.23	0.947	0.352
	Post-monsoon	24.53		
Soil Texture Sand	Pre-monsoon	66.11	2.106	0.04
	Post-monsoon	64.71		
Soil Texture Silt	Pre-monsoon	19.21	-1.964	0.060
	Post-monsoon	20.54		
Soil Texture Clay	Pre-monsoon	14.75	0.151	0.881
	Post-monsoon	14.68		

Table 31. Chemical properties in 2 seasons (Paired t test)

Chemical properties	Conditions	Mean values	t-stat	P value
Soil pH	Pre-monsoon	6.54	17.88	<2.2e-16
	Post-monsoon	5.25		
Electrical conductivity	Pre-monsoon	292.8	8.17	9.031e-09
	Post-monsoon	152.4		
Organic Carbon	Pre-monsoon	1.82	1.63	0.115

Organic Carbon	Post-monsoon	1.59		
Total Nitrogen	Pre-monsoon	1.35	6.87	2.215e-07
	Post-monsoon	1.08		
Total Phosphorus	Pre-monsoon	0.52	4.77	<0.001
	Post-monsoon	0.65		
Total Potassium	Pre-monsoon	120.61	20.82	<2.2e-16
	Post-monsoon	10.12		

Photoplate no.2
Study of soil properties



Fig (A)



Fig (B)



Fig (C)



Fig (D)

Fig A – Soil sample collection

Fig B, C, D – Soil samples in laboratory

4.1.3 Soil erosion

The highest average annual soil erosion during the study period was recorded in the newly burnt plots while it was least in the control plots. In all the three slopes, the highest annual erosion was recorded in the newly burned plots.

It was observed that during the study period the highest volume of soil was lost from the control plots, while the least amount of soil loss was from the newly burnt plots. Larger amount of soil was lost from control plots while the mass of soil lost during the period was least from the newly burnt area. (Table 31).

Table 32. Soil erosion in various slopes in different plots.

	Slope	Mean Height (mm)	Volume of Soil loss	Mass of Soil lost	Soil erosion per annum (Tonnes/ha/yr)
Control Area	Up slope	1 ± 0.7	3420 ± 2394	3032.48 ± 2112.74	0.018 ± 0.012
	Mid slope	0.4 ± 1.51	1368 ± 5164.2	1212.99 ± 4579.05	0.007 ± 0.027
	Lower slope	0.4 ± 1.51	1368 ± 5164.2	1212.99 ± 4579.05	0.007 ± 0.027
Originally Burnt Area	Up slope	1.6 ± 1.51	2142 ± 1796.9	1932.40 ± 1621.08	0.032 ± 0.027

Table 32 continued...

	Mid slope	0.4 ± 1.51	1428 ± 1796.9	1288.27 ± 1621.08	0.021 ± 0.027
	Lower slope	0.8 ± 2.77	952 ± 3296.3	858.84 ± 2973.76	0.014 ± 0.050
Newly Burnt Area	Up slope	2.8 ± 1.3	392 ± 182	360.78 ± 167.51	0.051 ± 0.024
	Mid slope	2.8 ± 1.9	364 ± 266	335.01 ± 244.82	0.048 ± 0.035
	Lower slope	2 ± 3.5	252 ± 490	231.93 ± 450.98	0.033 ± 0.064

Photoplate no.3
Study of soil erosion



Fig (A)



Fig (B)

Fig A- Erosion pin

Fig B- Taking monthly pin readings

4.2 VEGETATION ANALYSIS

Total enumeration of regeneration was carried out in all the plots (10 x10m) on monthly basis. Plants having height less than 50 cm was designated as seedlings and those having height in the range of 50-150cm and collar girth 1- 10 cm were designated as saplings. Thirty seven plant species were identified from the study area. They comprised of plants from 20 plant families, with Fabaceae being the most dominant family. Observations of plant regeneration recorded on monthly basis is given below.

January

In the control plots, 765 seedlings and 628 saplings were recorded. In the originally burnt plots, 352 seedlings and 209 saplings were recorded. No seedlings and saplings was recorded from the newly burnt area. Seedlings and saplings of 21 species were found in common among the control area and originally burnt area. No species were found in common among the originally burnt area and newly burnt area (Table no. 32 and Table no. 34)

February

In the control plots, 749 seedlings and 592 saplings were recorded. In the originally burnt plots, 416 seedlings and 239 saplings were recorded. In the newly burnt area 103 seedling individuals and only 5 saplings were found. Seedlings of 25 species were found in common among the control area and originally burnt area while 19 species were found in common among the originally burnt area and newly burnt area. Saplings of 21 species were found in common among the control area and originally burnt area while 2 species were found in common among the originally burnt area and newly burnt area (Table no. 32 and Table no. 34).

March

In the control plots, 671 seedlings and 701 saplings were recorded. In the originally burnt areas, 489 seedlings and 324 saplings were recorded. There found 267 seedlings and only 19 saplings in the newly burnt areas. Seedlings of 27 species were found in common among the control area and originally burnt area while 20 species were found in common among the originally burnt area and newly burnt area. Saplings of 20 species were found in common among the control area and originally burnt area while 4 species were found in common among the originally burnt area and newly burnt area (Table no. 32 and Table no. 34).

April

In the control plots, 851 seedlings and 663 saplings were found. In the originally burnt areas, 697 seedlings and 379 saplings were recorded. There found 469 seedlings individuals and only 54 saplings in the newly burnt areas. Seedlings of 27 species were found in common among the control area and originally burnt area while 23 species were found in common among the originally burnt area and newly burnt area. Saplings of 22 species were found in common among the control area and originally burnt area while 13 species were found in common among the originally burnt area and newly burnt area (Table no. 33 and Table no. 35).

June

In the control plots, 1217 seedlings and 800 sapling individuals were identified. In the originally burnt area, 1043 seedlings and 452 saplings were recorded. There found 715 seedling individuals and 155 saplings in the newly burnt area. Seedlings of 29 species were found in common among the control area and originally burnt area while 31 species were found in common among the originally burnt area and newly burnt area. Saplings of 18 species were found in common among the control area and originally burnt area while 16 species were found in common among the originally burnt area and newly burnt area (Table no.33 & 35).

July

In the control plots, 1327 seedlings and 922 saplings were present. In the originally burnt areas, 1321 seedlings and 570 saplings were recorded. There found 976 seedlings and 295 saplings in the newly burnt areas during this period. Seedlings of 32 species were found in common among the control area and originally burnt area while 33 species were found in common among the originally burnt area and newly burnt area. Saplings of 20 species were found in common among the control area and originally burnt area while 18 species were found in common among the originally burnt area and newly burnt area (Table no.33 & 35)

Table 33. Number of seedlings found in study area during January-March

Sl No.	Seedling Species	Family	January			February			March		
			CP	OBP	NBP	CP	OBP	NBP	CP	OBP	NBP
1	<i>Chromolaena odorata</i>	Asteraceae	74	71	0	81	58	7	75	67	23
2	<i>Mitracarpus hirtus</i>	Rubiaceae	21	8	0	7	0	0	1	5	2
3	<i>Helicterus isora</i>	Malvaceae	18	5	0	24	16	5	28	14	8
4	<i>Sterculia guttata</i>	Malvaceae	3	0	0	7	1	0	11	8	2
5	<i>Clerodendron infortunatum</i>	Lamiaceae	31	8	0	24	8	3	20	17	2

Table 33 continued...

6	<i>Cymbopogon flexuosus</i>	Poaceae	18	14	0	16	18	0	14	10	0
7	<i>Cajanus cajan</i>	Fabaceae	18	2	0	16	8	2	21	11	4
8	<i>Macaranga peltata</i>	Euphorbiaceae	3	5	0	6	4	1	11	7	3
9	<i>Bryophyllum spp.</i>	Crassulaceae	2	0	0	6	1	0	8	6	0
10	<i>Bombax ceiba</i>	Bombacaceae	1	3	0	3	5	1	3	5	1
11	<i>Urena lobata</i>	Malvaceae	0	0	0	0	0	0	0	0	0
12	<i>Hemidesmus indicus</i>	Asclepiadaceae	0	6	0	0	11	3	0	10	5
13	<i>Mimosa pudica</i>	Fabaceae	157	48	0	138	85	29	130	94	81

Table 33 continued...

14	<i>Mimosa diplotricha</i>	Fabaceae	21	4	0	24	16	8	31	24	27
15	<i>Vigna spp.</i>	Fabaceae	69	27	0	78	16	7	51	7	16
16	<i>Commelina spp.</i>	Commelinaceae	0	14	0	3	10	1	6	5	0
17	<i>Sida rhombifolia</i>	Malvaceae	19	26	0	24	29	2	21	28	6
18	<i>Holarrhena pubescens</i>	Apocynaceae	3	0	0	7	2	1	5	4	4
19	<i>Biophytum sensitivum</i>	Oxalidaceae	27	21	0	34	54	16	23	49	38
20	<i>Terminalia paniculata</i>	Combretaceae	6	0	0	5	0	0	0	0	1

Table 33 continued...

26	<i>Peperomia pellucida</i>	Piperaceae	18	26	0	14	18	7	9	11	21
27	<i>Pennisetum polystachyon</i>	Poaceae	174	27	0	151	20	0	126	46	0
28	<i>Centrosema molle</i>	Fabaceae	4	7	0	3	9	1	3	8	4
29	<i>Ficus hispida</i>	Moraceae	3	0	0	6	1	2	7	3	4
30	<i>Curculigo orchioides</i>	Amaryllidaceae	0	0	0	0	0	0	0	0	0
31	<i>Acacia auriculiformis</i>	Fabaceae	12	2	0	15	1	0	9	2	0

Table 33 continued...

32	<i>Acacia mangium</i>	Fabaceae	26	6	0	28	4	0	31	7	0
33	<i>Bridelia retusa</i>	Phyllanthaceae	0	0	0	0	0	0	0	3	0
34	<i>Selaginella delicatula</i>	Sellaginellaceae	5	2	0	4	0	0	7	4	0
35	<i>Drynaria quercifolia</i>	Polypodiaceae	0	0	0	0	0	0	0	0	0
36	<i>Cheilanthes tenuifolia</i>	Pteridaceae	11	0	0	0	0	0	0	0	0
37	<i>Parahemionitis cordata</i>	Pteridaceae	0	0	0	0	0	0	0	0	0
38	Total		765	352	0	749	416	103	671	489	267

Table 34. Number of seedlings found in study area during April-July

Sl no.	Seedling Species	Family	April			June			July		
			CP	OBP	NBP	CP	OBP	NBP	CP	OBP	NBP
1	<i>Chromolaena odorata</i>	Asteraceae	87	83	56	105	108	78	128	140	161
2	<i>Mitracarpus hirtus</i>	Rubiaceae	9	6	5	17	11	8	34	17	9
3	<i>Helicterus isora</i>	Malvaceae	39	12	15	58	18	21	78	25	32
4	<i>Sterculia guttata</i>	Malvaceae	16	7	6	21	12	11	24	11	13
5	<i>Clerodendron infortunatum</i>	Lamiaceae	35	19	7	42	33	18	68	21	24

Table 34 continued...

6	<i>Cymbopogon flexuosus</i>	Poaceae	19	22	0	27	27	0	24	30	0
7	<i>Cajanus cajan</i>	Fabaceae	24	27	5	35	38	11	44	26	16
8	<i>Macaranga peltata</i>	Euphorbiaceae	15	6	7	24	13	16	21	14	13
9	<i>Bryophyllum spp.</i>	Crassulaceae	5	8	6	28	17	10	26	24	7
10	<i>Bombax ceiba</i>	Bombacaceae	7	7	3	14	10	6	12	10	9
11	<i>Urena lobata</i>	Malvaceae	0	0	0	5	9	7	13	14	9
12	<i>Hemidesmus indicus</i>	Asclepiadaceae	0	13	9	0	16	18	0	18	16
13	<i>Mimosa pudica</i>	Fabaceae	167	162	117	183	198	146	151	226	179

Table 34 continued...

14	<i>Mimosa diplotricha</i>	Fabaceae	51	37	31	79	68	38	65	71	44
15	<i>Vigna spp.</i>	Fabaceae	54	4	18	84	18	14	71	23	15
16	<i>Commelina spp.</i>	Commelinaceae	5	8	0	16	16	6	13	11	8
17	<i>Sida rhombifolia</i>	Malvaceae	28	37	13	47	51	19	76	68	24
18	<i>Holarrhena pubescens</i>	Apocynaceae	11	9	5	20	9	8	32	6	13
19	<i>Biophytum sensitivum</i>	Oxalidaceae	48	84	71	67	147	85	61	219	127

Table 34 continued...

20	<i>Terminalia paniculata</i>	Combretacea e	7	1	0	1	6	5	9	8	11
21	<i>Sizyphus oenoplia</i>	Rhamnaceae	6	8	3	8	8	9	11	11	7
22	<i>Wrightia tinctoria</i>	Apocynaceae	5	4	0	9	7	3	8	12	5
23	<i>Desmodium gangeticum</i>	Fabaceae	13	12	14	18	16	23	15	18	19
24	<i>Indigofera hirsuta</i>	Fabaceae	0	8	5	0	13	6	3	19	2

Table 34 continued...

25	<i>Pycnospora lutescens</i>	Fabaceae	0	0	0	0	0	11	0	3	5
26	<i>Peperomia pellucida</i>	Piperaceae	11	19	34	67	41	62	80	97	109
27	<i>Pennisetum polystachyon</i>	Poaceae	136	61	21	181	68	28	193	104	41
28	<i>Centrosema molle</i>	Fabaceae	3	0	7	8	17	18	0	15	16
29	<i>Ficus hispida</i>	Moraceae	5	2	4	8	6	7	8	11	7
30	<i>Curculigo orchioides</i>	Amaryllidaceae	0	3	0	0	3	0	1	3	2

Table 34 continued...

31	<i>Acacia auriculiformes</i>	Fabaceae	14	4	0	17	6	5	23	5	4
32	<i>Acacia mangium</i>	Fabaceae	29	7	3	24	9	7	24	12	11
33	<i>Bridelia retusa</i>	Phyllanthaceae	0	3	0	0	0	0	3	1	0
34	<i>Selaginella delicatula</i>	Sellaginellaceae	2	7	0	4	11	0	5	13	0
35	<i>Drynaria quercifolia</i>	Polypodiaceae	0	3	0	0	5	3	0	7	7
36	<i>Cheilanthes tenuifolia</i>	Pteridaceae	0	4	0	0	8	0	0	6	0

Table 34 continued...

37	<i>Parahemionitis cordata</i>	Pteridaceae	0	0	4	0	0	8	3	2	11
38	Total		851	697	469	1217	1043	715	1327	1321	976

Table 35. Number of saplings found in study area during January – March.

Sl No.	Sapling Species	Family	January			February			March		
			CP	OBP	NBP	CP	OBP	NBP	CP	OBP	NBP
1	<i>Chromolaena odorata</i>	Asteraceae	121	48	0	116	61	4	176	98	13
2	<i>Mitracarpus hirtus</i>	Rubiaceae	0	0	0	0	0	0	0	0	0
3	<i>Helicterus isora</i>	Malvaceae	37	8	0	32	4	0	15	8	0
4	<i>Sterculia guttata</i>	Malvaceae	6	1	0	8	3	0	8	5	2

Table 35 continued...

5	<i>Clerodendron infortunatum</i>	Lamiaceae	72	21	0	81	28	1	117	33	3
6	<i>Cymbopogon flexuosus</i>	Poaceae	22	21	0	28	27	0	34	29	0
7	<i>Cajanus cajan</i>	Fabaceae	15	7	0	13	15	0	18	20	1
8	<i>Macaranga peltata</i>	Euphorbiaceae	8	3	0	11	4	0	12	4	0
9	<i>Bryophyllum spp.</i>	Crassulaceae	7	4	0	9	4	0	6	5	0
10	<i>Bombax ceiba</i>	Bombacaceae	7	2	0	7	4	0	6	4	0
11	<i>Urena lobata</i>	Malvaceae	18	7	0	15	9	0	16	12	0

Table 35 continued...

12	<i>Hemidesmus indicus</i>	Asclepiadaceae	0	2	0	0	5	0	0	6	0
13	<i>Mimosa pudica</i>	Fabaceae	3	3	0	1	7	0	0	4	0
14	<i>Mimosa diplotricha</i>	Fabaceae	1	1	0	0	4	0	5	2	0
15	<i>Vigna spp.</i>	Fabaceae	7	12	0	0	6	0	0	5	0
16	<i>Commelina spp.</i>	Commelinaceae	0	0	0	0	0	0	0	0	0
17	<i>Sida rhombifolia</i>	Malvaceae	4	8	0	6	5	0	3	5	0
18	<i>Holarrhena pubescens</i>	Apocynaceae	7	2	0	5	5	0	8	6	0

Table 35 continued...

19	<i>Biophytum sensitivum</i>	Oxalidaceae	0	0	0	0	0	0	0	0	0
20	<i>Terminalia paniculata</i>	Combretaceae	1	2	0	3	2	0	1	2	0
21	<i>Sizyphus oenoplia</i> L.	Rhamnaceae	0	1	0	2	3	0	2	3	0
22	<i>Wrightia tinctoria</i>	Apocynaceae	4	0	0	4	0	0	4	0	0
23	<i>Desmodium gangeticum</i>	Fabaceae	7	0	0	9	3	0	11	2	0

Table 35 continued...

