

Minireview Article

Effects of forest fire on soil properties

ABSTRACT

One of the most harmful challenges to our forest is fire. Following the fire, the surface soil of the burned region had higher soil pH, total nitrogen, accessible phosphorus, potassium, calcium, and magnesium levels than the unburned area. The low intensity of the fire caused the organic matter in the soil and the litter to burn, increasing the availability of nutrients and promoted herb regeneration and post-fire community expansion. Higher intensity fires completely destroy soil organic matter, volatilize nitrogen, phosphorus, and potassium, and kill microorganisms, while Mn, Mg, and other micronutrients were completely burnt at very high temperatures. Some nutrients were more readily available by the burning of soil organic matter (OM), such as N, P, and S, while others were volatilized. Controlled fire did not result in any significant changes to the nutrients or physico-chemical composition of soil and can be utilized as an efficient management technique to reduce the harm caused by wildfires to soil.

Keywords: Forest fire, soil, nutrients, water repellency, soil organic matter

1. INTRODUCTION

A natural disturbance such as fire can quickly alter the physical, chemical, and biological aspects of soil in a forest environment [15]. Fires have recently been linked to one of the main soil-forming factors [7]. Forest fires may have an impact on a combination of vegetation cover, structure, composition, density, and productivity leads to deforestation, population decline, consequences of the forest edge, and exotic animal immigration species [9,55]. Forest fire can change the soil properties including soil texture, soil color, soil water content, bulk density, CEC, hydraulic conductivity, porosity, pH, EC, macronutrients, micronutrients and microbes which is the effects of forest fires on soil properties.

2. A HISTORICAL PERSPECTIVE OF FOREST FIRE

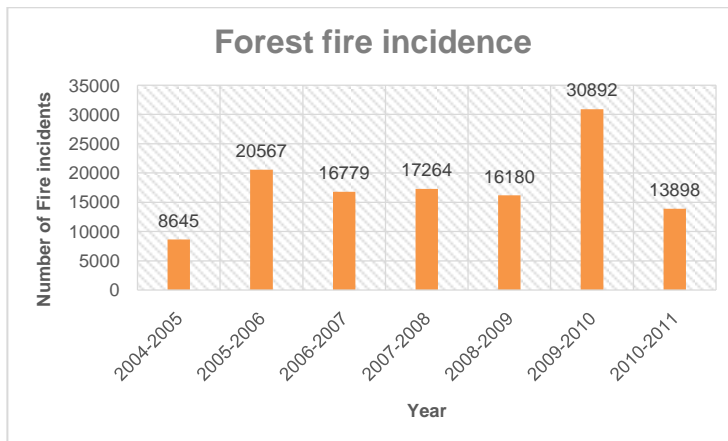
In the country, trees and other types of vegetation span 80.9 million hectares, or 24.62 percent of the total land. According to records from the forest inventory, 35.71% of India's woods have not yet experienced any significant fires, while the remaining 54.45% of forests are subject to occasional fires, 7.49% to moderately frequent fires, and 2.40% to high incidence levels. Madhya Pradesh has the biggest amount of forest cover overall in the nation. Madhya Pradesh, located in central India, is particularly vulnerable to forest fires followed by states like Maharashtra, Chattisgarh, and Odisha [18].

Comment [WU1]: Please add sentence or two about the impact of fire on physical soil properties, since you deal with it in the part of the text.

Comment [WU2]: Please add sentence about post-fire management

Comment [WU3]: Please provide references for this statement

Comment [WU4]: Please state in which country



(Data collected from FSI.,2012)

Fig 1 : Graphical distribution of year wise forest fire incidence during 2004 to 2011.

Comment [WU5]: Please specify the area to which these data relate

3. Factor influencing forest fire

Fire is brought into forests by various indigenous populations to help in the collection of non-timber forest products [54] and through in-cendiarism and accidental fires [33]. Dry deciduous woodland exhibits notable high burnt area [34]. High resin content in subtropical pine regions and dry conditions in tropical regions, according to [8] have been important factors in fire propagation in India.

