Phytosociology is the study of plant community structure and aspects of communal relations of plant. This study is important for understanding the functioning of community and implies knowledge of structure and composition of the component species. The fire behavior in turn determines the extent to which the plant populations are affected. The more intense the fire, the more vegetation is killed. The initial vegetation losses may look harsh, but the reduced number of trees and shrubs minimize competition among the surviving individuals. Therefore, it is crucial to understand the structure and function of a particular vegetation composition in an ecosystem. The structure and distribution of various strata like trees, shrubs and other ground flora are very sensitive to changes within a short spell of time due to various factors like fire but most influencing factors for these changes are edaphic. These factors exert strong influences on plant development, distribution, composition and association, which in turn improve the micro-habitat by regulating the community structure and ecosystem functioning. Spatial and temporal variation in severity within a fire can have long-lasting impacts on the structure and species composition of post-fire communities and the potential for future disturbances (Ryan, 2002). Fire frequency determines the floristic composition of an area by selecting species, which will continue to occupy a site.

Fire may also play a role in recycling nutrients from the ground-layer vegetation and litter to the over storey trees, thereby counteracting the infertile substrates and arrested decay (Vogl, 1974). Areas under larger burned patches have higher cover of tree seedlings and shrubs, greater densities of opportunistic species, and lower species richness than smaller patches (Turner et al., 1997). Low intensity surface or ground fire is less detrimental to trees but herbs and shrubs are most suffered. Since species present before a wildfire are supposed to be a strong indicator of what will return after, the creation and maintenance of accurate, understorey plant survey is recommended, particularly for exotic species or other species of concern. For present study, vegetation
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survey in the restored mined site having different vegetation compositions (plantations) and natural forest site was carried out for the analysis of ecological attributes such as frequency, density and abundance of trees, shrubs and herbs during pre and post monsoon seasons for the period of two years. Soil is another important parameter which is worst affected by such disturbances like fire as the most influential changes are those expressed in or near the soil surface. Soil samples were also collected from the plantation sites in restored area and natural forest before fire and after fire for the period of two subsequent years.

6.1 Floristic composition

Floristic composition in Site-1 i.e. Shisham plantation (Table- 1-5), a total of two species of tree, 10 shrub species, four species in form of saplings, 15 species of herbs and six species in form of seedlings were recorded during the study period. Site was dominated by Dalbergia sissoo. Acacia catechu though was present there, but has comparatively very low frequency than Dalbergia sissoo. The reason may be that at the time of restoration approach, main emphasis in that particular site was given for the use of Dalbergia sissoo. Among shrub vegetation Lantana camara remained the dominant species throughout the study period followed by Murraya koenigii. This is because Lantana camara is a light demanding species and it has quality to grow profusely on degraded sites whether it is due to fire or other reasons. Berry et al. (2011) concluded in their studies that Lantana camara is less ignitable species and it creates a more continuous layer of ‘ladder’ fuels, which may allow fire to reach the forest canopy. If establishment of native species is not checked in time, growth of other invasive species including Lantana in the area may turn the natural succession into retrogressive one. Among herbs Ageratum conyzoides and Bidens pilosa were the dominant herbs found in this site after fire. Bidens pilosa is not fire tolerant but quickly invades burnt areas (Smith, 1985). Composition of shrubs after fire was found to be more or less similar to pre-fire conditions (Table 2, 3 and Annexure-2).

In Site 2- Khair plantation (Table 5-10); there were three tree species, 13 shrub species, one species in form of saplings, 12 species of herbs and seven species in form of
seedlings present during the two year study period. Among trees species, *Acacia catechu* was found to be the densest species followed by *Dalbergia sissoo* and *Toona ciliata*. Similarly among shrubs, *Lantana camara, Murraya koenigii* were found to be the highest dense species. This can be attributed to the reasons that these species were present earlier also and there were findings which reported significant increase in *L. camara* seed germination in smoke and enhanced proliferation after fire (Raizada and Raghubanshi, 2010; Dobhal *et al.*, 2009). Among herbs, *Bidens pilosa, Ageratum conyzoides* showed the maximum density. The extensive fibrous root system of *Bidens pilosa* may give it the potential to establish itself sooner at the burnt areas after the removal of previous ground flora (Smith, 1985).