24	<i>Indigofera hirsuta</i>	Fabaceae	2	1	0	1	0	0	0	0	0
25	<i>Pycnospora lutescens</i>	Fabaceae	1	0	0	0	0	0	0	0	0
26	<i>Peperomia pellucida</i>	Piperaceae	0	0	0	0	0	0	0	0	0
27	<i>Pennisetum polystachyon</i>	Poaceae	224	46	0	188	28	0	207	59	0
28	<i>Centrosema molle</i>	Fabaceae	0	0	0	1	1	0	0	0	0
29	<i>Ficus hispida</i>	Moraceae	6	1	0	4	1	0	6	1	0

Table 36 continued...

3	<i>Helicterus isora</i>	Malvaceae	18	11	2	24	12	5	39	17	6
4	<i>Sterculia guttata</i>	Malvaceae	13	12	4	16	13	7	13	11	6
5	<i>Clerodendron infortunatum</i>	Lamiaceae	108	34	3	114	38	11	142	24	13
6	<i>Cymbopogon flexuosus</i>	Poaceae	40	18	0	38	21	0	54	38	0
7	<i>Cajanus cajan</i>	Fabaceae	27	24	3	31	20	4	28	23	7
8	<i>Macaranga peltata</i>	Euphorbiaceae	11	6	1	12	7	3	15	10	4
9	<i>Bryophyllum species</i>	Crassulaceae	8	7	1	11	9	2	10	12	0
10	<i>Bombax ceiba</i>	Bombacaceae	9	5	2	11	8	4	11	11	5

Table 36 continued...

11	<i>Urena lobata</i>	Malvaceae	14	10	0	17	11	0	21	8	1
12	<i>Hemidesmus indicus</i>	Asclepiadaceae	0	8	1	0	12	0	0	14	2
13	<i>Mimosa pudica</i>	Fabaceae	0	6	0	1	8	1	0	4	0
14	<i>Mimosa diplotricha</i>	Fabaceae	2	3	2	0	6	1	0	6	7
15	<i>Vigna spp.</i>	Fabaceae	6	9	3	11	12	4	9	14	6
16	<i>Commelina spp.</i>	Commelinaceae	0	0	0	0	0	0	0	0	0
17	<i>Sida rhombifolia</i>	Malvaceae	4	3	0	0	7	0	8	16	0
18	<i>Holarrhena pubescens</i>	Apocynaceae	9	6	0	11	8	2	10	8	4

Table 36 continued...

19	<i>Biophytum sensitivum</i>	Oxalidaceae	0	0	0	0	0	0	0	0	0
20	<i>Terminalia paniculata</i>	Combretaceae	1	3	0	0	5	0	3	5	2
21	<i>Sizyphus oenoplia</i>	Rhamnaceae	2	3	0	2	3	0	3	2	1
22	<i>Wrightia tinctoria</i>	Apocynaceae	5	1	0	5	0	0	4	2	1
23	<i>Desmodium gangeticum</i>	Fabaceae	6	5	1	9	4	0	7	6	
24	<i>Indigofera hirsutus</i>	Fabaceae	0	0	0	0	1	1	0	2	0
25	<i>Pycnospora lutescens</i>	Fabaceae	0	0	0	0	0	0	0	0	0
26	<i>Peperomia pellucida</i>	Piperaceae	0	0	0	1	0	0	0	0	0

Table 36 continued...

27	<i>Pennisetum polystachyon</i>	Poaceae	168	74	9	211	52	17	248	88	31
28	<i>Centrosema molle</i>	Fabaceae	0	0	0	0	3	0	0	4	0
29	<i>Ficus hispida</i>	Moraceae	4	1	0	6	0	0	4	0	0
30	<i>Curculigo orchioides</i>	Amaryllidaceae	0	0	0	0	0	0	0	0	0
31	<i>Acacia auriculiformes</i>	Fabaceae	26	6	0	25	7	1	22	11	2
32	<i>Acacia mangium</i>	Fabaceae	20	8	0	24	7	1	24	14	3
33	<i>Bridelia retusa</i>	Phyllanthaceae	0	1	0	0	2	0	0	3	0
34	<i>Selaginella delicatula</i>	Sellaginellaceae	3	0	0	3	0	0	2	0	0

Table 36 continued...

35	<i>Drynaria quercifolia</i>	Polypodiaceae	0	0	0	0	0	0	0	0	0
36	<i>Cheilanthes tenuifolia</i>	Pteridaceae	0	0	0	0	0	0	0	0	0
37	<i>Parahemionitis cordata</i>	Pteridaceae	0	0		0	0	0	0	0	0
38	Total		663	379	54	800	452	155	922	570	295

4.2.2 Diversity indices

4.2.2.1 Shannon- Weiner Diversity index

In the month of January, the largest seedling diversity was found in the originally burnt plots while the diversity was lowest in the newly burnt plots. The sapling diversity was found to be highest in the originally burnt plots while it was found to be lowest in the newly burnt plots (Table 36).

In the month of February, the largest seedling diversity was found in the originally burnt plots while the diversity was lowest in the newly burnt plots. The sapling diversity was found to be highest in the originally burnt plots while it was found lowest in the newly burnt plot (Table 36).

In the month of March, the largest seedling diversity was found in the originally burnt plots while the diversity was lowest in the newly burnt plots. The sapling diversity was found to be highest at originally burnt plots while it was found lowest in the newly burnt plots (Table 36).

In the month of April, the largest seedling diversity was found in the originally burnt plots while the diversity was lowest in the newly burnt plots. The sapling diversity was found to be highest in the originally burnt plots while it was found lowest in the newly burnt plot (Table 37).

In the month of June, the largest seedling diversity was found in the originally burnt plots while the diversity was lowest at control plots. The sapling diversity was found to be highest at originally burnt plots while it was found lowest at the newly burnt plot (Table 37).

In the month of July, the largest seedling diversity was found in the control burnt plots while the diversity was lowest at newly burnt plots. The sapling diversity was found to be highest at originally burnt plots while it was found lowest at the newly burnt plot (Table 37).

Table 37. Monthly Shannon-Weiner diversity index

	CP Seedling	CP Sapling	OBP Seedling	OBP Sapling	NBP Seedling	NBP Sapling
January	2.56	2.19	2.68	2.43	No value	No value
February	2.64	2.23	2.69	2.59	2.42	0.5
March	2.67	2.11	2.84	2.37	2.37	0.94
April	2.74	2.26	2.76	2.42	2.58	2
June	2.88	2.2	2.91	2.38	2.89	1.62
July	2.96	2.16	2.86	2.37	2.76	1.45

4.2.2.2 Pielou's evenness index

In the month of January, the greater species evenness among seedlings was found in the originally burnt plots while the evenness was lowest in the newly burnt plots. The species evenness among saplings was found to be highest in the originally burnt plots while it was found lowest at the newly burnt plot (Table 38).

In the month of February, the greater species evenness among seedlings was found in the newly burnt plots while the evenness was lowest at control plots. The species evenness among saplings was found to be highest at originally burnt plots while it was found lowest at control plot (Table 38).

In the month of March, the greater species evenness among was found in the originally burnt plots while the evenness was lowest at newly burnt plots. The species evenness among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plot (Table 38).

In the month of April, the greater species evenness among seedlings was found in the control plots while the evenness was lowest at originally burnt plots. The species evenness among saplings was found to be highest at newly burnt plots while it was found lowest at the control plots (Table 38).

In the month of June, the greater species evenness among seedlings was found in the control plots while the evenness was lowest at newly burnt plots. The species evenness among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 38).

In the month of July, the greater species evenness among seedlings was found in the control plots while the evenness was found equal at originally burnt plots and newly burnt plots. The species evenness among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 38).

Table 38. Pielou's evenness index (Monthly data)

Pielous	CP seedling	CP sapling	OBP seedling	OBP sapling	NBP seedling	NBP sapling
January	0.77	0.68	0.84	0.76	No value	No value
February	0.79	0.71	0.81	0.80	0.82	0.72
March	0.81	0.69	0.83	0.74	0.77	0.68
April	0.82	0.72	0.78	0.75	0.80	0.78
June	0.85	0.71	0.82	0.74	0.83	0.58
July	0.85	0.70	0.79	0.72	0.79	0.50

4.2.2.3 Margalef's diversity index

In the month of January, greater Margalef's index among seedlings was found in the originally burnt plots while it was found lowest at newly burnt plots. The Margalef's index among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 39).

In the month of February, greater Margalef's index among seedlings was found in the originally burnt plots while it was found lowest at newly burnt plots.

The Margalef's index among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 39).

In the month of March, greater Margalef's index among seedlings was found in the originally burnt plots while it was found lowest at control plots. The Margalef's index among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 39).

In the month of April, greater Margalef's index among seedlings was observed in the originally burnt plots while it was found lowest at newly burnt plots. The Margalef's index among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 39).

In the month of June, greater Margalef's index among seedlings was found in the originally burnt plots while it was found lowest at control plots. The Margalef's index among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 39).

In the month of July, greater Margalef's index among seedlings was found in the originally burnt plots while it was found lowest at newly burnt plots. The Margalef's index among saplings was found to be highest at originally burnt plots while it was found lowest at the newly burnt plots (Table 39).

Table 39. Margalef's diversity index observed during study period

	CP seedling	CP sapling	OBP seedling	OBP sapling	NBP seedling	NBP sapling
January	4.06	3.72	3.92	4.3	No value	No value
February	4.07	3.44	4.31	4.38	3.88	0.62
March	3.99	3.05	4.68	3.97	3.57	1.01
April	4	3.38	4.88	4.04	3.9	3
June	3.94	3.14	4.74	3.92	4.71	2.97
July	4.31	3.07	5	3.93	4.64	2.98

4.2.2.4 Simpson index

In the month of January, higher Simpson index among seedlings was found in the control plots while it was found lowest at newly burnt plots. The Simpson index among saplings was found to be highest at control plots while it was found lowest at the newly burnt plots (Table 40).

In the month of February, greater Simpson index among seedlings was found in the newly burnt plots while it was found lowest at originally burnt plots. The Simpson index among saplings was found to be highest at newly burnt plots while it was found lowest at the originally burnt plots (Table 40).

In the month of March, greater Simpson index among seedlings was found in the newly burnt plots while it was found lowest at originally burnt plots. The Simpson index among saplings was found to be highest at newly burnt plots while it was found lowest at the originally burnt plots (Table 40).

In the month of April, greater Simpson index among seedlings was found in the newly burnt plots while it was found lowest at control plots. The Simpson index among saplings was found to be highest at newly burnt plots while it was found lowest at the originally burnt plots (Table 40).

In the month of June, greater Simpson index among seedlings was found in both fire affected plots viz. originally burnt plots and newly burnt plots while it was found lowest at control plots. The Simpson index among saplings was found to be highest at newly burnt plots while it was found lowest at the control plots (Table 40).

In the month of July, greater Simpson index among seedlings was found in the newly burnt plots while it was found lowest at control plots. The Simpson index among saplings was found to be highest at newly burnt plots while it was found lowest at the control plots (Table 40).

Table 40. Simpson index observed during the study period

	CP seedling	CP sapling	OBP seedling	OBP sapling	NBP seedling	NBP sapling
January	0.11	0.18	0.09	0.12	No value	No value
February	0.10	0.16	0.09	0.11	0.12	0.6
March	0.10	0.18	0.08	0.14	0.14	0.47
April	0.09	0.15	0.10	0.14	0.11	0.19
June	0.07	0.17	0.08	0.18	0.08	0.36
July	0.06	0.17	0.08	0.18	0.09	0.44

4.2.2.5 Sorrensen similarity index

In the month of January, there were more species in common among the control plots and originally burnt plots. There were no species in common among the originally burnt plots and newly burnt plots as the newly burnt plots were readily burnt (Table 41).

In the month of February, there were more seedling and saplings species in common among the control plots and the originally burnt plots. There were less seedling species in common among the control plots and newly burnt plots and less sapling species in common among the originally burnt plots and newly burnt plots (Table 41).

In March, there were more seedling and saplings species in common among the control plots and the originally burnt plots. There were less seedling species in common among the control plots and newly burnt plots and less sapling species in common among the originally burnt plots and newly burnt plots (Table 41).

In April, there were more seedling and saplings species in common among the control plots and the originally burnt plots. There was less seedling species in common among the originally burnt plots and newly burnt plots and less sapling species in common among the control plots and newly burnt plots (Table 41).

In June, there were more seedling species in common among the control plots and the originally burnt plots and more sapling species in common among the originally burnt plots and newly burnt plots. There were less seedling and sapling species in common among the control plots and newly burnt plots (Table 41).

In July, there were more seedling species found in common among the originally burnt plots and newly burnt plots and least found among the control plots and newly burnt plots. There were more sapling species found in common among the control plots and newly burnt plots while the least were found in common among the originally burnt plots and newly burnt plots (Table 41).

Table 41. Sorrensen similarity index during the study period.

	Seedling			Sapling		
	CP*OBP	OBP*NBP	CP*NBP	CP*OBP	OBP*NBP	CP*NBP
January	0.81	No value	No value	0.82	No value	No value
February	0.91	0.83	0.72	0.88	0.14	0.16
March	0.95	0.78	0.75	0.75	0.28	0.32
April	0.89	0.79	0.83	0.91	0.68	0.66
June	0.92	0.90	0.88	0.76	0.78	0.73
July	0.92	0.94	0.89	0.83	0.82	0.84

Table 42: Welch's independent t test for diversity indices (p-value)

	Plots	Shannon-Weiner Index	Simpson's dominance index	Pielou's evenness index	Margalef's diversity index
Seedlings	CP*OBP	0.53	0.85	0.84	0.01**
	OBP*NBP	0.22	0.87	0.33	0.15
Saplings	CP*OBP	0.004**	0.1	0.005**	0.002**
	OBP*NBP	0.007**	0.002**	0.062	0.002**

Photoplate no. 4
Study of plant regeneration



Fig (A)



Fig (B)

Fig A- Regeneration of *Acacia mangium*

Fig B – Cataloguing regeneration

Photoplate no. 5
Major plant regenerations



(i) *Chromolena odorata*



(ii) *Biophytum sensitivum*



(iii) *Clerodendron infortunatum*



(iv) *Hemidesmus indicus*

4.3 STUDY OF SOIL MACRO-INVERTEBRATES

The total number of individuals found in the study area before the monsoon was less compared to those after the monsoon. There were macro-invertebrates representing 3 orders and 8 families. Most number of individuals was found in control plots in both seasons. In the pre-monsoon conditions, ground beetles were found in more number in the control plots. Flesh flies were the major organisms found from the originally burnt area while the click beetles were the larger group found in newly burnt plots. Least number of individuals was found in the newly burnt area. Ground beetle (Carabidae), click beetle (Elateridae) were found in all the three plots during this period. Members of the order Coleopterans and family Carabidae were identified as the major organisms (Table 41).

The total number of individuals found in the study area after the monsoon was more than those present in the pre-monsoon. There were 8 orders and 9 families. Most number of individuals were found from the control plots while the least was from newly burnt areas. Members of the family Formicidae, the ants were found more in number in the control plots. Ants and ground beetles were found more in number in the originally burnt plots while ants were in majority among the invertebrates found from the newly burnt plots. Darkling beetles, silvan flat bark beetles, ground beetles, earthworms, ants, cockroaches etc. were found from all the three plots during this period. Coleopterans were identified as the major order of invertebrates (Table 42).

Table 43. Macro invertebrates recorded in the pre-monsoon conditions.

Sample no:	Order	Family	Common name	CP	OBP	NBP
1	Coleoptera	Teebrionidae	Darkling Beetle	0	2	0
2	Coleoptera	Scarabaeidae	Dung Beetle	1	0	0
3	Coleoptera	Staphylinidae	Rove Beetle	2	1	0

Table 43 continued...

4	Coleoptera	Carabidae	Ground Beetle	7	3	1
5	Hemiptera	Cydnide	Burrower bug	1	4	0
6	Coleoptera	Elateridae	Click Beetle	7	2	4
7	Hemiptera	Veliidae	Broad Shouldered Water Striders	0	4	0
8	Coleoptera	Carabidae	Ground Beetle	11	0	3
9	Hemiptera	Cydnide	Burrower bug	4	0	0
10	Diptera	Sarcophagidae	Flesh Fly	2	5	0
Total	3	8		35	21	8

Table 44. Macro invertebrates recorded in the post-monsoon conditions.

Sample no:	Order	Family	Common name	C P	OB P	NB P
1	Blattode(Dictyoptera)		Cockroach	9	5	3
2	Araneae		Spiders	12	4	2
3	Isopoda	Armadillidiidae	Pillbug	16	2	0
4	Isoptera		Termite(Soldier caste)	9	0	0
5	Coleoptera	Passalidae	Bess bugs	4	7	0
6	Coleoptera	Silvanidae	silvan flat bark beetles	2	7	3

Table 44 continued...

7	Coleoptera	Terebrionidae	Darkling beetles	4	6	2
8	Haplotaxida		Earthworm	29	11	6
9	Hymenoptera	Formicidae	Ant	55	17	8
10	Coleoptera	Scarabaeidae	Dung Beetle	0	3	0
11	Coleoptera	Staphylinidae	Rove Beetle	2	5	0
12	Coleoptera	Carabidae	Ground Beetle	7	17	4
13	Hemiptera	Cydnide	Burrower bug	2	0	7
14	Diptera	Sarcophagidae	Flesh Fly	4	1	0
15			Millipedes	1	1	1
16			Centipedes	0	2	1
Total	9	10		156	88	37

Photoplate no.6
Study of soil macro-invertebrates.