The strength of the fire and other factors determine its size, harshness, heating of the soil, season of the burn, length of residency, and time since last fire. The direct reduction of biomass and carbon stored in seasonally dry tropical forests caused by fire had impact on biomass and carbon build up as well [30,58]. Johnson and Curtis (2001) [26] claims that wildfire consequences have an impact on soil productivity. The presence of vital nutrients, such as N, S, P, K, Ca, etc., maintains productivity which fire is capable of altering.

Comment [WU6]: When you start the sentence with the author name state it and then add number of reference in the bracket

The habitat of animals has been impacted by fire, and it could yet be either directly by habitat modification or death [40]. According to Kirkpatrick et al. (2006) [31], the longer-term reactions of many bird species are assumed to be predominantly caused by structural changes in the vegetation or changes in food availability as a result of fire severity.

Comment [WU7]: Same as previous comment

Comment [WU8]: This part of the text refers to consequences of fire not causes – factors that influence fires.

4. Fire effects on soil property

The soil characteristics close to the soil surface were altered by fire because they are exposed to surface heating [14]. The physical, chemical, and biological qualities of soil can be affected by forest fires.

4.1 Fire effects on physical properties of soil

4.1.1. Soil texture and colour The relative number of inorganic components in the soil's mineral composition is shown by the texture of the soil, which shows the particle size distribution. Due to the high temperature thresholds of sand, silt, and clay, the texture is not easily impacted by forest fires [3]. Clay has a lower critical temperature (400-800°C) than sand and other materials, for example silt (1414°C) [48]. Consequently, clay particles are more impacted in terms of texture. At higher temperatures, the soil matrix had turned red from the transformation of iron oxides and the full elimination of organic matter, whereas at lower temperatures, the ground layer was covered with black or grey ash [7].

Comment [WU9]: Unclear sentence.

Clay is the most sensitive textural component, and clay hydration and clay lattice structure start to collapse at soil temperatures of roughly 400°C. The interior clay structure may completely disintegrate at temperatures of 700 to 800°C [56]. According to Nardoto and Bustamante (2003) [47], fire also had an impact on soil texture, causing variations in sand, silt, and clay between burned and unburned sites at a depth of 0–5 cm. Unburned material increases the amount of sand

and silt (21%, 13%, respectively) to the burned site, however the clay was reduced from 74% to 66%. According to Pierson et al. (2008)[49], the texture of soil stayed the same following a fire clay loam with gravel and silt.

Comment [WU10]: How much sand and sil were in the unburned soil?

4.1.2 Soil water content Compared to unburned soil, burned soil has a greater soil water content. As a result of the destruction of vegetation by fire, evaporation is accelerated in burned areas during the dry and hot seasons [11]. Soil water repellency (SWR) increases runoff and decreases water infiltration, which leads to increased soil erosion [63]. Soil water content thus declines, which is another factor contributing to lower K salt and infiltration rates and low soil water content in burned soil. Only a minor quantity of the volatilized organic matter goes downward into the soil where it condenses to form a water-repellent layer that prevents infiltration [62].

Comment [WU11]: This sentence contradicts the rest of the paragraph

The modifications may also enhance water repellency, which results in decreased water consumption, among other indirect effects erosion is frequently made worse by infiltration and increased runoff [15]. Two weeks after the fire, burned soils had more water than unburned soils. Water repellency of the soil affects infiltration and erosion processes in a way that enhances overland flow and decreases water infiltration. It was determined that the low to a mild wildfire caused the soil aggregates to break down and the water repellency to increase, this resulted in more runoff [22].

Comment [WU12]: How can burnt soil had more water if its infiltration is reduced and runoff increased?

4.1.3 Bulk density Forest fires made a detrimental effect on soil bulk density, which impact on soil porosity [19, 29, 21]. Because of the collapse of the aggregate and the filling of the voids by the ash, bulk density was slightly raised (less than 1%), causing reduction in the porosity and permeability of the soil. After a fire, soil aggregation collapses and soil organic matter was destroyed, increasing the bulk density [3]. Heydari et al. (2017) [21] reported that an increase in soil bulk density was caused by a drop in organic matter. Since soil porosity and bulk density are inversely related, an increase in bulk density results in a decrease in porosity, further impact the hydrological properties of the soil [64,39].