In Site 3- Mixed plantation (Table- 11-15), six species of tree, 11 species of shrubs, two species in form of saplings, 11 herbs and seven species in form of seedlings were enlisted. *Acacia catechu* was recorded as the densest species in this site. The higher dominance of *Acacia catechu* may be due to its plantation during restoration activities in this site and its adaptability to the stressed conditions and other detrimental factors coupled with its colonizing behavior in degraded sites. Soni *et al.* (1992) and Chandola (2001) have reported the success of *A. catechu* in the rock phosphate mine area after 10 and 18 years of rehabilitation respectively. In shrubs during pre and post monsoon *Lantana camara* and *Tithonia diversifolia* remained the densest species throughout the study period. Among herbaceous vegetation, during the study year, *Bidens pilosa, Aerva scandens, Oplismenus compositus* and seedling of *Eupatorium glandulosum* showed the maximum density. It was due to dispersal and establishment of native plant species from surrounding areas as the site got ameliorated after restoration providing favorable condition for their establishment. Gairola (2010) also reported the presence of the shrubs (*Adhatoda zeylanica, Boehmeria platyphylla, Lantana camara, Vallaris solanacea*) and herbs (*Aerva scandens, Oplismenus compositus*) species in the Mixed plantation site.

Site 4- Natural forest (Table- 16-20), was having maximum no. of species with eight tree species, eight shrubs, eight species in form of saplings, 17 herbs and six species
of trees and shrubs in the form of seedlings. *Nyctanthes arbor-tristis, Mallotus philippensis* and *Flacourtia cataphracta* found to be the most abundant tree species. Among shrubs, *Adhatoda zeylanica, Boehmeria platyphylla, Murraya paniculata, Murraya koenigii* and *Lepidagathis cuspidata* were found to be the species with highest density values. Among herbs species like *Ageratum conyzoides, Cyperus rotundus, Bidens pilosa, Oplismenus compositus, Parthenium hysterophorus* and seedling of *Eupatorium glandulosum* showed the maximum density. Gairola (2010) has also reported the presence of species like *Murraya koenigii, Adhatoda zeylanica, Bidens pilosa, Oplismenus compositus, Cyperus rotundus* in this site.

The widespread dominance of species like *Murraya koenigii, Adhatoda zeylanica* and *Boehmeria platyphylla* in the restored plantation sites indicates that the plantation sites are proceeding towards similar characteristics of the adjacent natural forest area. Bhatt (1990) has reported the presence of *Eriophorum comosum, Pennisetum purpureum* and *Saccharum spontaneum* after eight years of restoration in the same area but after 23 years of succession these species have been replaced by higher successional species like *Murraya koenigii, Adhatoda zeylanica, Boehmeria platyphylla* (Gairola, 2010).

**Importance value Index**

Importance value index is a device to rank species in a community or often used to elucidate features of the community (Lamont et al., 1977). The importance value index for herbs, shrubs and trees were calculated separately during post and pre monsoon for two study years. The perusal of the data of floristic structure reveals that the species planted (*Dalbergia sissoo, Acacia catechu*) in their respective plantation sites showed maximum IVI. Some of the shrubby (*Murraya koenigii, Lantana camara*) and herbaceous species (*Aerva scandens, Ageratum conyzoides, Cynodon dactylon, Parthenium hysterophorus*) showed higher IVI values in plantation sites in comparison to natural forest area. The occurrence of these species in varied microclimatic and edaphic conditions is indicating their high potential niche. Wide occurrence of species like *Lantana camara and Parthenium hysterophorus* in plantation sites is because of disturbed
conditions (fire). These species being exotic and invasive in nature, once introduced into the ecosystem, proliferate themselves vigorously.

**Richness of species**

The analysis of data showed that species richness index was maximum in Natural forest area as compared to the Plantation sites for all the strata i.e. tree layer, shrub and herb layer. The lower species richness in Plantation sites as compared to Natural forest may be due to site is still in process of succession which is further triggered by the impact of fire on vegetation composition. However, Gairola (2010) found that the value of richness of species was maximum for Site 1- Shisham plantation for herbs closely followed by Natural forest area while in the present study which is conducted after fire; the richness index for herbs and shrubs was minimum in Shisham plantation than Natural forest. Reason attributed to this was the disturbance caused by fire which adversely affected the ground and understorey vegetation in the plantation site.