Fig (C)



Fig (D)

Fig A- Hand sorting of macro invertebrates

Fig B- Extraction of macro-invertebrates using Berlese tullgren funnel

Fig C- Darkling Beetle

Fig D- Burrower bug

V. DISCUSSION

The current study was conducted during 2021-2022 to understand and assess the impacts of the forest fire on the vegetation and soil physicochemical and biological properties in the fire burnt areas of Poongode section of Wadakkanchery forest range of Thrissur forest division in Kerala. It was also intended to compare and contrast the changes in the vegetation and soil between burnt and control areas over a time period of six months. For the convenience of representation, control plots, originally burnt plots and newly burnt plots were designated as CP, OBP and NBP respectively.

5.1 Soil studies

5.1.1 Trends in physicochemical properties of soil within and between seasons

Soil moisture content showed a declining trend in general, with increase in number of fires. The newly burnt plots had least average moisture content in both the depths and seasons. This might be due higher burn severity and high soil temperature pre-existed. Soil moisture has an important role in determining extend of fire impacts on soil organic matter (González-Pérez *et al.*, 2004). The decreased soil moisture in burnt plots will facilitate the conditions of a subsequent fire as the process of pre-heating will happen faster. Less energy will be consumed to burn up a fuel to start the fire spread. In the present study the decline is seemed to be a short term effect as the post monsoon observations were not showing any significant difference between the plots in both dry and wet basis. The closer range of soil moisture content of originally burnt plots and control plots in the post monsoon season indicates the recovery of soil moisture in course of time.

Soil bulk density was found higher in the burnt classes of plots than the control plots (NBP>OBP>CP) and this trend reversed in the post monsoon conditions. There was no significant difference in the bulk density between the burned and unburnt plots in the study area. The bulk density (dry basis) ranged

from 0.81- 0.95 gm cm⁻³ in the control area, 0.72-1.16 in the originally burnt area and 0.89-1.15 gm cm⁻³ on the newly burnt sites. The soil types having bulk density below 1.5 g cm⁻³ is considered to be good for plant growth (Chungu, 2020). According to Certini (2005) the bulk density of the top layer of the soil increases slightly after a fire, which is a short term effect. This increment is attributed to the collapse of aggregates and clogging of voids by the ash formed and clay minerals dispersed. This will result in the reduced soil porosity and permeability. This short lived increment in bulk density is also reflected in the present study (Table 7 and Table 8).

Burned classes of plots showed an increase in water holding capacity after fire at the depth of 0-15cm. The water holding capacity of control plots remained highest after the fire in the depth of 15-30 cm. In a similar study conducted by Kamble (2021) in the Gadichiroli forest circle in central India, half of the sampling locations showed an increase in water holding capacity while the other half showed a decrease in water holding capacity. This can be due many reasons. Most studies concluded that the variable heating of the forest soil alters their wet ability and changes the water repellency. The partial combustion of the soil organic matter is the cause of fire induced water repellency. The hydrophobic organic substances in the topsoil which gets heated are volatilized and lost upward in the smoke during burning. A variable proportion moves downward in response to the temperature gradient in the soil till they condense and cover the mineral soil particles in cooler and deeper layers. This process of volatilization and condensation partly explains the strong water repellency in deep layers. Zavala *et al.* (2010) found that water repellency increased when soil heated in the range of 170-200° while water repellency get destroyed when it heated up in the range of 270-300°C. Another factor that influence the soil water holding capacity is the amount and kind of litter consumed in the fire event. The immediate soil moisture before a fire event also has role in determining the soil water holding capacity (Covington, 1991).

Soil texture in both control plots and burnt plots in our study was found to be sandy loam. They followed a trend (Sand % > Silt% > Clay %) throughout the plots. None of the soil textural fractions between plots were found to be significant. The mean values for soil texture in two seasons was found to be non-significant. The soil texture indicates the particle size distribution in the soil. It is the relative proportion of inorganic elements which are less than 2mm of mineral soil. Since the sand, silt and clay exhibit high temperature thresholds, the texture is not easily affected by forest fire, which agrees with the findings of our study (Alcaniz *et al.*, 2016). According to Neary *et al.* (2005), the temperature threshold is lowest for clay particles (400-800°C), ie. They are more sensitive to change in temperatures. This is when the clay hydration and lattice structure begins to collapse. The highest resilience to temperature among the textural fractions are for sand and silt which has its threshold at 1414 °C. Thus the unchanged textural fractions can be explained on the basis of lower temperature increase in the soil after fire.

Average soil pH was found highest in the newly burnt plots in the pre-monsoon conditions. The soil pH levels of originally burnt area and control area remained in a very closer range in both seasons indicating a quick recovery of soil pH level to its original level. The increased pH in the newly burnt plots (immediately collected after burning) during the pre-monsoon can be attributed to the higher temperature experienced during the burning which might have raised in the range of 200 500°C (Terefe *et. al.*, 2008). This increase in soil pH can also be due to the larger ash content deposited on the stand after fire. This will prevent aluminium toxicity and other problems related with the acidic soils (Xue *et al.*, 2014). This liming process is observed to have a positive impact on the biological recovery of the soils after fire (Pietri and Bookes, 2008). The large quantities of essential micronutrients present in the ash can improve the plant growth and contribute to forest productivity (Neff *et al.*, 2005). The mean values of the soil pH in two seasons when compared were found to be highly significant. This may be due to the loss of ash through leaching after the monsoon rain.

In the present study, fire had no effects on soil electrical conductivity. In a similar study conducted at Mudumalai Tiger reserve, the 2 year old burnt plots showed lower electrical conductivity and in the 5, 15 year old burnt plots higher EC were recorded. This reduction of EC in the soil samples could be due to the crumbling of clay minerals, formation of base oxides. Along with this, coarse sand size particles which can enclose the base oxides also forms (Verma, 2019). In some cases an ephemeral increase of soil electrical conductivity was observed. This is due to the release of inorganic ions to the soil followed by the burning of vegetation (Naidu and Srivasuki, 1994). The mean values of the soil electrical conductivity in two seasons when compared were found to be highly significant.

Average soil organic carbon was found highest in the newly burnt plots in both the seasons. This was expected since the addition of fire burnt vegetative residues took place in the sites. This can be due to lack of enough temperature of forest fire required for the oxidation of organic matter present in the soil. This can be further increased due to the incorporation of charred material and ash of dried biomass. The root biomass also have something to contribute to this increment most times (Kamble, 2021). The levels of average organic carbon content in the originally burnt area was close to restoration to the levels of control plots after an year. The mean values of the soil organic carbon in two seasons when compared were found to be non-significant. This might be due to the leaching experienced in the past monsoon seasons.

Burnt classes of plots had more amount of total nitrogen than the control plots. Still there was no significant difference in the amount of total nitrogen between the plots. The increase of total nitrogen after fire can be attributed to the increased accumulation of forest slash in the burned area during the time being. Burning may have increased the release of nitrogen from the residues which could end up in the increased soil nitrogen. A similar study conducted by Chungu (2020), in the Muchinga provinces of Zambia conforms to these outcomes. The study reveals that more than 100% of increase in the total nitrogen was observed in

burned sites (0.04%) compared to the control sites (0.02%). The mean values of total soil nitrogen in two seasons when compared were found to be highly significant. In a similar study conducted by Verma (2019), at Mudumalai Tiger Reserve, the 2 year old burnt plots showed lower nitrogen content while the 5 year and 15 year old burnt plots started showing recovery to its original stage.

Total phosphorus was found highest in the fire affected plots in both seasons. In both the seasons, unburned plots possessed the least P content. The reason behind this observation can be attributed to the larger fire intensity experienced. Along with the increase in the exchangeable cations like Ca^{2+} , Mg^{2+} , mineralized nitrogen, the phosphorus content was also increased with increase in fire intensity (Verma *et al.*, 2019). The phosphorus is the second most limiting factor for the plant growth. It is also notable that, during the forest fire, the organic phosphorus in the organic matter mineralizes to form available orthophosphate which are readily plant absorbable. The addition of ash onto the soil surface, reduced phosphorus losses due to higher vaporization and the apatite (insoluble P) formation (PO_4^{3-}) can also be the causes behind the increased phosphorus levels in the fire affected plots compared to the control plots (Zhang and Biswas, 2017). The mean values of total phosphorus in two seasons when compared were found to be significant. This might be due to the surface run off took place after the monsoon rainfall.

There was no significant difference in the levels of potassium between the plots in both the seasons. The newly burnt plots showed a decrease in the potassium levels immediately after the fire. The mean values of the total potassium in two seasons when compared were found to be highly significant and is due to excessive leaching in the monsoon season. Findings of the present study conforms to the results of a similar study undertaken by Verma (2019) at Mudumalai tiger reserve. This study carried out to assess the variations in the potassium level in fire affected soils of reserve. They found out that the changes in the concentration of potassium after fire was highly significant. The study recorded that the levels of potassium

decreased initially and was lower till the second year of burning and started increasing after the third year.

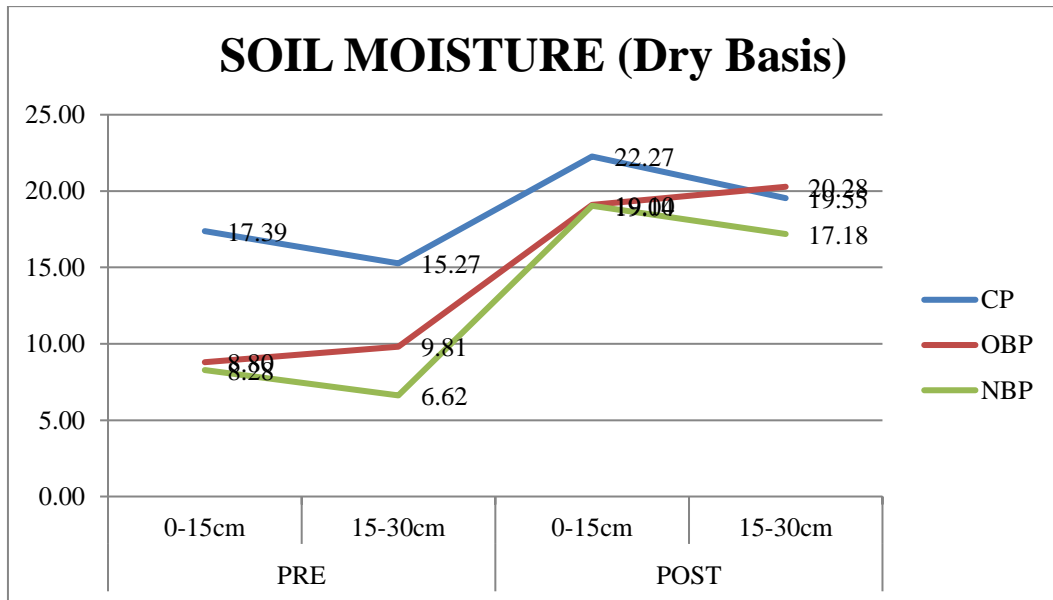


Fig 6. Average soil moisture (Dry basis) in different plots in 2

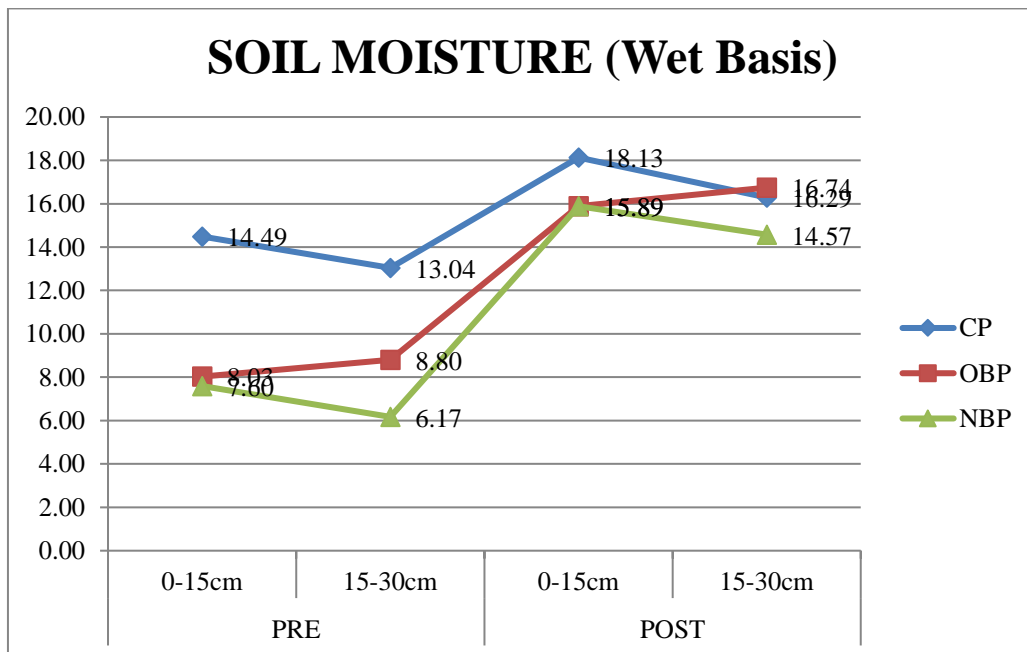


Fig 7. Average soil moisture (Wet basis) in different plots in 2 seasons (%)

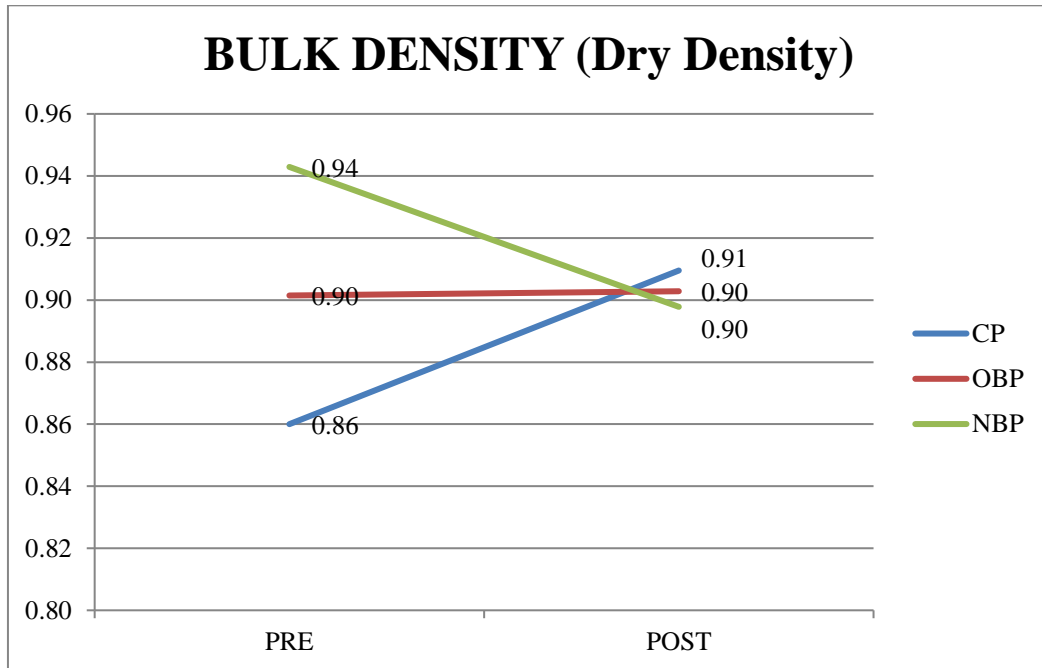


Fig 8. Average bulk density(Dry basis) in different plots in 2

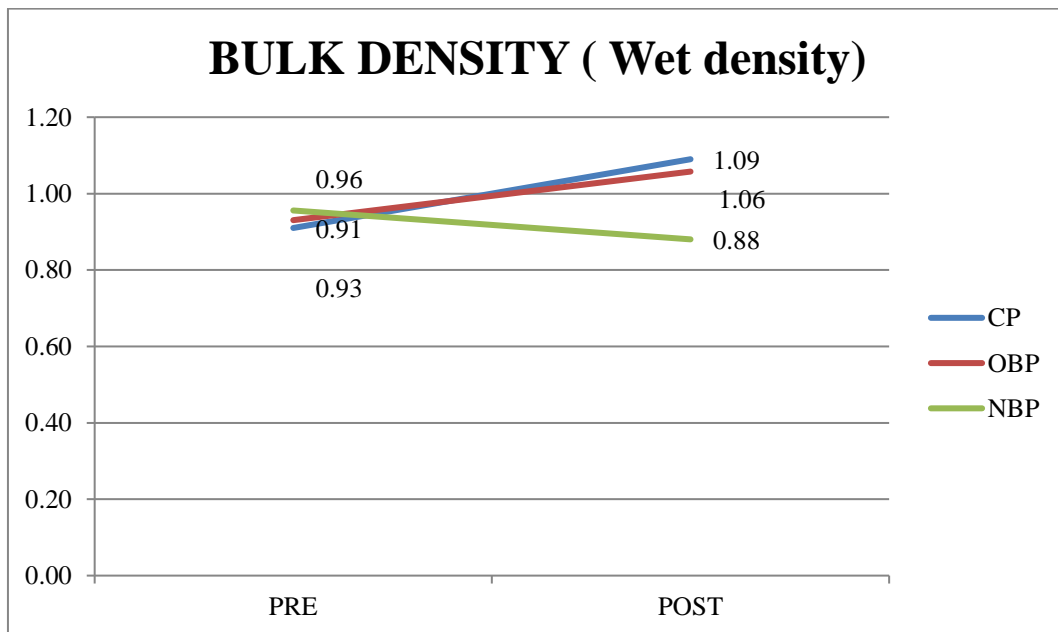


Fig 9. Average bulk density (Wet basis) in different plots in 2 seasons(g/cm^3)