Comment [WU13]: What study does this data refer to? Please provide reference

4.1.4 Hydraulic conductivity and porosity Burned soils had lower saturated hydraulic conductivity and porosity than unburned soils. The amount of disruption caused by fire to the surface material typically, organic detritus protecting the underlying mineral soil, is the main determinant of hydraulic conductivity. According to research by Valzano et al. (1997) [57], hydraulic conductivity dropped by around 50% in burned soils compared to unburned soils.

Comment [WU14]: Some references?

4.2 Fire effects on chemical properties of soil

4.2.1 Soil pH and EC Only at higher temperatures can forest fires considerably raise the soil pH from 5 to 6.3 at depths of 0 to 10 cm and 5.7 to 6.2 at depths of 11 to 20 cm depth [16]. High pH of the ash may raise the soil pH. An extremely small increase in soil electrical conductivity was seen after one year of controlled fire. Due to the release of inorganic ions from the burned soil organic matter, EC was somewhat higher in burned plots than in unburned plots after the fire [46,20,59]. The presence of base cations in the ash, such as calcium, magnesium, and potassium, causes an elevation in pH and EC [38].

Comment [WU15]: Reference?

Comment [WU16]: In which study? Reference?

4.2.2 Soil organic matter The third largest terrestrial carbon store is soil organic matter (SOM), with an estimated amount of 1526 Pg C [36]. According to Nabatte and Nyombi (2013) [45], burning reduces the amount of organic matter content in burned plots was lower (4.593%, range 2.6-6.1 %) than in unburned plots (5.11%, range 2.8-8.2%). Wildfire can cause a significant loss of soil carbon, but low intensity prescribed fire often causes little change in soil carbon [28].

Comment [WU17]: Is this a mean value?

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Comment [WU19]: Can you explain why is that?

According to studies, the amount of organic matter following a forest fire may rise because of a large amount of dead root biomass [37] or fall due to a lack of aboveground litter fall inputs [10]. Red pine (*P. resinosa*) had more organic materials following burning [2]. Ash covering the top soil layer of the burned parts had risen the organic material content [5,41].

4.2.3 Cation exchange capacity Burning lowers soil CEC. However, soil with high levels of organic carbon had less impact on the CEC of mineral soils [23].

Comment [WU20]: Unclear sentence. I assume You meant that fires had less impact on organic soil (with high level of SOC) compared to mineral soils (with lower SOC content). Also , brief explanation of reasons for that would be appropriate

Comment [WU21]: Agricultural production?

4.2.4 Soil Nitrogen A considerable amount of N is lost during a fire, which has a negative impact on production. Due to the high temperature, nitrogen is lost through volatilization, and at 500°C, 50% of the nitrogen in OM can be volatilized [48]. However, burning can raise the leftover material's nitrogen concentration. It's likely that nutrients are either volatilized away or released in a highly soluble form and deposited on the soil surface. According to Rundel (1997) and Kutiel and Inbar (1993)[53,35], N loss can happen during a fire period through volatilization, and after a fire, there may be an increase in biological N fixation due to an increase in the rate of soil mineralization.

A small increase in nitrogen availability was seen across all land uses after a controlled fire that lasted twelve months, at 0-5cm depth, and the highest percentage increase in available N was observed under burnt pine forest reaching upto 2.84% [60]. Burned soils were found to have greater organic N concentrations than unburned soils. Johnson and Curtis

[2001] [27] also noted that following a forest fire, the number of N-fixing bacteria rose, which was a direct result of increases in N and C content in upper soil.

4.2.5 Available phosphorus and Potassium In post-burned soils, phosphate and potassium levels were higher. For plants to absorb, organic phosphorus in the organic matter mineralizes, after forest fires to create accessible orthophosphate [65]. Exchangeable cations including Ca^{2+} , Mg^{2+} , K^+ and Na^+ have been shown to increase after forest fires in various studies [50,4]. Plants and leftovers burn, turning to ash in the soil, increasing the P content [12]. Increased exchangeable cation concentrations in soils following a fire, however may only be temporary and quickly revert to pre-fire levels [19,42,25]. Exchangeable cation losses might result from ash erosion, cation leaching, plant uptake during post-fire succession, and their high vaporization thresholds [6].

Comment [WU22]: References?