**Diversity Index**

Species diversity is of considerable importance in the study of plant succession since variation in diversity is presumed to be positively correlated with the stability of various biotic and abiotic components of the ecosystem (Leigh, 1965). Shannon index is maximum when all the species in a sample are equally abundant, decrease towards zero as the relative abundance of species diverse away from the evenness due to environmental disturbances (Ismail and Dorgham, 2003). The present data on diversity index (Table 21-24) revealed maximum diversity by shrubs and herbaceous layer as compared to the tree layer in all the sites. Natural forest exhibited high diversity index for all the plant forms as compared to Shisham, Khair and Mixed plantation sites. Site- 1 (Shisham plantation) which was adversely affected by fire exhibited the low diversity index for both shrubs and herbs as compared to Khair plantation site during first year i.e. right after fire.
Evenness Index

The evenness index value was maximum for the tree vegetation in Site-3 Mixed plantation throughout the study period. But in contrary to this, the diversity of tree vegetation was more in Natural forest. This is because of more number of trees in Natural forest as compared to Mixed plantation. Similar with case of herbaceous layer, the evenness though was higher in Mixed plantation but diversity index was low as compared to Natural forest because of lesser number of herbaceous plants in the former than later. However, in case of shrubs, the evenness index was maximum in Natural forest and so was the diversity index.

Similarity index

For tree layer, the maximum similarity was found between Khair and Shisham plantation sites and minimum between Mixed plantation and Natural forest (Table- 25). This is due to similar tree species composition between Khair and Shisham plantation than Mixed plantation and Natural forest.

For shrub layer during pre monsoon of the first year, maximum similarity was between Shisham and Mixed plantation and minimum between Shisham plantation and Natural forest while during post monsoon season of same year, maximum similarity was found between Shisham and Khair plantation indicating that species which recorded after the fire were more or less similar in Khair and Shisham plantation.

For herb layer in first year of study, maximum similarity was between Shisham and Mixed plantation and minimum between Shisham plantation and Natural forest while during post monsoon season of same year, maximum similarity was found between Shisham plantation and Natural forest and minimum in Shisham and Mixed plantation. Reason can be the herbaceous flora which recorded after fire in Shisham plantation was similar to the herbs present in the Natural forest indicating the regeneration of the common species which were reported earlier also from the same site.

For shrub layer during both pre and post monsoon season of the second year of study, maximum similarity was calculated between Shisham and Khair plantation
indicating that species which came after the fire were similar in Khair and Shisham plantation. For herb layer, during both pre and post monsoon season of the second year of study, maximum similarity was between Shisham and Khair while minimum between Mixed plantation and Natural forest during pre monsoon period and between Khair plantation and Natural forest during post monsoon season of second year. It can be explained as gradual change in herbaceous flora over a period of time after the occurrence of fire. Herbaceous flora which came after fire in Khair plantation was not much similar to the Natural forest. One of the reasons can be the species which were reported earlier (before the fire) and were common to the species reported from Natural forest were failed to establish themselves and therefore disappeared in the second year of study.

6.2 Vegetation change after fire in Fire-affected sites

Site-1 Shisham Plantation (burnt site)

Analysis of shrub vegetation from the data given in Table 2 & 3 and Annexure –2 revealed that out of previously reported 14 shrub and sapling species (Gairola, 2010), only four species reported in sampling after fire i.e. Lantana camara, Murraya koenigii, Ricinus communis, Tithonia diversifolia. Reason can be these species are resistant to disturbances like fire and can survive even in harsh conditions. However, during later post monsoon and pre monsoon sampling of first and second year respectively, previously present species like Boehmeria platyphylla, Colebrookea oppositifolia and sapling of Leueana leucocephala and Toona ciliata were reported to come back again at the burnt site.