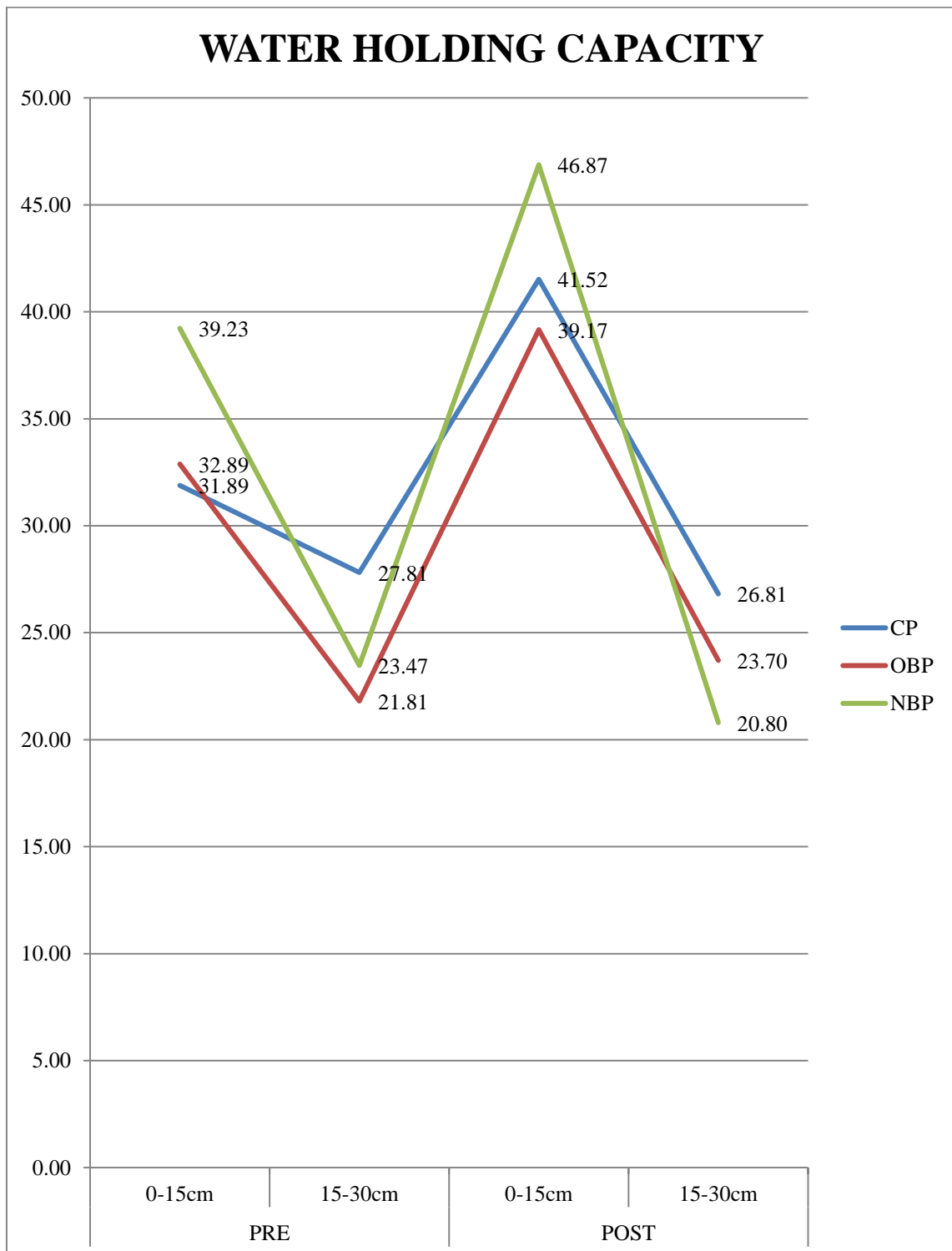


Fig 10. Average water holding capacity in different plots in 2 seasons(%).

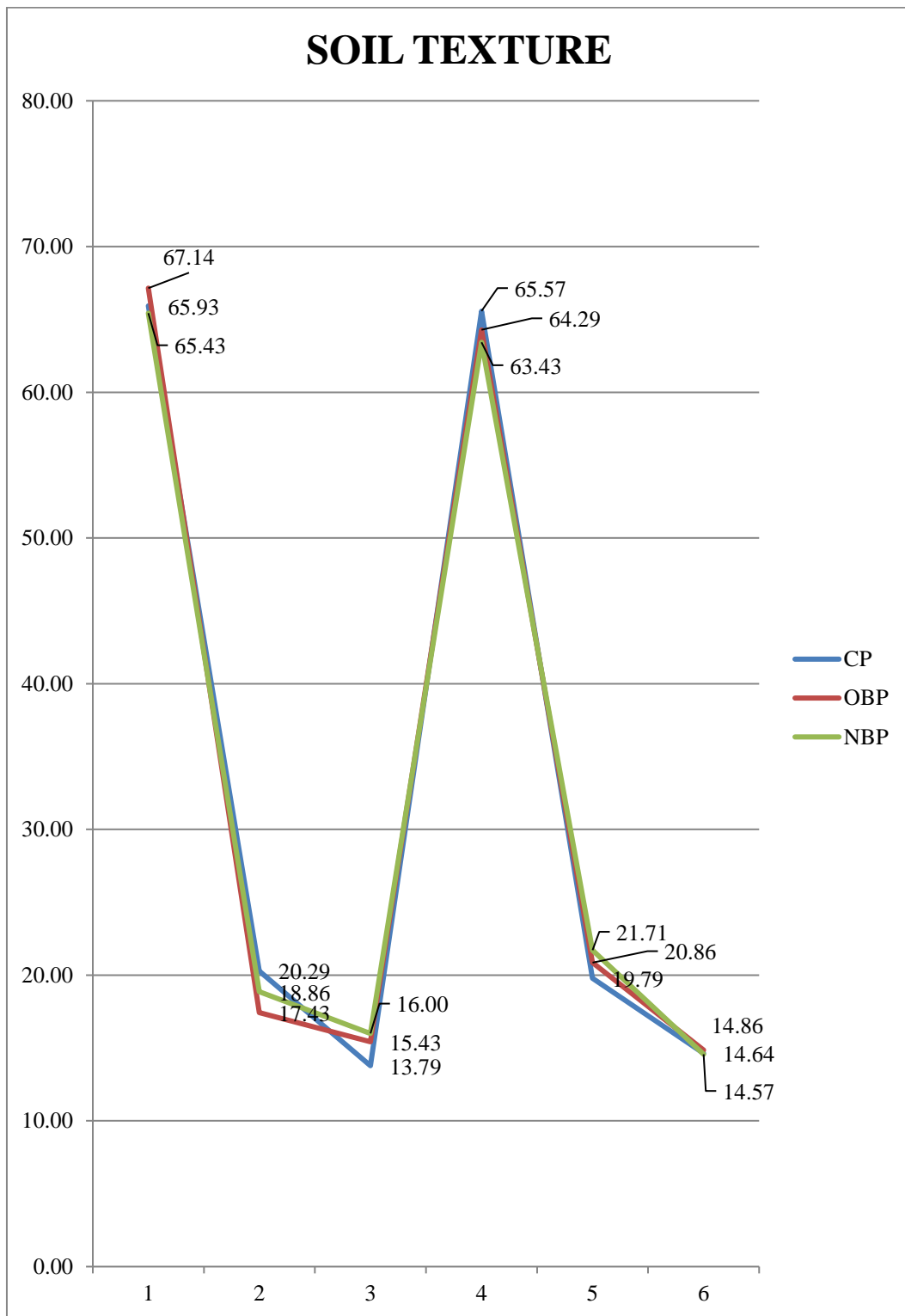


Fig 11. Average soil texture in different plots in 2 seasons

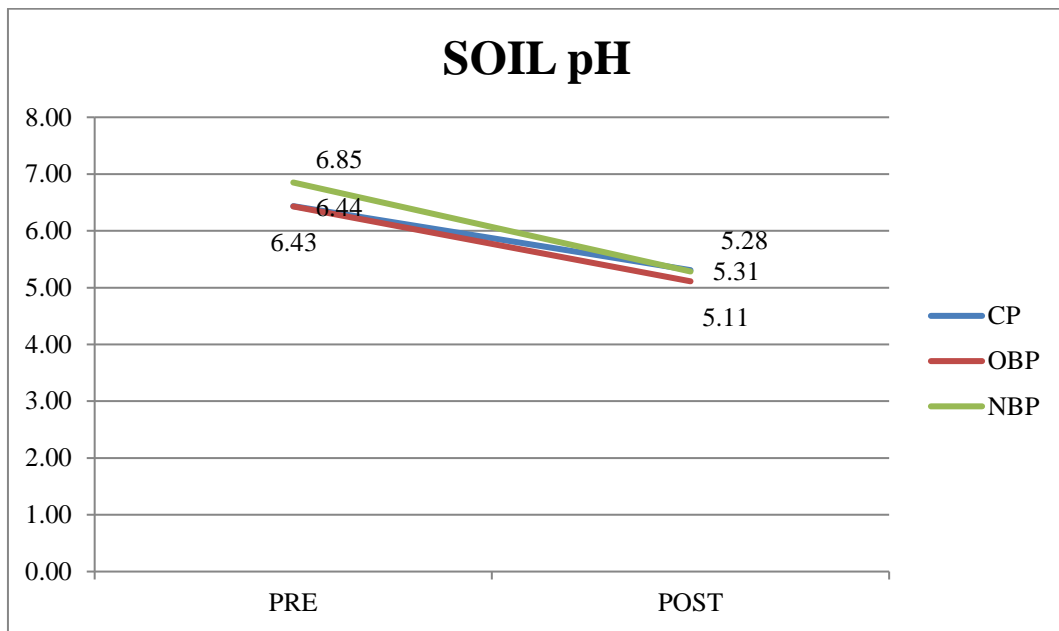


Fig 12. Average soil pH in different plots in 2 seasons

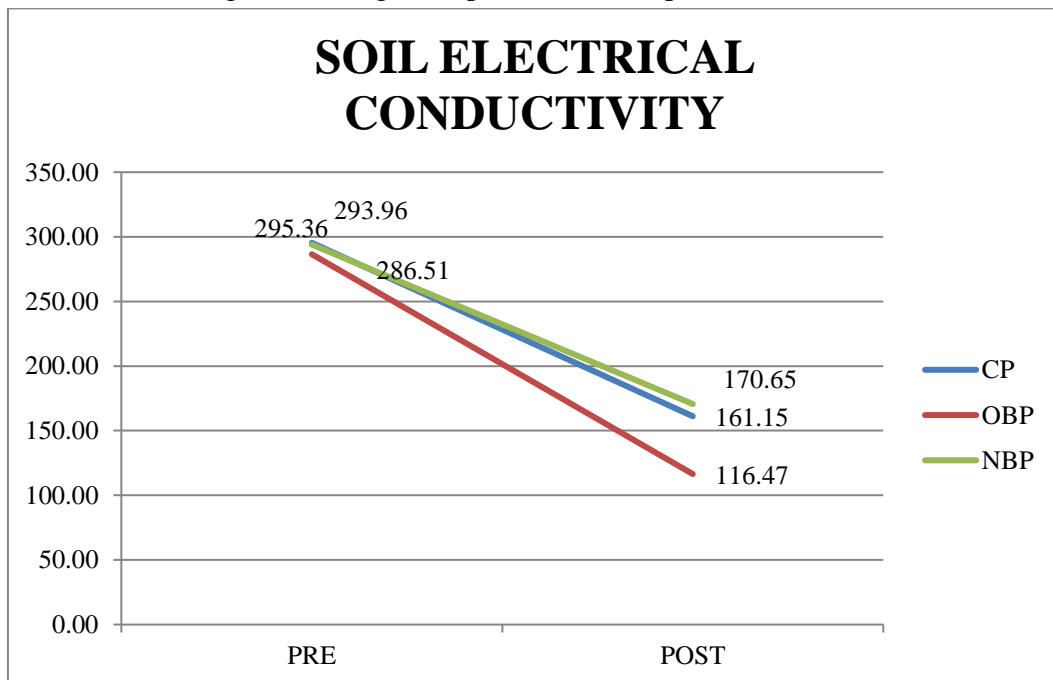


Fig 13. Average soil electrical conductivity (mS/m) in different plots in 2 seasons

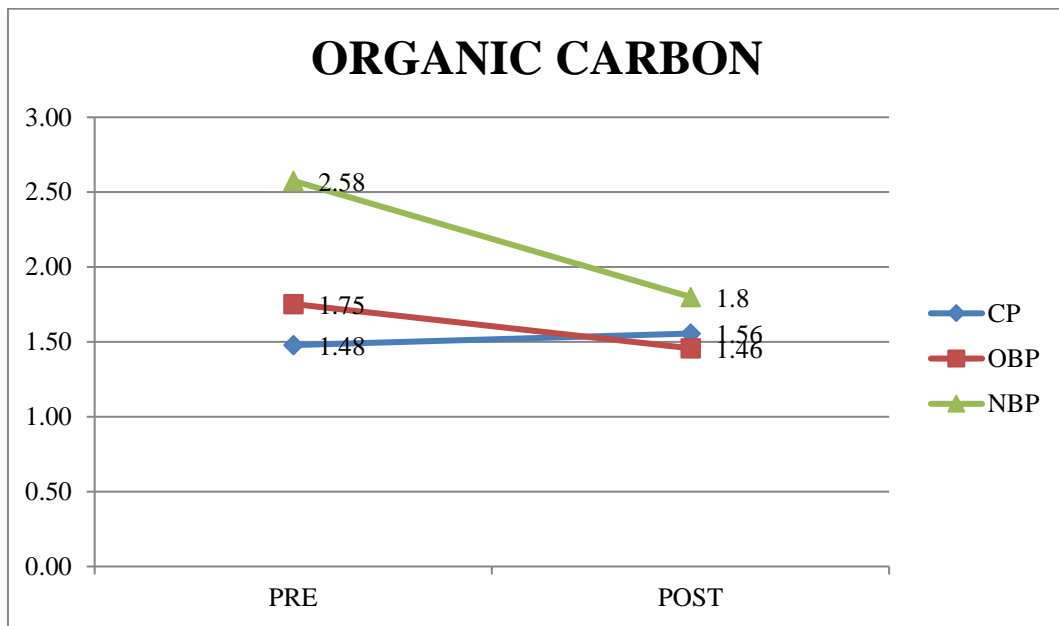


Fig 14. Average soil organic Carbon (%) in different plots in 2 seasons.