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4.2.6 Micronutrients Fe content decreased by 12%, Mn by 14%, and Zn by 4% following a fire. However, there is a report that the amount of Mn and Zn increased and that of Fe and Co decreased, but no fire effect on Cu availability. After a fire, the impact of micronutrients like Fe, Cu, Zn, B, and Mo was not well understood [7].

Comment [WU24]: Please list study - Reference?

Comment [WU25]: Reference?

4.3. Fire effects on biological properties of soil

The heating of soils by wildfires causes variations in soil biological properties (microorganisms, biota activities, and soil invertebrates). Two examples of biological species that could be impacted by fire are invertebrates and bacteria. Fire in the forest significantly alters the microbes that affect the nitrogen cycle. Following fire accidents, the bacterial population increased. The growth of the fungal population in burnt soil was also gradual [52]. Actinomycetes were less abundant in burned soils as a result of the burning of spores. The burnt site has identical spores but a lower viability of AM fungi, which maintain the general health of the forest [51]. [Knelman et al. 82015](#) and [Moya et al. \(2019\)](#) [32, 44] stated that the MBC in burnt soils had dropped after high severity wildfires.

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The release of chemicals that prevent fungal growth, a decrease in the amount of nutrients available, and the loss of microbial biomass due to fire might be contributing factors to the decline in MBC [20,1]. The impact of fire reduces the biomass of soil microorganisms. Severe fire can greatly reduce the biomass of microorganisms[13]. The microbial community was once dominated by fungi but became dominated by bacteria as a result of fire.

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Increased pH and the availability of nutrients after a fire may change the microbial communities [43,61]. In addition to altering the microbial ecology, fire affects the enzymatic activity of burned soils. In burnt forest soils, [32,44] showed lower beta glucosidase activity and linked the loss to the occurrence of fire and the richness in nutrients caused by ash deposits. Reduced acid phosphatase was found by [18, 44] and this could be the result of injury or a fall in microbial biomass activity.

Table 1: Mean values of physical, chemical and biological properties of burned and unburned forest soil

Soil parameters	Burned	Unburned
EC ($\mu\text{hos cm}^{-1}$)	576.67a	189.67b
PH (1:2.5 water:soil)	5.88	5.41
Organic nitrogen (%)	0.57a	0.44b
Microbial biomass carbon (mg C g soil ⁻¹)	2.00	2.00
Urease activity (mg kg ⁻¹ 2h ⁻¹)*	2.28b	4.97a
Soil organic carbon (%)	7.14	7.74
Available P(mg kg ⁻¹)	51.74a	18.52b
Available K(mg kg ⁻¹)	194.15a	167.05b
Cation exchange capacity (cmol kg ⁻¹)	20.13	25.27
Total porosity %	48.52b	53.44a
Bulk density (g cm ⁻³)	1.31	1.22
Hydraulic conductivity (cm h ⁻¹)	5.47b	10.50a
Soil water content (%)	1.93	4.10

Comment [WU29]: Please describe the data from the table in the text

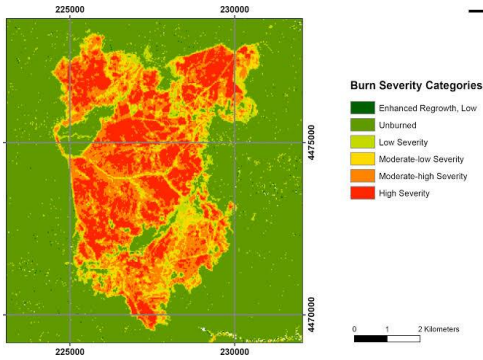
(HUSEYIN EKINCI, 2006)

5. Post Fire management in soil

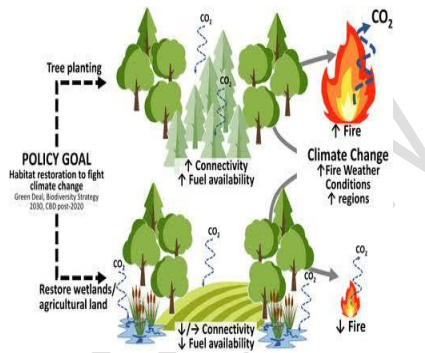
- The detection of forest fires, the calculation of burned areas, and the determination of changes in land use were the main uses of remote sensing technology.
- Planting quick-growing species helps hasten the sequestration of carbon.
- GIS technology is used to analyze probable forest fires.
- Legal provisions for preventing and controlling fires should be enforced firmly.