New invading species reported after fire from that site were Callicarpa macrophylla, Cassia tora, Pogostemon benghalensis, Urtica dioica and saplings of Mallotus philippensis and Dalbergia sissoo. However, during the post monsoon sampling of second year, species of Urtica dioica and saplings of Toona ciliata, Dalbergia sissoo were disappeared again. Species namely Adhatoda zeylanica, Carissa opaca and saplings of Celtis australis, Adina cordifolia and Ficus palmata which were reported earlier before fire were not reported again in two years of time after fire. They may or may not come
back in future. Species which were reported before fire i.e. *Lantana camara, Murraya koenigii, Ricinus communis, Tithonia diversifolia* showed change in their IVI. All the other three species except *Lantana camara* showed increase in their IVI after fire. However all other species which came and then disappeared in the after event of fire in the span of two years were observed with low frequency and may be that was the reason they were replaced or disappeared.

Analysis of herb vegetation from the data given in Table 4 & 5 and Annexure –2 revealed that out of previously reported 19 species of herb (Gairola, 2010), only two species reported were after fire i.e. *Lantana camara* (seedling) and *Ageratum conyzoides* along with *Parthenium hysterophorus* which was not reported earlier. Species namely *Achyranthes aspera, Aerva scandens, Malvastrum coromandelianum, Urena lobata* and seedlings of *Adhatoda zeylanica, Woodfordia fruticosa* were not reported again in two years of time after fire. Whereas during later post monsoon and pre monsoon sampling of first and second year respectively, previously present species like *Ageratum conyzoides, Artemisia vulgaris, Bidens pilosa, Cynodon dactylon, Commelina benghalensis, Eupatorium glandulosum, Oplismenus compositus, Oxalis corniculata, Sida acuta, Sida humilis* were reported to come back again at the burnt site.

New invading species reported from that site after fire were namely *Cissaempelos pareira, Cyperus rotundus, Parthenium hysterophorus, Rumex nepalensis, Rungia pectinata* and seedlings of *Boehmeria platyphylla, Urtica dioica, Toona ciliata*. However, during the post monsoon sampling of second year, species of *Cissaempelos pareira, Cyperus rotundus, Rumex nepalensis, Rungia pectinata* were disappeared again. Similar to shrubs, in case of herb layer also, species which resist the fire and were present even after fire i.e. *Ageratum conyzoides* and seedling of *Lantana camara* showed increase in their IVI value after fire.

**Site-2 Khair Plantation (burnt site)**

Analysis of shrub vegetation from the data given in Table 7 & 8 and Annexure –3 revealed that out of previously reported 15 shrub species (Gairola, 2010), only five species reported at the site after fire i.e. *Adhatoda zeylanica, Lantana camara,*
Pogostemon benghalensis, Murraya koenigii and sapling of Mallotus philippensis. However during later post monsoon and pre monsoon sampling of first and second year respectively, along with these five species previously present species i.e. Boehmeria platyphylla also reported to come back again at the burnt site. Nine new invading species reported from that site after fire were namely Cassia tora, Colebrookea oppositifolia, Ricinus communis, Tithonia diversifolia, Vallaris solanacea, Vitex negundo, Urtica dioica and Mimosa himalayana. However, during the post monsoon sampling of second year, species Tithonia diversifolia, Mimosa himalayana were disappeared again.

Previously reported species from that site before fire namely Jasminum officinale and saplings of Adina cordifolia, Ehretia laevis, Flacourtia cataphracta, Grewia optiva, Holarrhena antidysenterica, Millettia auriculata, Casearia tomentosa, Nyctanthes arbortr-tis were not reported again in two years of time after fire. In Khair plantation site also, the trend was similar to Shisham plantation site i.e. most of the species which resist the disturbance showed increase in their IVI after fire.

The reason of the disappearance of these species which were reported earlier and disappeared after fire can be explained by the fact that these species were less frequent and also having low population (low density). On account of low density of these species, the chances of their survival were very low.