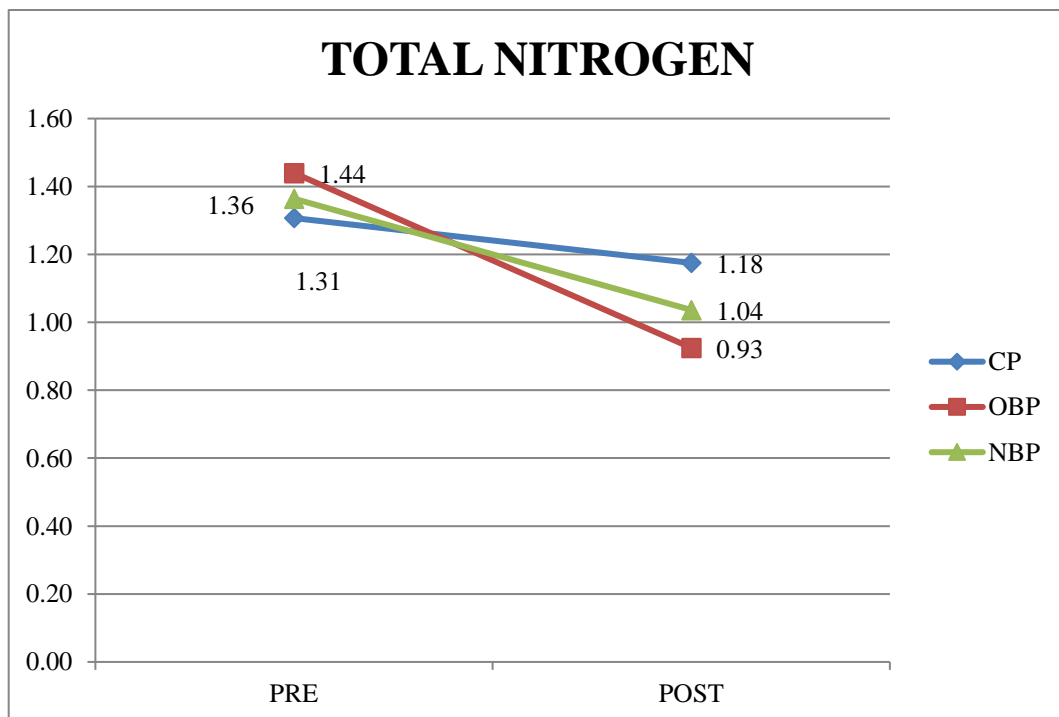


Fig 15. Average soil total Nitrogen (%) in different plots in 2 seasons

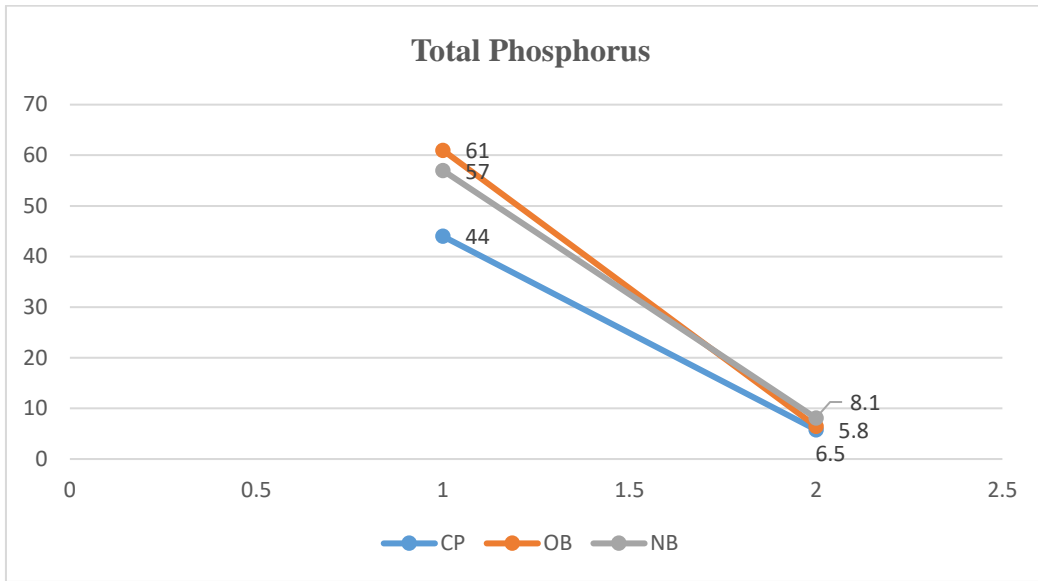


Fig 16. Average soil total Phosphorous (ppm) in different plots in 2 seasons

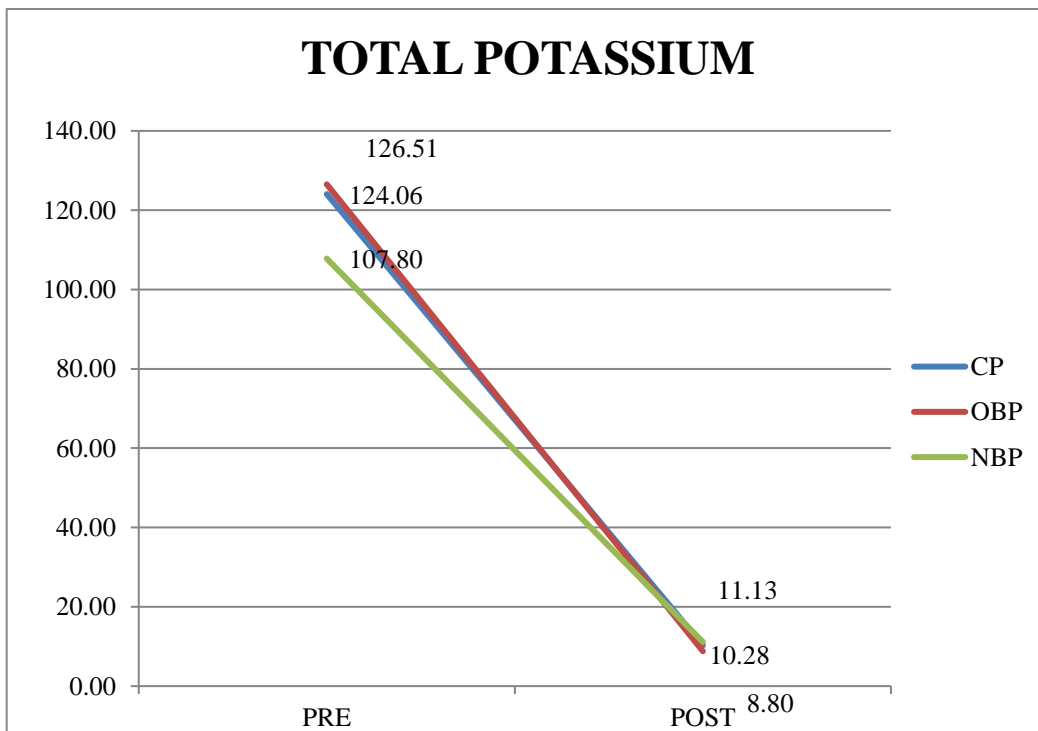


Fig 17. Average soil total potassium (ppm) in different plots in 2 seasons

5.1.2 Soil Erosion

A significant hike in the annual soil erosion was recorded in both the burned areas compared to the control area. This can be due to the decreased vegetation primarily. Breakdown of organo-mineral aggregates and clogged soil pores by ash or free minerals which resulted in the increase of bulk density of the soil after fire may also have boosted the erosion. (Alcaniz *et al.*, 2018). This will lead to a decline in water holding capacity and consequently accelerating runoff and soil erosion will come into play soon which affects the plant growth (Martin and Moody, 2001). Deban and Conrad (1978) suggested that the nutrients in live twigs and dead plant matter can be lost either by volatilization during a fire or be released and deposited on the soil in a more soluble form. These soluble forms of nutrients can be either absorbed easily by plants or be lost by soil erosion post fire.

The rate of soil erosion in the originally burnt area is less than that in the newly burnt area. This is evidently due to the plant regeneration in the area (Table 32). According to a study by Nikolaos (2020), using the Arcmap programme to estimate the average annual soil loss in a fire affected area, the annual average soil loss increased from 69 t/ha/year to 94 t/ha/year post fire. It has come down to 64 t/ha/year after 15 years of the fire incidence.

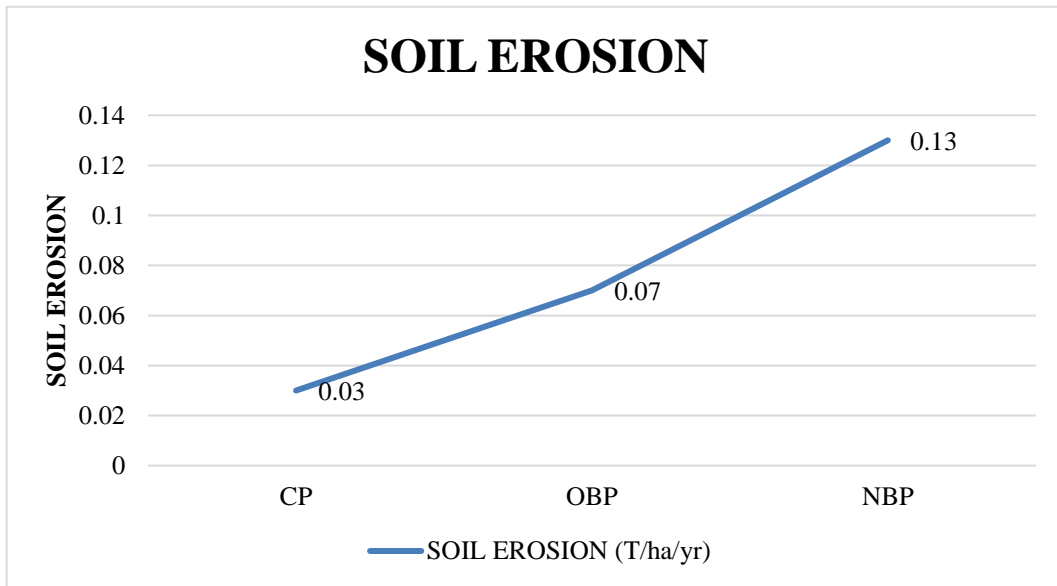


Fig 18. Average annual soil erosion (tonnes/ha/year)

5.2 REGENERATION STUDY

The present study area is a plantation comprises of *Acacia mangium*, *Acacia auriculiformis* and *Eucalyptus spp.* in a small patch. The mismanaged plantation was overgrown with large growth of weeds and grasses. The vegetation analysis using various diversity indices revealed the species composition which markedly varied between the three different plots viz. the control area, originally burnt area and newly burnt area over the time frame of 6 months from 2021 January to 2021 July.

A total of 37 plant species representing 20 plant families from the study area in two fire frequency classes and control plots were recorded. Thirty one species were present in all classes during the study period while six species viz. *Pycnospora lutescens*, *Bridelia retusa*, *Selaginella delicatula* *Cymbopogon flexuosus*, *Hemidesmus indicus* and *Drynaria quercifolia* were not present in all classes throughout the study period. Three plant species were exclusively found in fire affected plots. They were *Hemidesmus indicus*, *Pycnospora lutescens* and *Drynaria quercifolia*. Members of the family Fabaceae dominated among the plant families.

A larger increment in the regeneration than previous months was recorded after the onset of monsoon. A significant number of tree regenerations were observed during this period. Sapling density was comparatively lower in fire classes than seedling density. Regeneration of *Acacia auriculiformis* and *Acacia mangium* which made up the plantation was found in all the plots though it was absent in the burned plots in the initial months post fire.

The present study of regeneration is highly relevant as the area is prone to forest fire throughout the year. The dry and dessicating wind through Palghat gaps make the region drier which consequently make them prone to fire. The recent records of frequent fire incidences in the years from 2010- 2020 are evidence for this. It is noteworthy that the vulnerability to forest fires varies with kind of vegetation. The mean fire return interval in the tropical dry deciduous forests of

the Mudumalai tiger reserve had significantly increased to 9.28 years (1999-2013) from 3.3 years (1989-2002). This increase in mean fire return interval is attributed to the change in plant species in the forest over time after each fire. 150 years ago, present Mudumalai tiger reserve was dominated by *Pterocarpus marsupium*, *Lagerstroemia microcarpa* and *Dalbergia latifolia*. It has been replaced by *Anogeissus latifolia* and *Terminalia crenula* over time. In our present study, though many species had its presence in all classes of plots, frequent fire events may subsequently change the species dynamics.

Eleven tree species were recorded during the study period among the regeneration. This includes *Acacia mangium* and *Acacia auriculiformis* along with other nine species. They are *Bridelia retusa*, *Ficus hispida*, *Wrightia tinctoria*, *Terminalia paniculata*, *Macaranga peltata*, *Holarrhena pubescens*, *Sterculia guttata*, *Helicteres isora* and *Clerodendron infortunatum* representing 9 families. They are Apocynaceae, Fabaceae, Malvaceae, Phyllanthaceae, Combretaceae, Euphorbiaceae, Lamiaceae, Moraceae and Bombacaceae. All the above species are recorded from all classes of plots. Thus the effects of fire on the regeneration of these species found to be questionable pointing that the count of the individuals was lower in the fire affected plots in comparison with the control plots. The results of a similar study conducted by Manjula (2012) conforms to this. The author justifies the elimination of species in the site as a temporary phenomenon since the seeds can be dispersed again from the fire untouched parts of forest. The response of species to fire varies with the frequency and intensity of fires. The intensity of the fire varies since the fuel load in the stand varies with events between fire events.

The comparatively lower number of tree species individuals recorded in the sapling stage points at the higher infestation of exotic weeds like *Chromolaena odorata* in the study area after the fire in the short time frame. *Cymbopogon flexuosus* and the *Pennisetum polystachium* were the grasses identified from the study area. These were found in both the control and burned plots. Four fern species

were recorded from the study area in which the *Drynaria quercifolia* and *Cheilanthes tenuifolia* were found exclusive from fire affected area.

The area lies in the catchment of the river Bharatapuzha. There are 24 small streams within this area but carrying very low volume of water and remain dry most of times in an year. Vegetation density of an area has more influence on the hydrology of an area rather than the vegetation diversity. The area if restored properly will be a blessing to the people inhabiting around as it can ensure sustained water flow throughout the year.

5.2.2 Diversity indices

The average Shannon Weiner diversity index of seedlings were high for the one year old burnt plots which ranged from 2.68-2.91. The highest value was registered for the observations in the control plots in the month of July (2.96). The Shannon Weiner index of saplings were high for the one year old burnt plots which ranged from 2.37 and 2.59. The lowest range was found for the newly burnt plots among both seedlings and saplings (table 37).

The average Pielou's evenness index among the seedlings was found higher in the control plots in which their values ranged between 0.77-0.85. The particular index ranged between 0.72-0.80 among saplings. The lowest range was found for the newly burnt plots among both seedlings and saplings (table 38)

The average Margalef's diversity index was highest for one year old burnt plots among both seedlings and saplings. The values ranged between 3.92-5.00 and 3.92-4.38 for seedlings and saplings respectively. The lowest range was found for the newly burnt plots among both seedlings and saplings (table 39).

The average Simpson index for seedlings and saplings were highest for newly burnt plots as they ranged between 0-0.14 and 0- 0.47 respectively. The lowest range was found for the OBP among both seedlings and saplings (table 40).

Sorrensen similarity index value gives the concept of the presence of common species among different plots. Higher the value, greater will be the overlapping. Highest number of seedling species were found in common amongst control plot vs one year old burned plot was in the month of March and one year old burnt plot vs newly burnt plot and control plot vs newly burnt plots was in the month of July. Highest number of sapling species were found in common amongst control plot vs one year old burned plot was in the month of April and one year old burnt plot vs newly burnt plot and control plot vs newly burnt plots was in the month of July (table 41).

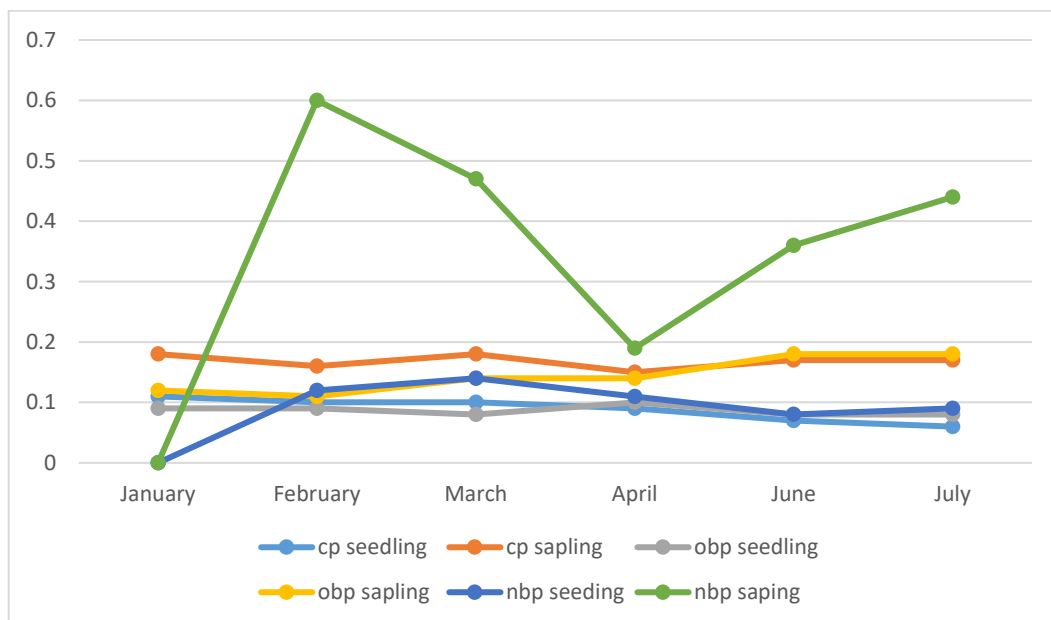


Fig 19: Shannon –Weiner diversity indices (monthly)

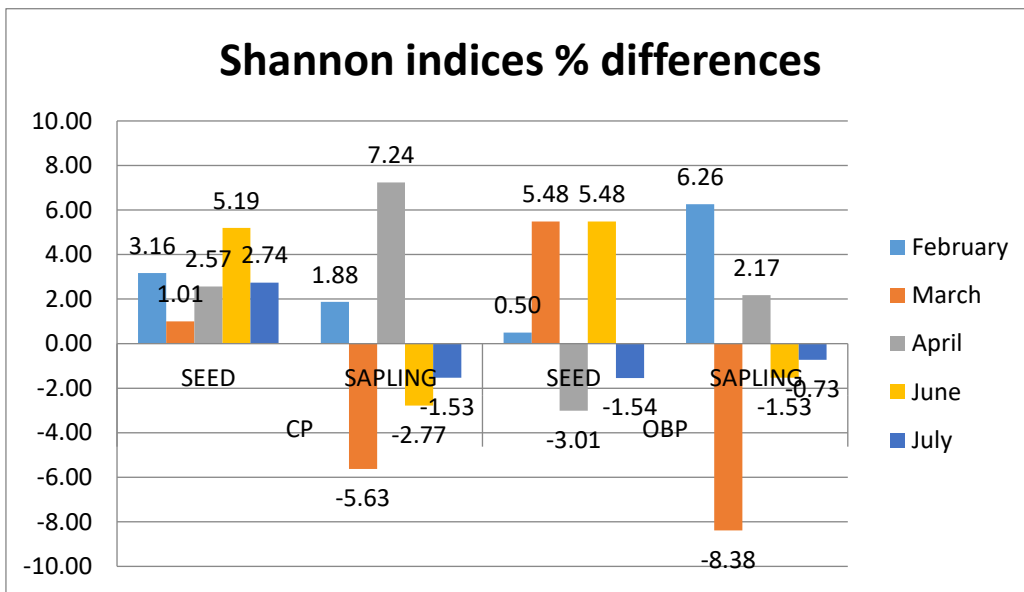


Fig 20. Monthly difference in Shannon-Weiner indices (%)