Comment [WU30]: I suggest to reformulate these into the plain text (full sentences with the references) Also, a brief explanation of every claim would be appropriate

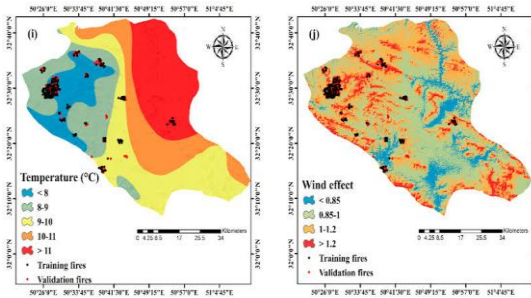
- Management of woody residues within the fire prescription may be a significant N management in a fire setting because some forest soils have the ability to fix nitrogen when wood decays on the surface and in the soil profile [8].



a. Remote sensing tool to delineate burnt area



b. Planting Fast growing species



c. GIS technology



d. Woody residues for N management

Figure 2: Post Fire management in soil

6. Conclusion

Forests are undoubtedly and significantly impacted by fire. Fires alter the soil colour, pH, bulk density, and texture, which causes erosion and run-off of the soil. Furthermore, forest fires bring adjustments to the nutrient cycles and the organic matter in the soil, which can alter the productivity of the ecosystem. Microorganisms and invertebrates both experience a loss in quantity and species due to fire. In relation to soil erosion, loss of soil and sediment was accelerated by the fire. Maintaining all forest types is crucial from a conservation standpoint since they include a significant amount of plant and wild animals.

As a tool for predicting fires, remote sensing, and GIS are highly essential. Several important locations for the protection of forest biodiversity have been invaded by species including *Lantana camara*, *Eupatorium glandulosum*, *Parthenium hysterophorus*, *Cassia tora*, and *C. occidentalis*, among others. Hence it's important to understand how fire affects physical, chemical, and biological aspects of forest ecosystems.

Comment [WU31]: In the text remote sensing and GIS were listed as a tools for post fire management not prediction of fires

Comment [WU32]: This statement is not conclusion derived from data presented in the text