Analysis of herb vegetation from the data given in Table 9 & 10 and Annexure –3 revealed that out of previously reported 15 species of herb (Gairola, 2010), only four species reported at the site after fire i.e. Bidens pilosa, Oplismenus compositus, Sida humilis and seedling of Murraya koenigii along with two more species of Ageratum conyzoides and seedling of Pogostemon benghalensis which were not reported earlier. Reason can be these species are resistant to disturbances such as fire. Species which were present before fire i.e. Justicia simplex, Urena lobata and seedlings of Adhatoda zeylanica, Desmodium gangeticum, Toona ciliata were not reported again in two years of time after fire.

Whereas during later post monsoon and pre monsoon sampling of first and second year respectively, previously present species like Achyranthes aspera, Bidens pilosa, Oplismenus compositus, Sida humilis and seedlings of Boehmeria platyphylla, Lantana
camara, *Murraya koenigii* were reported to come back again at the burnt site. Six new invading species reported after fire from that site were namely *Artemisia vulgaris, Aerva scandens, Parthenium hysterophorus, Rumex nepalensis, Solanum nigrum* and seedling of *Ipomoea carnea*. However, during the post monsoon sampling of second year, species of *Artemisia vulgaris, Rumex nepalensis, Solanum nigrum, Sida humilis* and seedlings of *Ipomoea carnea, Murraya koenigii, Pogostemon benghalensis* were disappeared again.

### 6.3 Soil properties

**Soil moisture**

Maximum value of soil moisture was recorded from the natural forest site (9.42%) followed by Mixed, Khair and Shisham plantation. Shisham plantation (burnt) showed the lowest value for soil moisture (6.84 %). Reason can be attributed to the fact that, maximum numbers of herbs and shrubs were reported in natural forest and these ground and understorey vegetation seem to be helpful in moisture retention while Shisham plantation (burnt) exhibited low density of herb layer after fire (Annexure-1a). Nardoto and Bustamante (2003) observed that the soil moisture content was significantly higher in the unburnt site as compared to burnt site.

**Soil bulk density**

The soil bulk density was found to be changing significantly with change in site ($p< 0.001$). However, seasonal variation for soil bulk density was found to be non-significant. Bulk density ranges from 1.25 g cm$^{-3}$ to 1.55 g cm$^{3}$. Maximum value (1.55 g cm$^{-3}$) of soil bulk density was recorded from the Shisham plantation (fire affected site) while Natural forest showed the lowest value (1.25 g cm$^{-3}$) (Table 35). Bulk density affects the pore space and it is also an indicator of soil compaction. High bulk density is an indicator of low soil porosity and high soil compaction. It may cause restrictions to root growth, and poor movement of air and water through the soil (Arshad et al., 1996). Burning and heating can increase bulk density and decrease organic matter. Wohlgemuth and Hubbert (2008) reported increase in bulk density by 27 percent after the fire in soils.
of chaparral steeplands, Southern California. However, there are also studies which also suggested that the bulk density usually remains unaffected by the fires (Ulery and Graham, 1993).

**Soil pH**

Change in pH value with respect to site was observed significant ($p<0.001$) during both the years of the study (Table 36). Maximum value of soil pH was recorded from the Shisham plantation (burnt) (7.77) while Natural forest showed the lowest value for soil pH (7.34). Nardoto and Bustamante (2003) observed that the pH values were significantly higher in the burnt site. In the unburnt site, no significant differences in the pH values were found between the rainy and dry season.

**Soil Organic Carbon**

The analysis of soil organic carbon revealed that the change in soil organic carbon was significant with change in site during both the study years ($p<0.001$). Minimum soil organic carbon was estimated for the Shisham plantation (burnt) (16.81 tons ha$^{-1}$) and maximum value estimated for the Natural forest (24.82 tons ha$^{-1}$) (Table 37). The effect of fire on the carbon content and soil organic matter content is highly variable, and depends on several factors including the type and intensity of the fire, soil moisture, soil type, nature of the burned materials and even slope (González-Pérez et al., 2004). Kauffman et al. (1994) also found similar findings during their study. They found that C, N, and S were the nutrients that were consistently lost in the highest quantities during fire. However, losses of P were intermediate, and K and Ca were negligible.