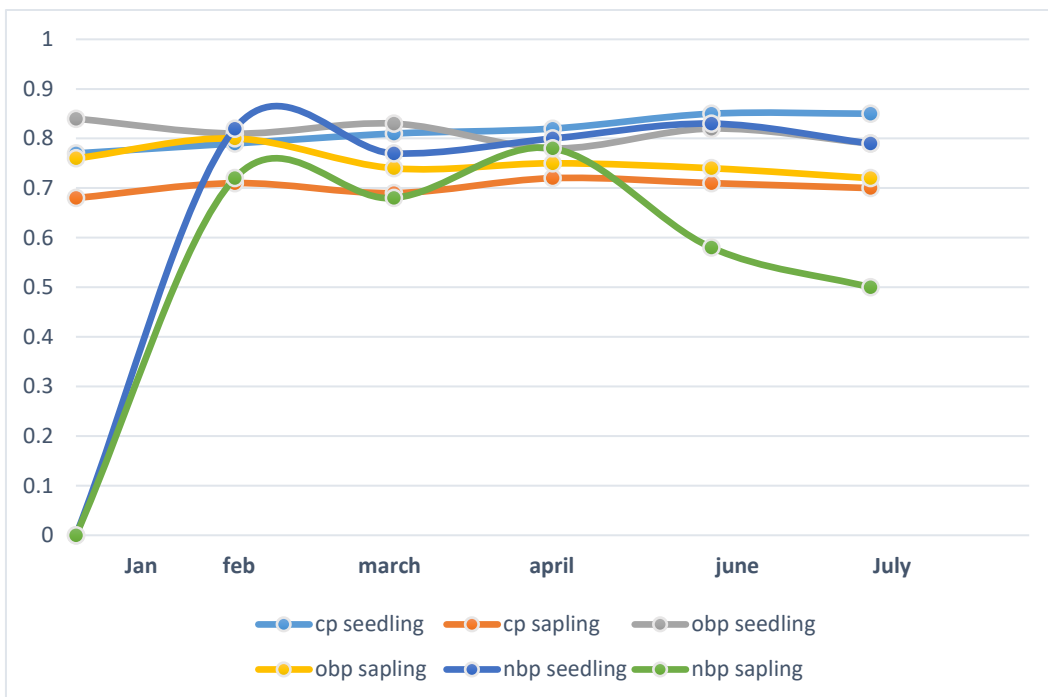


Fig 21. Pielou's evenness index (monthly)

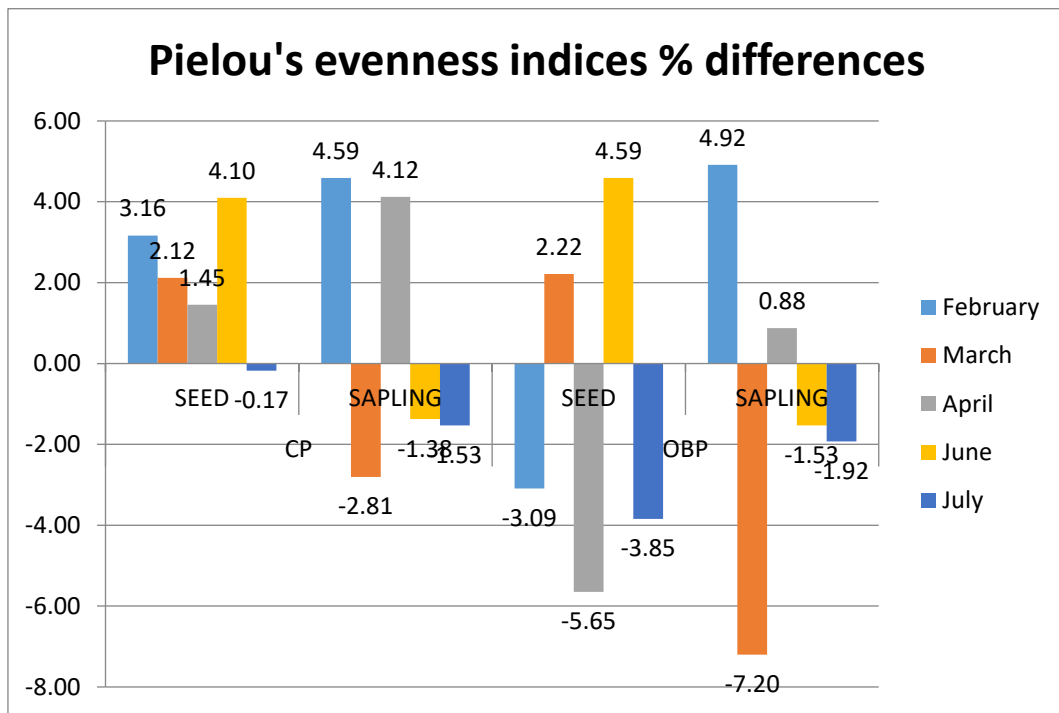


Fig 22. Monthly difference in Pielou's evenness indices (%)

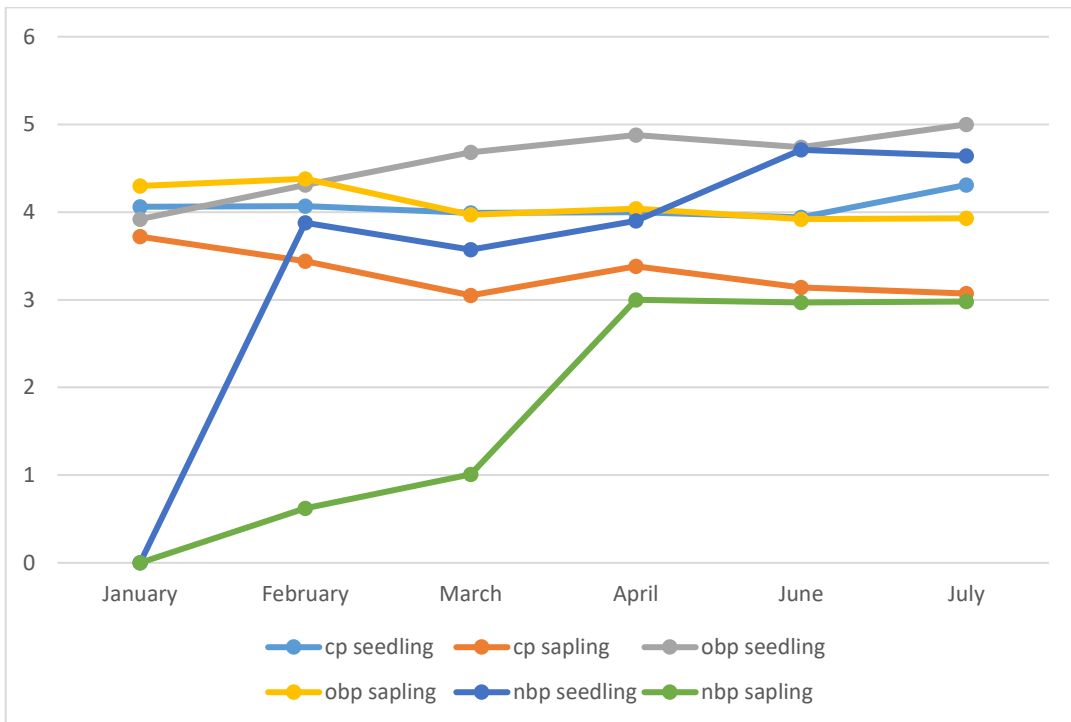


Fig 23. Margalef's diversity index

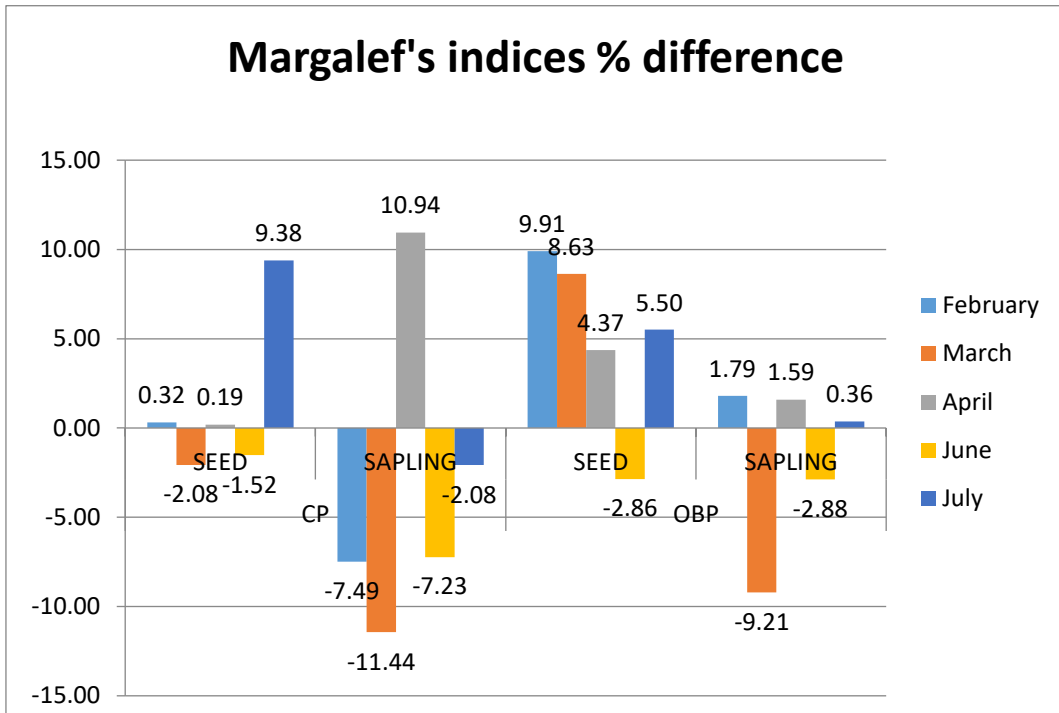


Fig 24. Monthly difference in Margalef's diversity indices (%)

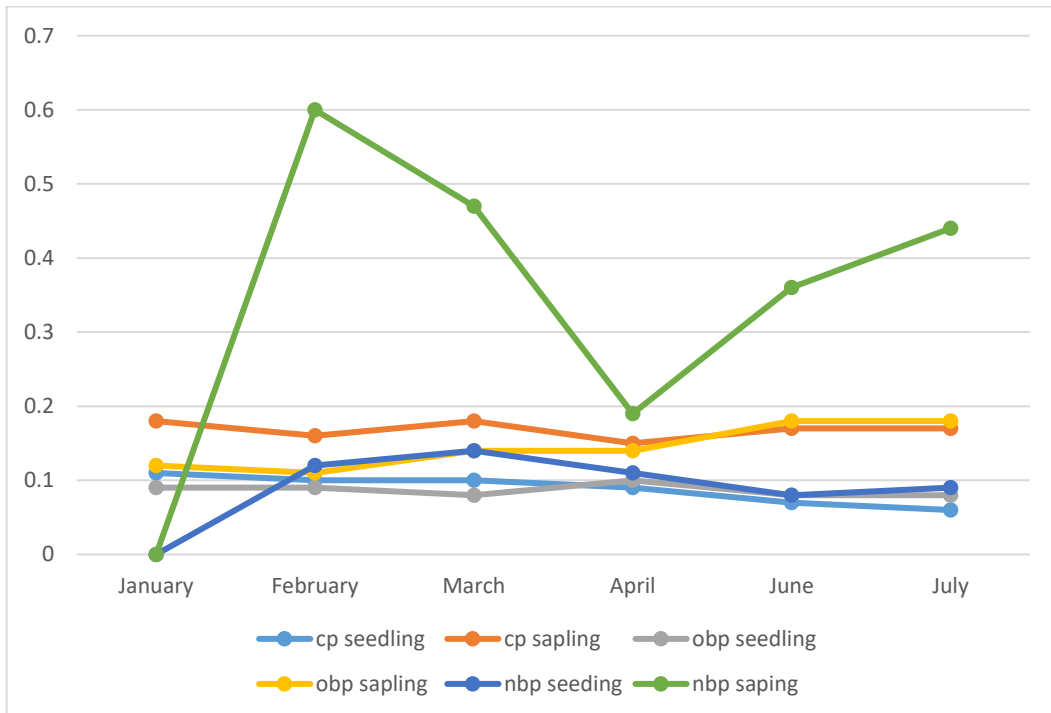


Fig 25. Simpson's dominance index

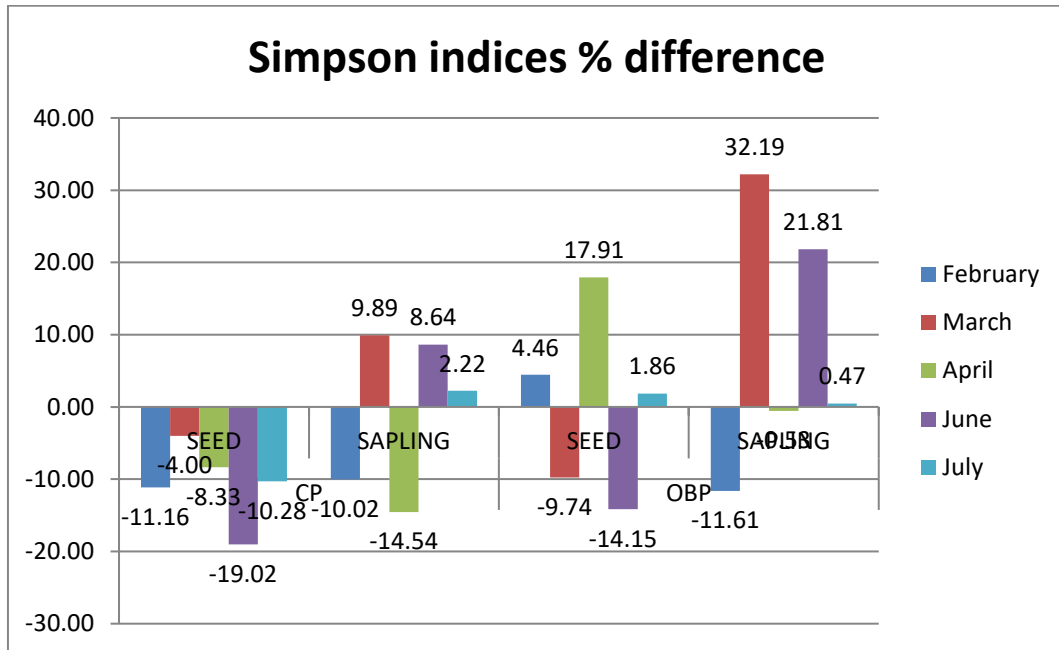


Fig 26. Monthly difference in Simpsons’s dominance indices (%)

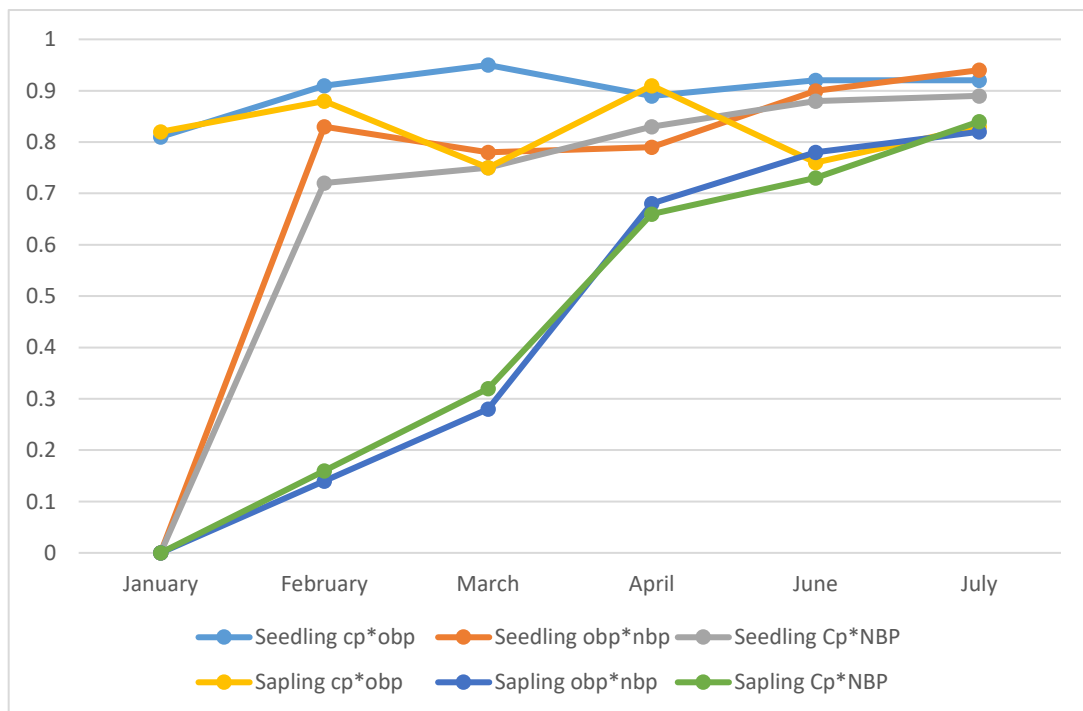


Fig 27. Sorrenson similarity indices (Monthly)