REFERENCES

1. Akburak S, Son Y, Makineci E and Çakir M. Impacts of low-intensity prescribed fire on microbial and chemical soil properties in a *Quercusfrainetto* forest. *J For Res.* 2018; 29(3):687–696.
2. Alban DH. Influence on soil properties of prescribed burning under mature red pine (Vol. 139). Department of Agriculture, Forest Service, North Central Forest Experiment Station.1977.
3. Alcañiz M, Outeiro L, Francos M, Farguell J, Úbeda X. Long-term dynamics of soil chemical properties after a prescribed fire in a Mediterranean forest (Montgrí Massif, Catalonia, Spain). *Sci Total Environ.* 2016; 572:1329–1335.
4. Alexakis D, Kokmotos I, Gamvroula D and Varelidis G. Wildfire effects on soil quality: Application on a suburban area of West Attica (Greece). *Geosciences Journal.* 2021; 25: 243-253.
5. Badia, D and Marti, C. Fire and rainfall energy effects on soil erosion and runoff generation in semi-arid forested lands. *Arid Land Research and Management.* 2008; 22(2): 93-108.
6. Caon L, Vallejo VR, Ritsema CJ and Geissen V. Effects of wildfire on soil nutrients in Mediterranean ecosystems. *Earth-Science Reviews.* 2014; 139:47-58.
7. Certini G. Effects of fire on properties of forest soils: a review. *Oecologia,* 2005.
8. Chandra S. Application of remote sensing and GIS Technology in forest fire Risk Modeling and management of forest fires: A case study in Garhwal Himalayan Region. *Geo-information for Disaster management.* In: Oosterom, P., Zlatanova, S. and E. (Eds.) 2005, XXVI, 1434p. 516 illus, ISBN: 978-3-540-24988-7.
9. Cochrane MA & Laurance WF. Fire as a large-scale edge effect in Amazonian forests. *Journal of Tropical Ecology.* 2002; 18, 311–325.
10. Covington WW and Sackett SS. The effect of a prescribed burn in southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor. *Forest Science.* 1984; 30(1): 183-192.
11. Creighton M. Litton Creighton M. Litton Rómulo Santelices Moya Rómulo Santelices Moya. Early post-fire succession in a *Nothofagus glauca* forest in the Coastal Cordillera of south-central Chile. *International Journal of Wildland Fire.* 2002; 11(2).DOI: 10.1071/WF02039.
12. DeBano LF and Conrad CE. The effect of fire on nutrients in a chaparral ecosystem. *Ecology.* 1978; 59(3):489-497.
13. DeBano LF, Neary DG and Ffolliott PF. *Fire's effects on Ecosystems.* John Wiley and Sons Inc., New York, USA. 1998.
14. DeBano LF. Effects of fire on chaparral soils in Arizona and California and postfire management implications. in *Fire and Watershed Management.* 1989;55.
15. DeBano LF. The effect of fire on soil properties. *Proceedings-Management and Productivity of Western-Montane Forest Soils.* In: A. E. Harvey and L. H. Neuenschwander (Eds). USDA. 1991; Forest Service General Technical Report INT-280,151-156.
16. Fatubarin AR and Olojugba MR. The influences of forest fire on the vegetation and some soil properties of a savanna ecosystem in Nigeria. *Journal of Soil Science and Environmental Management.* 2014; 5(2): 28-34.
17. Fernández-García V, Miesel J, Baeza, MJ, Marcos E and Calvo L. Wildfire effects on soil properties in fire-prone pine ecosystems: Indicators of burn severity legacy over the medium term after fire. *Applied Soil Ecology.* 2019; 135:147-156.
18. FSI. 2012. [technical information series vol1 no1.pdf \(fsi.nic.in\).](#)
19. Granged, A.J., Jordán, A., Zavala, L.M., Muñoz-Rojas, M. and Mataix-Solera, J., 2011. Short-term effects of experimental fire for a soil under eucalyptus forest (SE Australia). *Geoderma,* 167, pp.125-134.
20. Hernandez T, Garcia C, & Reinhardt I. Short-term effect of wildfire on the chemical, biochemical and microbiological properties of Mediterranean pine forest soils. *Biology and Fertility of Soils.* 1997; 25, 109–116. <https://doi.org/10.1007/s003740050289>.
21. Heydari M, Rostamy A, Najaf F, Dey DC. Effect of fire severity on physical and biochemical soil properties in Zagros oak (*Quercusbrantii*Lindl.) forests in Iran. *J for Res.* 2017; 28(1):95–104.
22. Hosseini M, Geissen V, González-Pelayo O, Serpa D, Machado AI, Ritsema C and Keizer JJ. Effects of fire occurrence and recurrence on nitrogen and phosphorus losses by overland flow in maritime pine plantations in north-central Portugal. *Geoderma.* 2017; 289: 97-106.
23. HuseyinEkinci. Effect of Forest Fire on Some Physical, Chemical and Biological Properties of Soil in Çanakkale, Turkey. *International Journal of Agriculture & Biology.* 2006; 8(1):102-106.
24. James CE and Krumland B. Immediate post-forest fire salvage logging, soil erosion, and sediment delivery. *Forest Science.* 2018;64(3): 246-267.
25. James JA, Kern CC and Miesel JR. Legacy effects of prescribed fire season and frequency on soil properties in a *Pinusresinosa* forest in northern Minnesota. *Forest ecology and management.* 2018; 415: 47-57.
26. Jhariya MK and Raj A. Human Welfare from Biodiversity. *Agrobios Newsletter.* 2014; 12(9): 89-91.
27. Johnson DW and Curtis PS. Effects of forest management on soil C and N storage: meta analysis. *Forest ecology and management.* 2001;140(2-3):227-238.