**Available Nitrogen**

Variation in available nitrogen was significant with change in site ($p<0.001$). Overall, maximum available nitrogen was estimated for the natural forest site (0.980 tons ha$^{-1}$) and minimum value (0.465 tons ha$^{-1}$) estimated for the Shisham plantation (Table 38). Thomas et al. (1999) reported increased losses of total nitrogen, exchangeable potassium and available phosphorus by 3-4 orders of magnitude after fire which is in
support of this study. Results were also similar to the findings of Kauffman et al. (1994) who found that N were consistently lost in the higher quantities during fire.

**Available Phosphorus**

Data revealed that the variation in available phosphorus was significant with change in site ($p < 0.001$) (Table 39). Maximum available phosphorus was estimated for the Natural forest (0.0332 tons ha$^{-1}$) and minimum estimated for the Shisham plantation (burnt) (0.0210 tons ha$^{-1}$). Reason of low phosphorus content in fire affected site were similar to findings of Debano and Conrad (1978) who also noticed that phosphorus and nitrogen content was found to be lower after fire. Even if fire results in an enrichment of available phosphorus in some cases, this enrichment is destined to decline very soon (Serrasolsas and Khanna, 1995). Fire-induced changes to cycles of soil nutrients other than N and P generally are slighter and more ephemeral. Values in Mixed plantation (unburnt) found to be more than that of Natural forest indicating the progress of restoration is approaching towards natural conditions of the area.

**Exchangeable Potassium**

Perusal of data exhibited that the variation in exchangeable potassium was significant with change in site ($p < 0.001$) (Table 40). Minimum exchangeable potassium was estimated for the Shisham plantation (burnt) (0.403 tons ha$^{-1}$) and maximum value for the Natural forest (0.758 tons ha$^{-1}$). Low levels of cations like K after fire was also documented by Wells et al. (1979) and they said these losses occur due to surface erosion.

**Soil Microbial Biomass Carbon**

Data presented in the Annexure-1h revealed the soil microbial biomass carbon was recorded maximum from the Natural forest while among plantation sites maximum microbial biomass carbon was found in Mixed plantation followed by fire affected sites-Khair and Shisham plantation respectively. The values were in order of 333.48 µg g$^{-1}$,
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305.26 µg g⁻¹, 235.98 µg g⁻¹ and 189.25 µg g⁻¹ respectively. Among plantation sites maximum value next to Natural forest was found in Mixed plantation which was remained unaffected by fire indicating that the values were trying to approach the conditions of adjacent natural forest if the plantation sites were not affected by any disturbances. Ruzek et al. (2001) also reported that there were clear relationships between time since restoration and increases in soil microbial biomass. Microbial biomass values were found to be lower in fire affected sites reason can be fire can kill the microorganisms present in the soil surface thus reduction in their activity or their killing can result in lower values.

Soil Microbial Biomass Nitrogen

Maximum value of soil microbial biomass nitrogen was recorded from the Natural forest (41.68 µg g⁻¹) while Shisham plantation (burnt) showed the least value for soil microbial biomass nitrogen (23.66 µg g⁻¹). Similar reason for lower values in fire affected sites can be quoted here also i.e. fire can kill the microorganisms present in the soil surface thus reduction in their activity or their killing can result in lower values at these sites. Groffman et al. (2001) indicated that the MBC, MBN values were significantly lower in plantation stands than in natural secondary forests. The higher MBC and MBN in the natural secondary forests than in plantation stands are mainly attributable to the greater availability of organic matter in natural secondary forests. This is also evident from the significant positive correlations between soil microbial biomass and soil organic matter.

6.4 Relationship between plants and soil properties

Density during post monsoon was found to be positively correlated with soil bulk density and soil pH whereas density during post monsoon was negatively correlated with soil carbon, available phosphorus, available nitrogen, exchangeable potassium, soil microbial biomass carbon, soil microbial biomass nitrogen and soil moisture (Table- 47). Kumar et al. (2010) also found the similar results that tree density was clearly negatively
correlated to variables like phosphorus and nitrogen but found positively correlated with carbon which was in contrast to our findings. Soil organic carbon was positively correlated with available nitrogen, soil microbial biomass carbon and soil microbial biomass nitrogen. Jia et al. (2005) also found that soil microbial biomass was markedly correlated with the organic carbon and total nitrogen content of soil. Soil microbial biomass carbon is positively related to soil organic carbon so as soil organic carbon increases, an increase in microbial biomass carbon should also result.