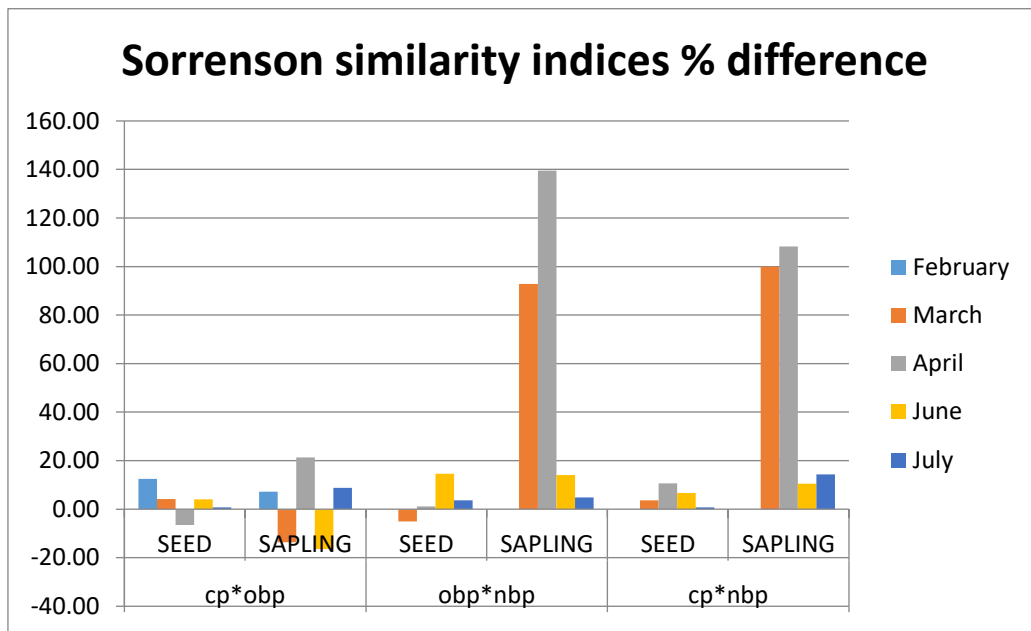


Fig 28. Monthly difference in Sorrenson similarity indices (%)

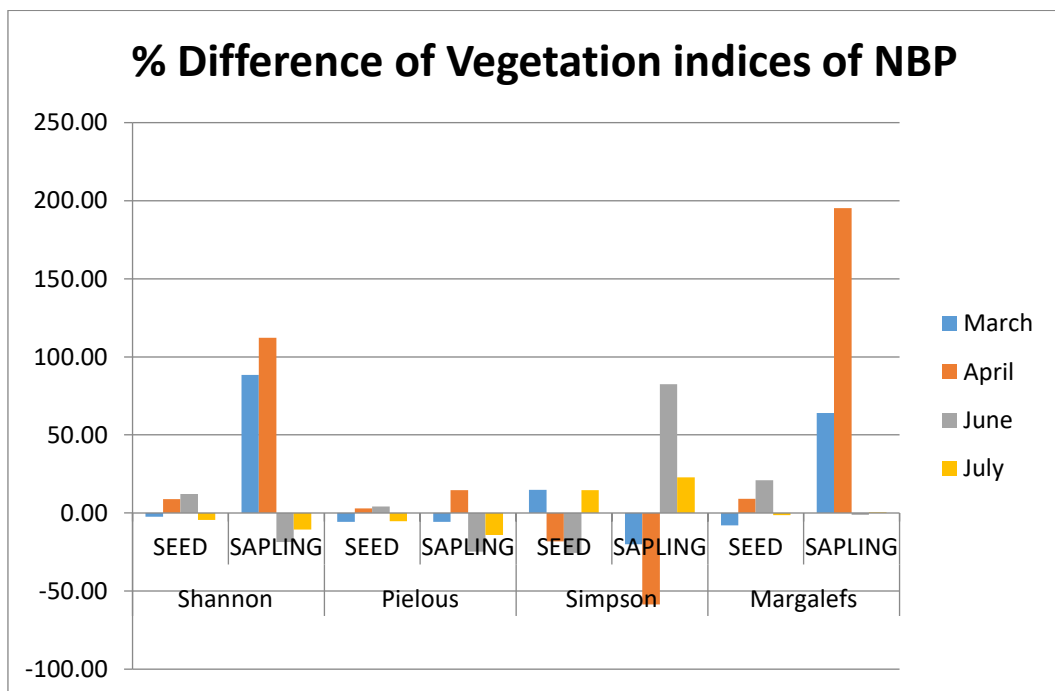


Fig 29. Variations (%) in the vegetation indices of newly burnt plots.

5.3 MACRO-INVERTEBRATES

Most members were recorded from the control plots than both the fire affected classes. The ants which were representing the Formicidae family were present in all the plots in both the seasons. An increase in the number of individuals was observed after the monsoon. The hard coated beetles registered their presence in significant number in the burned classes and the soft bodied animal like earthworm, centipedes and millipedes were absent immediately after the fire but appeared after the monsoon suggesting that the temperature variation in the ecosystem made them to move away. This agrees with Neuman (2010), as he also in a similar study pointed out the decrease in the millipedes immediately after the fire due to the removal of litter and increased temperature around. The responses to natural or man-made fire disturbances are generally associated with the fire dependence or sensitivity of the ecosystem in question. Other factors include frequency and intensity of fires and life history traits of the soil organisms.

The unavoidable physical, chemical and biological changes happening to the soil after every fire incident are potentially able to influence the soil fauna. Ants and earthworms were recorded from the fire affected plots. These are invasive in nature. These two major faunal groups are able to change the soil physical properties, rate of decomposition and nutrient dynamics (Holdsworth *et al.*, 2012). The effects of these organisms on a forest ecosystem are yet to be understood well in combination with others.

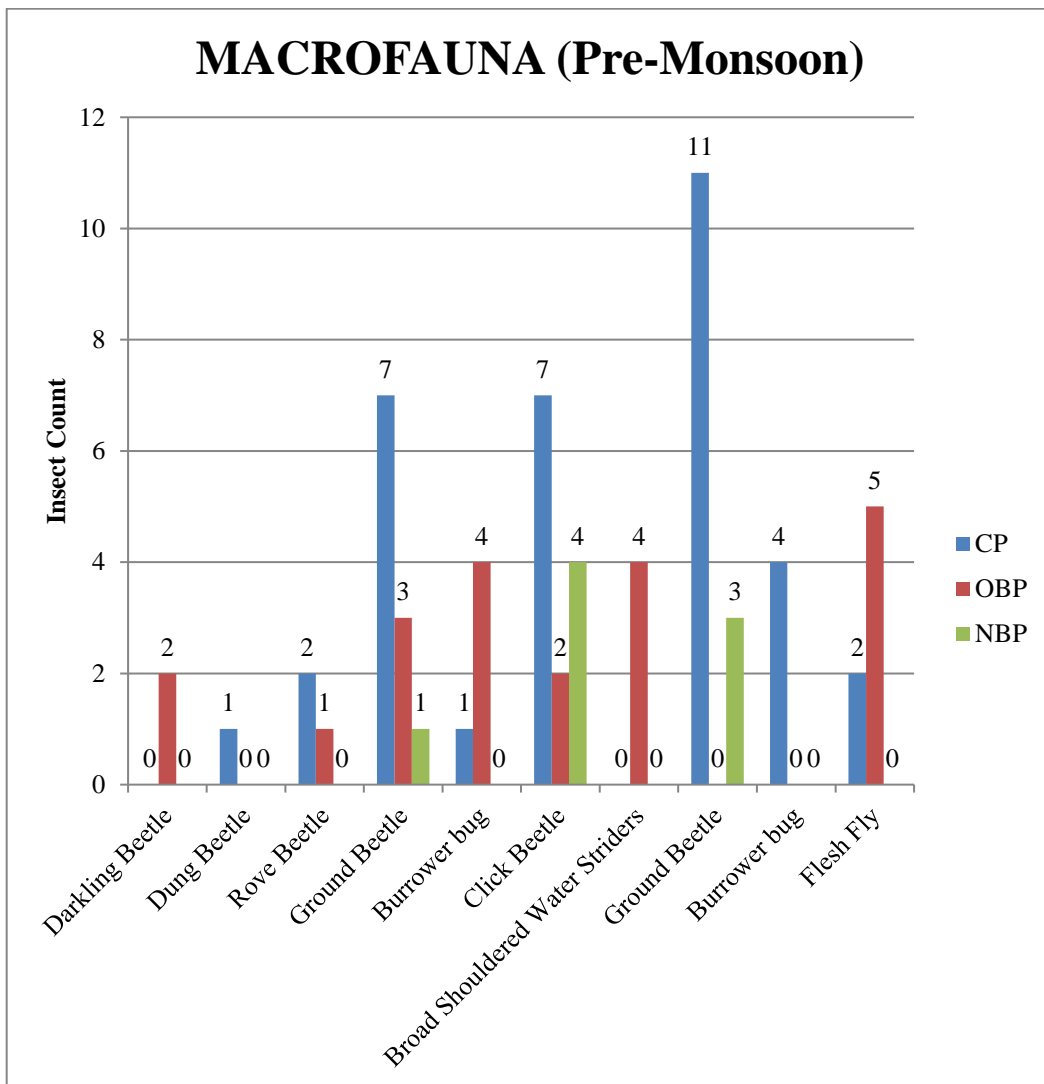


Fig 30. Macro invertebrates present in different plots in pre-monsoon

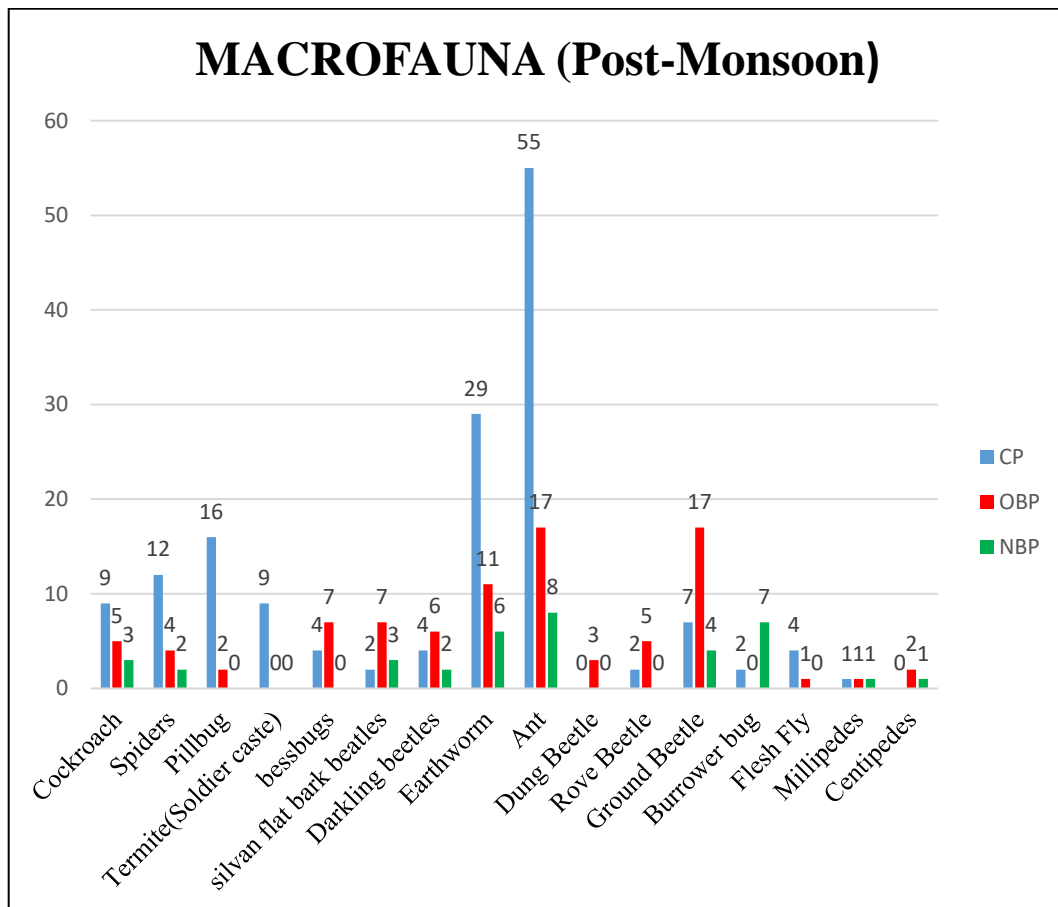


Fig 31. Macro invertebrates present in different plots in post monsoon

The study done to understand impacts of forest fire on vegetation, soil physicochemical and biological properties and macro invertebrates in the fire burnt areas of Poongode section of Wadakkanchery forest range of Thrissur forest division revealed that floristic composition, diversity, soil physico-chemical and biological properties and macro faunal population are clearly different in the fire affected areas. As already explained, the reasons for this could be attributed to several factors like fire intensity, fire duration, previous fire records, pre-existed biotic and abiotic conditions in the fire affected area. These factors need to be individually studied to conclusively establish their influence on the post fire environment. The present situation may be changed further as the area is having frequent fire records and higher biotic pressure as the surroundings are largely populated. The variations in the species combination existing in various fire

frequency classes may be an indicator to an evolving fire resistant plant community. Changes happened to soil physicochemical and biological properties are short lived. These will be restored to original state in due course of time. The increased soil erosion in the fire affected area is also a short lived phenomenon as it can be stabilized with establishment of vegetation. The shifting of macro fauna followed by a fire is observed to be a temporary phenomenon. Once favourable situations sets in, these will get back to their previous habitats. A better understanding on the fire effects on a tropical forest ecosystem is possible only if it is put under investigation for longer periods.

Future line of study

The impacts of fire on soil and vegetation has been extensively studied in various parts of the world but very little studies has been done on this topic in the tropical forests of India. A more elaborate, long duration study on the effects of fire on vegetation and soil along various fire affected forest ecosystems across Kerala and India are to be conducted. It is important to study the changes happening over a fire affected area for a longer time frame (eg: 5, 10, 15 years) since many of the variations are short lived and are able to recover to original stage. It is also important to monitor fire prone areas to find out the suitable species for a site as it is a time consuming process. This can help forest departments in drawing a better eco-restoration plan for such areas. The responses of soil, regeneration, macro-invertebrates may vary with the fire intensity and severity, fire duration, site characteristics and pre-burn conditions. The variations in the hydrological features like water quality and quantity caused by fire must also be brought under investigation hereafter as it has its effects on human water uses. The wildfires are expected to increase with the climate change. Hence it highlights the requirement for research on the effects of the large landscape-scale perturbations on soil, vegetation, macro invertebrates along with the forest water.

VI. SUMMARY

The present study attempted to investigate the effects of forest fire on vegetation and soil in a forest ecosystem. Concurrently an attempt was made to understand the changes happening in that forest ecosystem over a time period of six months. The study entitled “Fire effects on vegetation and soil in a forest ecosystem in Wadakkanchery forest range, Thrissur forest division, Kerala” was undertaken to analyse the effects of fire had on vegetation, soil and composition of macro invertebrates. The outcomes obtained from this study are summarized in this chapter.

1. A total of 37 plant species representing 20 plant families from the study area were recorded in two fire frequency classes and control plots. Members of the family Fabaceae dominated the plant families. 31 species were present in all classes. 3 plant species were exclusively found at fire affected plots.
2. Twelve tree species were recorded during the study period among the regeneration. This includes *Acacia mangium* and *Acacia auriculiformis* along with other nine species. They are *Bridelia retusa*, *Ficus hispida*, *Wrightia tinctoria*, *Terminalia paniculata*, *Macaranga peltata*, *Holarrhena pubescens*, *Sterculia guttata*, *Helicteres isora* and *Clerodendron infortunatum* representing 9 families.
3. The comparatively lower number of individual tree species recorded in the sapling stage points to the higher infestation of exotic weeds like *Chromolaena odorata* in the study area after the fire in the short time frame. *Cymbopogon flexuosus* and the *Pennisetum polystachium* were the grasses identified from the study area.
4. Four fern species were recorded from the study area in which the *Drynaria quercifolia* and *Cheilanthes tenuifolia* were found only from fire affected area.
5. The average Shannon Weiner diversity index of seedlings were high for the 1 year old burnt plots which ranged from 2.68-2.91. The highest value was

registered for the observations in the control plots in the month of July (2.96). The Shannon Weiner index of saplings were high for the one year old burnt plots which ranged from 2.37 and 2.59. The lowest range was found for the newly burnt plots among both seedlings and saplings (table 36).

6. The average Pielou's evenness index among the seedlings was found higher in the control plots in which their values ranged between 0.77-0.85. The particular index ranged between 0.72-0.80 among saplings.
7. The average Margalef's diversity index was highest for one year old burnt plots among both seedlings and saplings. The values ranged between 3.92-5.00 and 3.92-4.38 for seedlings and saplings respectively.
8. The average Simpson index for seedlings and saplings were highest for newly burnt plots as they ranged between 0-0.14 and 0- 0.47 respectively.
9. Highest number of seedling species were found in common amongst control plot vs one year old burned plot in the month of March and one year old burnt plot vs newly burnt plot and control plot vs newly burnt plots in the month of July. Highest number of sapling species were found in common amongst control plot vs one year old burned plot in the month of April and one year old burnt plot vs newly burnt plot and control plot vs newly burnt plots in the month of July.
10. More members were recorded from the control plots than both the fire affected classes in 2 seasons. This may be due to the shifting of macro-invertebrates due to increased temperature experienced during the fire.
11. Soil moisture content showed a declining trend in general, with increase in number of fires. Average soil moisture content ranged from 8.28% in the newly burnt plots to 17.39% in the control plots (0-15cm). Average soil moisture content ranged from 6.62% in the newly burnt plots to 15.27% in the control plots (15-30 cm). In the post monsoon conditions, the average soil moisture content ranged from 19.04% in newly burnt plots to 22.27% in the control plots (0-15cm). The average soil moisture content ranged

from 17.18% in the newly burnt plots to 20.28% in the originally burnt plots (15-30cm). The newly burnt plots had least average moisture content in both the depths and seasons.