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28. Johnson DW. Effects of forest management on soil carbon storage. *Water Air Soil Pollut.* 1992; 64: 83-120.
29. Jordán A, Zavala LM, Mataix-Solera J, Nava AL, Alanís N. Effect of fire severity on water repellency and aggregate stability on Mexican volcanic soils. *CATENA.* 2011; 84(3):136–147.
30. Kauffman JB, Steele MD, Cummings DL and Jaramillo VJ. Biomass dynamics associated with deforestation, fire, and conversions to cattle pasture in a Mexican tropical dry forest. *Forest Ecology and Management.* 2003; 176: 1-12.
31. Kirkpatrick C, Conway C and Jones PB. Distribution and relative abundance of forest birds in relation to burn severity in southeastern Arizona. *The Journal of Wildlife Management.* 2006; 70: 1005–1012.
32. Knelman JE, Graham EB, Trahan NA, Schmidt SK and Nemergut DR. Fire severity shapes plant colonization effects on bacterial community structure, microbial biomass, and soil enzyme activity in secondary succession of a burned forest. *Soil BiolBiochem.* 2015; 90:161–1.
33. Kodandapani N, Cochrane MA and Sukumar R. A comparative analysis of spatial, temporal, and ecological characteristics of forest fires in a seasonally dry tropical ecosystem in the Western Ghats, India. *Forest Ecology and Management.* 2008; 256: 607-617.
34. Krishna PH and Reddy CS. Assessment of increasing threat of forest fires in Rajasthan, India using multi-temporal remote sensing data (2005-2010). *Current Science.* 2012; 102(9): 1288-1297.
35. Kutiel P and Inbar M. Fire impacts on soil nutrients and soil erosion in a Mediterranean pine forest plantation. *Catena.* 1993; 20(1-2):129-139.
36. Lal R. Soil carbon sequestration to mitigate climate change. *Geoderma,* 2004; 123: 1-22.
37. Lee WK, Choi K and Oh MY. Effect of forest fire on soil properties and vegetation. *The Research Reports of the Forestry Research Institute (Korea Republic).* 1988.
38. Litton CM and Santelices. Effect of wildfire on soil physical and chemical properties in a *Nothofagusglauca* forest, Chile. *Revista Chilena de Historia Natural.* 2003; 76(4):529-542.
39. Lucas-Borja ME, Ortega R, Miralles I, Plaza-Álvarez PA, González-Romero J, Peña-Molina E, Moya D, Zema DA, Wagenbrenner JW and De las Heras J. Effects of wildfire and logging on soil functionality in the short-term in *Pinushalepensis* Mill. forests. *Eur J for Res.* 2020;139:935–945.
40. Lyon L, Jack, Huff, Mark H, Hooper, Robert G, Telfer, Edmund S, Schreiner, David Scott and Smith Jane Kapler. *Wildland Fire in Ecosystems Effects of Fire on Fauna.* JFSP Synthesis Reports. 2000; 7. <http://digitalcommons.unl.edu/jfspsynthesis/7>.
41. Martín A, Díaz-Raviña M and Carballas T. Short-and medium-term evolution of soil properties in Atlantic forest ecosystems affected by wildfires. *Land Degradation & Development.* 2012; 23(5): 427-439.
42. Maynard DG, Paré D, Thiffault E, Lafleur B, Hogg KE and Kishchuk B. How do natural disturbances and human activities affect soils and tree nutrition and growth in the Canadian boreal forest?. *Environmental Reviews.* 2014; 22(2): 161-178.
43. Mikita-Barbato RA, Kelly JJ, Tate RL III. Wildfire effects on the properties and microbial community structure of organic horizon soils in the New Jersey Pinelands. *Soil BiolBiochem.* 2015; 86:67–76.
44. Moya D, González-De Vega S, Lozano E, García-Orenes F, Mataix-Solera J, Lucas-Borja ME and de Las HJ. The burn severity and plant recovery relationship affect the biological and chemical soil properties of *Pinushalepensis* Mill. stands in the short and mid-terms after wildfire. *J Environ Manage.* 2019; 235:250–256.
45. Nabatte P and Nyombi K. Effect of pine plantation surface fires on soil chemical properties in Uganda. *Research Journal of Agriculture and Forestry Sciences.* 2013. ISSN, 2320, p.6063.
46. Naidu CV & Srivasuki KP. Effect of forest fire on soil characteristics in different areas of Seshachalam hills. *Annals of Forestry.* 1994; 2: 166–173.
47. Nardoto GB and Bustamante MMDC. Effects of fire on soil nitrogen dynamics and microbial biomass in Savannas of Central Brazil. *Pesq. Agropec. Bras.* 2003; 38(8): 955-962.
48. Neary DG, Klopatek CC, DeBano LF. Fire effects on below ground sustainability: a review and synthesis. *Forest Ecology and Management.* 1999; 122: 51-71.
49. Pierson FB, Robichaud PR, Moffet CA, Spaeth KE, Williams CJ, Hardegree SP and Clark PE. Soil water repellency and infiltration in coarse-textured soils of burned and unburned sagebrush ecosystems. *Catena.* 2008;74(2):98-108.
50. Rahimi S, Sharifi Z and Mastrodonardo G. Comparative Study of the Effects of Wildfire and Cultivation on Topsoil Properties in the Zagros Forest, Iran. *Eurasian Soil Science.* 2020; 53: 655-1668.
51. Rashid A, Ahmed T and Ayub N. Effect of forest fire on number, viability and post-fire reestablishment of arbuscular mycorrhizae. *Mycorrhiza.* 1970; 7: 217-220.
52. Renbuss MA, Chilvers GA and Pryar LD. Microbiology of an ash bed, *Proc. Linn. Soc. N.S.W.* 1973; 97: 302-311.
53. Rundel PW. Impact of fire on nutrient cycles in Mediterranean-type ecosystems with reference to chaparral. In: Kruger, F.J., D.T.Mitchell, J.U.M. Jarvis, (Eds.), *Mediterranean-type Ecosystems: The Role of Nutrients* Springer. 1983; 192–207. Berlin SAS Institute, 1997.
54. Saha S. Anthropogenic fire regime in a central India deciduous forest. *Current science.* 2002; 82: 1144-1147.