Soil organic carbon was negatively correlated with soil bulk density. High bulk density is an indicator of low soil porosity and soil compaction. It may cause poor movement of air and water through the soil. Compaction can result in poor plant growth and reducing vegetative cover available to protect soil from erosion. Soil organic matter and soil organic carbon is inversely related to bulk density. As bulk density decreases, soil organic matter and organic carbon value increases. The same is reported in the present study also. Soil available nitrogen was significantly correlated with soil microbial biomass carbon and soil microbial biomass nitrogen.

6.5 Soil: Before and after fire

Fire increases or decreases soil nutrient amounts, depending on the intensity and duration of the burn. Two obvious direct effects are volatilization of certain elements and modification of soil particles due to heat. Volatilization releases carbon, hydrogen, and oxygen into the atmosphere, along with varying amounts of sulfur (S), and phosphorus (P) depending on the composition of the organic matter burned and the degree of combustion (Raison, 1979). Nutrients in mineral form are affected by the changing physical properties of soil particles due to heating and subsequent cooling. When micaceous minerals and clays dehydrate or fracture, the solubility of elements such as phosphorus (P) and potassium (K) can increase or decrease (White et al., 1973).

In the present study also, soil nutrients like C, N, P, K found to be decreased after fire when compared to pre fire levels in fire affected sites. However, the pH values and bulk density increased after fire occurred in the plantation sites in comparison to pre-fire values. Nardoto and Bustamante (2003) also found the pH values to be significantly
higher in the burned site as compared to unburned site in their study. Owensby and Wyrill (1973) in agreement with present study also found a larger increase in pH from winter and midspring burning than after late spring burns. This rise in pH is because mineral substances are released as oxides or carbonates that usually have an alkaline reaction (Schripsema, 1977). Bulk density also increases after fire in fire-affected sites and the same was reported by Giovannini et al. (1988) and Durgin and Vogelsang (1984). They explained the reason of increased bulk density was the result of the collapse of the organo-mineral aggregates and the sealing due to the clogging of soil pores by the ash. Burning and heating can increase bulk density and decrease organic matter (Stoof et al., 2010). This can explained the reason of low organic carbon in fire affected sites. Hopmans (2003) also reported same in his studies. His results showed a general decline in surface soil C and N associated with low-intensity fires at three-year intervals.

Thomas et al. (1999) reported increased losses of total nitrogen, exchangeable potassium and available phosphorus by 3-4 orders of magnitude after fire. This can be attributed to increased erosion and high nutrient concentrations at the soil surface in the burned forests, where burning of organic matter and vegetation increased nutrient availability. Enhanced rates of loss were sustained for at least 3 years, resulting in much greater post-fire nutrient losses than reported in drier regions of the Mediterranean. Although there is ample evidence that N in organic matter is volatilized, some authors report an increase in total soil N (which would include organic N, nitrate, and ammonia) after a fire in contrast to this study (Vlamis et al., 1955; White and Gartner 1975).

Fire intensity, amount of green material, and fuel moisture has been reported to influence the amount of N lost through volatilization (Dunn and DeBano, 1977). Schripsema (1977) also found nitrogen related compounds like nitrate and ammonia declined in August following a winter burn; total N was also lower on a spring burn. Although an overall increase of most cations is well documented, fire can induce losses in some cases. Losses may be due to surface erosion (Wells et al., 1979), movement below the root zone from leaching (Stark, 1979), dilution effects of increased runoff (DeBano
and Conrad, 1978), and losses in fly ash (DeByle, 1976). These findings confirm that actual effects on soil nutrients at any given site will be variable depending on the condition of the vegetation, character of the soil and topography, and climatic factors (Vogl, 1974).