12. Soil bulk density was found higher in the burned classes of plots than the control plots (NBP>OBP>CP). The bulk density ranged from 0.86 to 0.94 gm/cm³. This trend reversed in the post monsoon conditions.
13. Burned classes of plots showed an increase in water holding capacity after fire at the depth of 0-15cm. The average water holding capacity in this depth ranged from 31.89% in the control plots to 39.23% in the newly burnt area. The average water holding capacity of control plots remained highest (27.81%) after the fire in the depth of 15-30 cm.
14. Soil texture in both control plots and burnt plots in our study was found to be sandy loam. They followed a trend (Sand %> Silt %> Clay %) throughout the plots. None of the soil textural fractions between plots were found to be significant.
15. Average soil pH was found highest (6.85) in the newly burnt plots before the monsoon. The soil pH levels of originally burnt area and control area remained in a very closer range in both seasons indicating a quick recovery of soil pH level to its original level.
16. In the present study, fire had no significant effects on soil electrical conductivity. The soil electrical conductivity ranged from 286.51 mS/m in the originally burnt plots to 295.36 mS/m in the control plots.
17. In both seasons, the average soil organic carbon was found to be highest in the newly burnt plots. The average soil organic carbon ranged from 1.48% in the control plots to 2.58% in the newly burnt plots.
18. There was no significant difference in amount of total nitrogen between the plots after the fire. The amount of total nitrogen ranged from 1.30% in the control plots to 1.44% in the originally burnt area.

19. Total phosphorus was found highest in the fire affected plots in both seasons. In both the seasons, unburned plots possessed the least P content (44ppm in pre-monsoon to 58ppm in post monsoon).
20. There was no significant difference in the levels of potassium between the plots in both the seasons. The newly burnt plots showed a decrease in the potassium levels (107.80 ppm) immediately after the fire.
21. A significant hike in the annual soil erosion was recorded in both the burned areas compared to the control area. The average annual soil erosion ranged from 0.03 tonnes/ha/year to 0.13 tonnes/ha/year.

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**FIRE IMPACTS ON VEGETATION AND SOIL IN A FOREST
ECOSYSTEM IN WADAKKANCHERRY FOREST RANGE,
THRISSUR FOREST DIVISION, KERALA**

BY

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ABSTRACT OF THE THESIS

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ABSTRACT

Fire is being used as a tool in forest management and protection in several parts of the world. A forest fire is an unplanned, uncontrolled and unpredictable fire in an area of combustible vegetation. The after effects of forest fire includes air pollution, destruction of forests and wildlife, altered species composition, outbreaks of pests and diseases etc. The frequency of wild fires around the world increases with changing climate. Considering the growing importance of tropical forest ecosystems and also because of its fire susceptibility, it is relevant to study the effects of forest fire on vegetation and soil in a forest ecosystem.

The present study was undertaken in Chembikkunnu area of Poongode section of Wadakkanchery forest range in Thrissur forest division in state of Kerala. The study was carried out to assess the impacts of an unplanned forest fire on the vegetation and soil physico-chemical and biological properties in the fire burnt areas of Poongode section of Wadakkanchery forest range of Thrissur forest division. Concurrently the study also compared and contrasted the changes in vegetation and soil between burnt and control areas over a time period of six months.

Physico- chemical properties of soil viz. soil moisture, bulk density, water holding capacity, soil pH, soil organic carbon, total nitrogen and total phosphorous showed marked differences between the fire affected classes themselves and between control areas. Other soil properties like soil texture, soil electrical conductivity and total potassium remained without any significant effects after the fire. Soil physico-chemical properties showed differences between pre-monsoon and post monsoon season. Soil moisture content (%) decreased with increase in frequency of fires. In the pre-monsoon conditions, the bulk density of the newly burnt area increased to 0.94g/cm^3 . Water holding capacity of the fire affected areas at the depth of 0-15 cm increased to 39.23% in pre-monsoon season. Soil pH of the newly burnt areas increased to 6.85 immediately after the fire. Soil organic carbon (%) followed the trend (NBP>OBP>CP). Total Nitrogen (%) and total

Phosphorous (ppm) content of the burnt plots was higher compared to the control area. As vegetation intercepts rain and reduced the kinetic energy of rain water, soil erosion (Tonnes/ha/yr) of the study area followed the trend (NBP (0.13)> OBP (0.07)>CP (0.03)).

Total enumeration of regeneration was carried out in the 10m x 10m plots on a monthly basis. 37 plant species representing 20 families were recorded. Among them there were 11 tree species, 2 grass species and 4 species of ferns. *Hemidesmus indicus*, *Pycnospora lutescens* and *Drynaria quercifolia* were found only in the fire affected plots. The Shannon- Weiner diversity index of saplings in the month of July are in the range of (1.45-2.37) while it is more for seedlings (2.76-2.96). The Sorrensen similarity indices of July (0.81(saplings), 0.91(seedlings)) points to the increased number of common species among plots. The increased evenness and reduced diversity in the fire affected plots are mainly attributed to the invasion of weeds like *Chromolaena odorata*, *Mimosa diplotricha* and grass species like *Pennisetum polystachyon*.

Unavoidable physical, chemical and biological changes happening to the soil after every fire incident are potentially able to influence the soil fauna. Darkling beetles, broad shouldered water striders, dung beetle and centipedes were recorded only from the fire affected plots. Ants were present in all the plots in both the seasons. An increase in the number of individuals was observed after the monsoon. The hard coated beetles registered their presence in significant number in the burned classes and the soft bodied animal like earthworm, centipedes and millipedes were absent immediately after the fire but appeared after the monsoon suggesting that the temperature variation in the ecosystem might have made them to move away.

The outcomes of present study necessitate longer duration study in different tropical forest types for more comprehensive understanding of the post fire dynamics of tropical forest ecosystems.

സംഗ്രഹം

ലോകത്തിന്റെ പല ഭാഗങ്ങളിലും വന പരിപാലനത്തിലും സംരക്ഷണത്തിലും തീ ഒരു ഉപകരണമായി ഉപയോഗിക്കുന്നു. എളുപ്പം കത്തിപ്പിടിക്കാവുന്ന സസ്യജാലങ്ങളുള്ള പ്രദേശത്ത് ആസൂത്രണം ചെയ്യാതെയും അനിയന്ത്രിതമായും പ്രവചനാതീതവുമായി സംഭവിക്കുന്നതാണ് കാട്ടുതീ. കാട്ടുതീയുടെ അനന്തരഫലങ്ങളിൽ വായു മലിനീകരണം, വനങ്ങളുടെയും വന്യജീവികളുടെയും നാശം, മാറിയ ജീവിവർഗങ്ങളുടെ ഘടന, കീടങ്ങളുടെയും രോഗങ്ങളുടെയും പൊട്ടിപ്പുറപ്പെടൽ തുടങ്ങിയവ ഉൾപ്പെടുന്നു. കാലാവസ്ഥ മാറുന്നതിനനുസരിച്ച് ലോകമെമ്പാടുമുള്ള കാട്ടുതീയുടെ ആവൃത്തി വർദ്ധിക്കുന്നു. ഉഷ്ണമേഖലാ വന ആവാസവ്യവസ്ഥയുടെ വർദ്ധിച്ചുവരുന്ന പ്രാധാന്യവും അതിന്റെ തീപിടുത്തത്തിനുള്ള സാധ്യതയും കണക്കിലെടുത്ത്, ഈ വന ആവാസവ്യവസ്ഥയിലെ സസ്യജാലങ്ങളിലും മണ്ണിലും കാട്ടുതീയുടെ ഫലങ്ങളെക്കുറിച്ച് പഠിക്കുന്നത് പ്രസക്തമാണ്.

കേരളത്തിലെ തൃശൂർ ഫോറസ്റ്റ് ഡിവിഷനിലെ വടക്കാഞ്ചേരി ഫോറസ്റ്റ് റേഞ്ചിലെ പൂങ്കോട് സെക്ഷനിലെ ചെമ്പിക്കുന്ന് പ്രദേശത്താണ് ഈ പഠനം നടത്തിയത്. തൃശൂർ ഫോറസ്റ്റ് ഡിവിഷനിലെ വടക്കാഞ്ചേരി ഫോറസ്റ്റ് റേഞ്ചിലെ പൂങ്കോട് സെക്ഷനിലെ തീപിടിത്ത സാധ്യതയുള്ള

പ്രദേശങ്ങളിലെ സസ്യജാലങ്ങളിലും മണ്ണിന്റെ ഭൗതിക-രാസ, ജൈവ ഗുണങ്ങളിലും ആസൂത്രിതമല്ലാത്ത കാട്ടുതീയുടെ ആഘാതം വിലയിരുത്തുന്നതിനാണ് പഠനം നടത്തിയത്. അതോടൊപ്പം, ആറ് മാസത്തെ കാലയളവിൽ, സ്വാഭാവികമായി കത്തിയതും നിയന്ത്രണവിധേയമായി കത്തിച്ചതുമായ പ്രദേശങ്ങളിലുള്ള സസ്യങ്ങളുടെയും മണ്ണിന്റെയും മാറ്റങ്ങളെ താരതമ്യം ചെയ്യുകയും ചെയ്തു.

മണ്ണിന്റെ ഭൗതിക-രാസ ഗുണങ്ങൾ. മണ്ണിലെ ഈർപ്പം, ബൾക്ക് ഡെൻസിറ്റി, വെള്ളം നിലനിർത്താനുള്ള ശേഷി, മണ്ണിന്റെ പി.എച്ച്, മണ്ണിലെ ഓർഗാനിക് കാർബൺ, മൊത്തം നൈട്രജൻ, മൊത്തം ഫോസ്ഫറസ് എന്നിവ അഗ്നിബാധയേറ്റ വിഭാഗങ്ങൾക്കിടയിലും നിയന്ത്രണ മേഖലകൾക്കിടയിലും പ്രകടമായ വ്യത്യാസങ്ങൾ കാണിച്ചു. മണ്ണിന്റെ മിടച്ചിൽ, വൈദ്യുത ചാലകത, മൊത്തം പൊട്ടാസ്യം തുടങ്ങിയ മറ്റ് ഗുണങ്ങൾ തീപിടുത്തത്തിന് ശേഷം കാര്യമായ മാറ്റങ്ങളൊന്നും കൂടാതെ നിലനിന്നു. മണ്ണിന്റെ ഭൗതിക-രാസ ഗുണങ്ങൾ മഴക്കാലത്തിനു മുമ്പും പിമ്പും വ്യത്യാസങ്ങൾ കാണിച്ചു. തീയുടെ ആവൃത്തി കൂടുന്നതിനനുസരിച്ച് മണ്ണിലെ ഈർപ്പം (%) കുറഞ്ഞു. മൺസൂണിന് മുമ്പുള്ള സാഹചര്യങ്ങളിൽ, കത്തിച്ച പ്രദേശത്തിന്റെ ബൾക്ക് സാന്ദ്രത 0.94g/cm^3 ആയി വർദ്ധിച്ചു. അഗ്നിബാധയുണ്ടായ പ്രദേശങ്ങളിൽ 0-15 സെന്റിമീറ്റർ ആഴത്തിൽ

ജലസംഭരണശേഷി 39.23% ആയി വർദ്ധിച്ചു. മഴക്കാലത്തിനു മുന്പുള്ള കാലയളവിൽ കത്തിച്ച പ്രദേശങ്ങളിലെ മണ്ണിന്റെ പിഎച്ച് 6.85 ആയി ഉയർന്നു. മണ്ണിലെ ഓർഗാനിക് കാർബൺ (%) ഈ പ്രവണത(NBP>OBP>CP) പിന്തുടർന്നു. സ്വാഭാവികമായി കത്തിയ പ്ലോട്ടുകളിലെ മൊത്തം നൈട്രജനും (%) മൊത്തം ഫോസ്ഫറസും (പിപിഎം) നിയന്ത്രണ മേഖലയുമായി താരതമ്യപ്പെടുത്തുമ്പോൾ കൂടുതലാണ്. സസ്യജാലങ്ങൾ മഴയെ തടസ്സപ്പെടുത്തുകയും മഴവെള്ളത്തിന്റെ ഗതികോർജ്ജം കുറയുകയും ചെയ്തതിനാൽ, പഠനമേഖലയിലെ മണ്ണൊലിപ്പ് (ടൺ/ഹെ/വർഷം) ഈ പ്രവണത പിന്തുടർന്നു (NBP (0.13)> OBP (0.07)>CP (0.03)).

10 മീറ്റർ x 10 മീറ്റർ പ്ലോട്ടുകളിൽ പ്രതിമാസ അടിസ്ഥാനത്തിൽ നീജനരേഷനുകളുടെ ആകെ കണക്കെടുപ്പ് നടത്തി. 20 കുടുംബങ്ങളെ പ്രതിനിധീകരിക്കുന്ന 37 ഇനം സസ്യങ്ങൾ രേഖപ്പെടുത്തിയിട്ടുണ്ട്. അവയിൽ 11 ഇനം മരങ്ങളും 2 ഇനം പുല്ലുകളും 4 ഇനം പന്നൽചെടികളും ഉൾപ്പെടുന്നു. ഹെമിഡെസ്മസ് ഇൻഡിക്കസ്, പൈക്നോസ്പോറ ലൂട്ടെസെൻസ്, ഡ്രൈനാരിയ ക്വെർസിഫോളിയ എന്നിവയെ അഗ്നിബാധയുണ്ടായ പ്ലോട്ടുകളിൽ മാത്രമാണ് കണ്ടെത്തിയത്. ജൂലൈ മാസത്തിലെ ഷാനൺ-വീനർ വൈവിധ്യ സൂചിക സാപ്സിറ്റികൾക്ക് (1.45-2.37) പരിധിയിലാണെങ്കിലും സീഡ്സിറ്റികൾക്ക് (2.76-2.96)

കൂടുതലാണ്. ജൂലൈയിലെ സോറൻസെൻ സാമ്യത സൂചികകൾ (0.81 (സാപ്ലിങ്ങുകൾ), 0.91 (സീഡ്ലിങ്ങുകൾ)) പ്ലോട്ടുകൾക്കിടയിൽ വർദ്ധിച്ചുവരുന്ന പൊതുവായ സ്ലീഷീസുകളുടെ എണ്ണത്തിലേക്ക് വിരൽ ചൂണ്ടുന്നു. ക്രോമോലൈന ഓഡോറാറ്റ, മിമോസ ഡിപ്ലോട്രിക് തുടങ്ങിയ കളകളുടെയും പെന്നിസെറ്റം പോളിസ്റ്റാക്കിയോൺ പോലുള്ള പുല്ലുകളുടെയും അധിനിവേശമാണ് തീപിടുത്തമുണ്ടായ പ്ലോട്ടുകളിലെ വർദ്ധിച്ച തുല്യതയ്ക്കും കുറഞ്ഞ വൈവിധ്യത്തിനും കാരണം.

ഓരോ തീപിടിത്തത്തിനും ശേഷം മണ്ണിൽ സംഭവിക്കുന്ന ഭൗതികവും രാസപരവും ജൈവപരവുമായ അനിവാര്യമായ മാറ്റങ്ങൾ മണ്ണിലെ ജന്തുജാലങ്ങളെ സ്വാധീനിക്കാൻ സാധ്യതയുണ്ട്. വണ്ടുകൾ, ബ്രോഡ് ഷോൾഡർഡ് വാട്ടർ സ്ക്രൈഡറുകൾ, പഴുതാരകൾ എന്നിവ അഗ്നിബാധയേറ്റ പ്ലോട്ടുകളിൽ നിന്ന് മാത്രമേ രേഖപ്പെടുത്തിയിട്ടുള്ളൂ. രണ്ട് ഋതുക്കളിലും എല്ലാ പ്ലോട്ടുകളിലും ഉറുമ്പുകൾ ഉണ്ടായിരുന്നു. മൺസൂണിന് ശേഷം ഇവയുടെ എണ്ണത്തിൽ വർദ്ധനവ് രേഖപ്പെടുത്തി. കഠിനമായ പുറംചട്ടയുള്ള വണ്ടുകൾ, കത്തിച്ച വിഭാഗങ്ങളിൽ ഗണ്യമായ എണ്ണം രേഖപ്പെടുത്തി, മണ്ണിര, പഴുതാര , അട്ട തുടങ്ങിയ മൃദുല ശരീരമുള്ള ജീവികൾ തീപിടുത്തത്തിന് തൊട്ടുപിന്നാലെ ഇല്ലായിരുന്നു, എന്നാൽ ഇവ മഴക്കാലത്തിനുശേഷം പ്രത്യക്ഷപ്പെട്ടത്

ആവാസവ്യവസ്ഥയിലെ താപനില വ്യതിയാനം അവയെ ചലിപ്പിക്കാൻ പ്രേരിപ്പിച്ചിരിക്കാമെന്ന് സൂചിപ്പിക്കുന്നു.

കാട്ടുതീയ്ക്കു ശേഷമുള്ള ഉഷ്ണമേഖലാ വന പരിസ്ഥിതി വ്യവസ്ഥകളെക്കുറിച്ചുള്ള സമഗ്രമായ ധാരണയ്ക്കായി, കൂടുതൽ ദൈർഘ്യമുള്ള പഠനങ്ങൾ ആവശ്യമാണ് എന്നാണ് ഈ പഠനത്തിന്റെ ഫലങ്ങൾ സൂചിപ്പിക്കുന്നത്.