55. Turner IM. Species loss in fragments of tropical rain forest: A review of the evidence. *The Journal of Applied Ecology*. 1996;33: 200–209.
56. Ulery AL and Graham RC. Forest fire effects on soil color and texture. *Soil Science Society of America Journal*. 1993;57(1): 135-140.
57. Valzano FP, Grene RSB and Murphy BW. Direct effects of stubble burning on soil hydraulic and physical properties in a direct drill tillage system. *Soil and Tillage Res*. 1997;42: 209–19.
58. Van der Werf GR, Randerson JT, Collatz GJ and Giglio L. Carbon emissions from fires in tropical and subtropical ecosystems. *Global Change Biology*. 2003; 9: 547-562.
59. Verma S, Singh D, Singh AK and Jayakumar S. Post-fire soil nutrient dynamics in a tropical dry deciduous forest of Western Ghats, India. *Forest Ecosystems*. 2019; 6(1):6 <https://doi.org/10.1186/s40663-019-0168-0>.
60. Vishvamitera S, Sharma U and Guleria A. Fluctuations in soil nutrients and physico-chemical properties following controlled fire in North-Western Himalayas. *Environment Conservation Journal*. 2022; 23(1&2):283-289.
61. Wang L and Fu Q. Soil quality assessment of vegetation restoration after a large forest fire in Daxing'anling, northeast China. *Canadian Journal of Soil Science*. 2020; 100(2):162-174.
62. Wells WG. Some effects of brushfires on erosion processes in coastal Southern California. *Erosion and Sediment Transport in Pacific Rim Steep lands, Christchurch, New Zealand*. International Association of Hydrological Sciences, Christchurch, New Zealand. 1981; 132:305–342.
63. Weninger T, Filipović V, Mešić M, Clothier B, Filipović L. Estimating the extent of fire induced soil water repellency in Mediterranean environment. *Geoderma*. 2019; 338:187–196.
64. Wieting C, Ebel BA, Singha K. Quantifying the effects of wildfire on changes in soil properties by surface burning of soils from the Boulder Creek Critical Zone Observatory. *Journal of Hydrology: Regional Studies*. 2017;13:43-57.
65. Zhang Y and Biswas A. The effects of forest fire on soil organic matter and nutrients in boreal forests of North America: a review. *Adaptive soil management: From theory to practices*. 2017; 465-476.