Trabaud (1994) also noticed the nutrient losses of N, C, P, K, Na, Ca after fire. The relative order of nutrient losses observed by him was N>C>Na>Ca>P>K>Mg. Estimated losses of N, C and P from combustible plant matter exceeded 98, 97 and 79% respectively. Losses of available P had the greatest potential for reductions in soil fertility. P as phosphate is another nutrient released by burning. Schripsema (1977) found the availability of P to vary by site in burnt areas. In contrast to present study, there are some studies who have found availability to increase (White and Gartner 1975; Raison, 1979). White and Gartner (1975) found an increase in available phosphorus only if temperatures did not exceed 392 F (200°C). They also speculated that soil moisture and heat determine the extent of the increase in P availability.

In case of microbial biomass, there are many studies with similar findings who reported decrease in soil microbial biomass after fire or burning. Esquilín et al. (2008) also noted that in burned plots, microbial biomass was 60 to 70% lower than the undisturbed plots. An interesting observation by them was that total soil C concentration in scarified plots was nearly half of the level measured in undisturbed plots. Their data support the hypothesis that soil scarification can have long-term reductions in forest soil C and OM as well as microbial biomass. Örlander et al. (1996) in similar findings also reported lower total C in scarified vs. control soils in Swedish Scots pine (Pinus sylvestris L.) forests. Microbial carbon biomass and microbial abundance were highest in the unburned area, followed by the area burnt 2 years ago and lastly by the area studied immediately after fire (Mabuhay, 2003). Hossain et al. (1995) also reported that frequent under burning of Eucalyptus pauciflora stands (2-3 times a year) reduces microbial biomass, but burning at 7-year intervals increases it. They state that in many cases burning reduces microbial biomass temporarily; but generalizations cannot be made, since differences in the reaction of microflora arise from different time of sampling, soil and ecosystem type, intensity of fire and microbiological methodology. Wu¨ thrich et al. (2002) also reported the similar results in case of microbial biomass. They reported a
decrease in microbial biomass on the burnt site, whereas the reference site (unburned site) showed a distinct rise in microbial biomass.

In present study, soil samples were collected from the fire affected sites, fire unaffected plantation site and Natural forest for next 2 years after fire. Soil nutrients levels in Mixed plantation and Natural forest were remained same with slight increase in values during pre monsoon season and decrease during post monsoon seasons during both the study years. Reason of slight decrease in values in post monsoon season data can be leaching of nutrients and soil erosion during monsoons. Overall, a slight increase in values of all the soil nutrients was noticed. Whereas in case of fire affected Shisham and Khair plantation sites, it was noticed that soil nutrients were in recovering phase and trying to recover after fire although the levels after 2 years were still lower as compared to pre-fire levels. In the present study, the pre-fire data for microbial biomass was however not available for comparison. But as we know microbial biomass ranges from 1 to 5% of the soil organic carbon (Insam and Domsch, 1988), we can say that microbial biomass was also declined in the sites where organic carbon was declined.

According to Solera et al. (2006) fire can affect soil organic carbon quantitatively and qualitatively, depending on the severity of the fire. Soil micro biota is one of the soil components most affected. A high severity of fire can delay the natural restoration of vegetation and consequently increase the susceptibility to erosion and degradation processes. An apparently good and natural reestablishment of vegetation has occurred with the presence of most of the species existing before fire. Their results suggest that directly by the fire or indirectly by post fire soil erosion, a degradation of soil has occurred, demonstrated by the quantitative decreases in all of the soil parameters studied related to soil organic carbon. Also the successional stage of the forest stand determines the risk of burning. Fires seldom spread in forest stands younger than 25 years and recently burned areas can actually act as fire breaks (Schimmel and Granström, 1997).

In present study also, if we compared between the two fire affected sites i.e. Shisham and Khair plantation, recovery of nutrients is faster in Khair plantation as compared to Shisham plantation. Thus we can conclude that Khair plantation was found to be more resilient for such disturbances than Shisham plantation. So in case of
ecosystem where disturbances are more likely to occur such as fire, plantation of *Acacia catechu* (Khair) can be a good suggestion as from the present study it came out to be more pliant. Mixed plantation however was approaching closer to Natural forest in terms of soil and vegetation pattern. Thus we can assume that in case fire has not occurred and disturbed the two plantation sites i.e. Shisham and Khair plantation, they would have also been approached near to the conditions of Natural forest by this time as in case of Mixed plantation.