



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

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www.agronomyjournals.com

2024; 7(11): 335-340

Received: 05-08-2024

Accepted: 12-09-2024

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Studies on impact of forest fire on physical and chemical properties of soil under different vegetation types in Uttara Kannada district

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DOI: <https://doi.org/10.33545/2618060X.2024.v7.i11e.1995>

Abstract

A study was carried out to analyse the impact of forest fire on the physical and chemical properties of soil under different vegetation types in Uttara Kannada district during 2021-2022. Composite surface soil samples (0-30cm) were collected from two vegetation types (dry deciduous and moist deciduous forests) and two canopy density classes (very dense and moderately dense canopy) along with three fire disturbance levels (completely fire affected, partially fire affected and non-fire affected). Three-factor factorial RBD was carried out with twelve treatments and three replications. The individual effect and interaction effect of factors were studied. The results revealed that soils of moist deciduous forests showed higher porosity (49.72%), pH (6.36), organic carbon (1.77%), organic matter (3.05%), available nutrients such as N (203.50 kg/ha), P₂O₅ (26.15 kg/ha), K₂O (210.78 kg/ha), exchangeable Ca (4.86 meq/100g), Mg (2.15 meq/100g) and micronutrients viz., Mn (31.49 ppm), Fe (64.32 ppm), Cu (3.75 ppm), Zn (3.17 ppm). But bulk density (1.12 g/cc) and particle density (2.13 g/cc) were found lower. Soils under very dense canopy showed maximum pH (6.31), organic carbon (1.98%), organic matter (3.41%), available P₂O₅ (25.56 kg/ha), available K₂O (211.73 kg/ha), exchangeable Ca (4.55 meq/100 g) and available S (18.61kg/ha). Soil bulk density (1.23 g/cc), pH (6.55) and available P₂O₅ (25.12 kg/ha) increased in the fire-affected soils while soil porosity (46.06%), organic carbon, organic matter, available K₂O (188.49 kg/ha), available S (20.36 kg/ha), micronutrients viz., Fe and Cu decreased in the fire-affected soils.

Keywords: Forest fire, soil, physical properties, chemical properties

Introduction

Fire is regarded as an evolutionary force employed by mankind to transform the world. The earliest evidence of fire dates back to the Carboniferous age, approximately 400 million years ago (Spinage, 2012) [40]. Wildfires affect a million hectares of forest each year, threatening the biota, the structure and functioning of the ecosystem, and the terrain's stability. According to WWF International, the average length of the global fire season increased by 19 per cent between 1979 and 2013, while the frequency of global fire alarms increased by 13 per cent between 1979 and 2019. Human activities are responsible for around 75 per cent of forest fires, which damage plant and animal life and often affect villages and other human habitation. Tropical dry deciduous forests are often more prone to fires than any other forest types and have undergone more forest fires in India, followed by tropical moist deciduous forests and tropical semi-evergreen forests (Anon, 2012) [5]. According to forest inventory statistics, 35.71 per cent of forests in India have not yet been subjected to any significant fires, while 7.49 per cent are exposed to moderately frequent fires, 2.40 per cent to high incidence levels, and 54.40 per cent are exposed to occasional fires (Anon, 2021) [6].

Fire has both positive and negative consequences. Despite the fact that it destroys flora and fauna and severely affects the environment, it is remarkably good for nutrient cycling and plant regeneration (Rowell and Moore, 2000) [37]. Forest fires are regarded as a resource management approach for improving ecological conditions and reducing excess fuel accumulation in forest areas. Fire can affect a range of soil physical and chemical properties, including the loss of organic matter and structure, decreased porosity and increased pH.

The effects of fire on soil properties are determined by the environmental conditions prevailing before the fire, fire behaviour, the season of fire and pre- and post-fire climatic conditions. The direct impact of forest fires on soil is determined by the "fire duration and intensity of burning" and it can be either beneficial or detrimental (Neary *et al.*, 1999) [32].

Severe fires have a negative impact on the structure and porosity of the soil, as well as the loss of organic matter. Fire has a wide range of effects on different ecosystems. Fire is essential for the opening of cones of some tree species and seed germination in several environments, including boreal forests (Alexander and Cruz, 2012) [3]. Fire can occasionally alter the species composition and cause nutrient loss by volatilization, leaching, soil erosion, and other means. The effect of forest fire on soil properties is quite unpredictable and no typical trends can be suggested (Gonzalez-Perez *et al.*, 2004) [22]. There has been few research on the ecological dynamics of the forest following a fire in tropical settings. Furthermore, understanding the sources of fire, its extent and its impact on forest ecosystems aids in improved landscape management.

Materials and Methods

The study was carried out in the dry deciduous and moist deciduous forests of Banavasi and Dandeli respectively, to analyze the impact of forest fire on the physical and chemical properties of soil during the year 2021-2022. Banavasi is located at 14.53330° N latitude and 75.01580° E longitude, at an elevation of 712m above mean sea level on average. Dandeli is located at 15.16640° N latitude and 74.63730° E longitude, with an elevation of 472m above mean sea level on average. The fire incident occurred in the year 2019 in both forests. Two vegetation types (dry deciduous (V1) and moist deciduous forests (V2)), two canopy density classes (very dense (D1) and moderately dense canopy (D2)) and three fire disturbance levels (completely fire-affected (F1), partially fire-affected (F2) and non-fire-affected (F3)) were taken and RCBD was carried out with three replications. Composite surface soil samples (0-30cm) were collected from two vegetation types and two canopy density classes along with three fire disturbance levels. Soil samples were air-dried, powdered (wooden pestle and mortar) and passed through a 2mm sieve. Finally, stored in plastic bags and used for analyzing the physical and chemical properties of soil.

The Core sampler method, as described by Black *et al.* (1965) [8] was used to determine bulk density. Keen's cup method was adopted to assess particle density and porosity (Piper, 1966) [34]. Soil pH was evaluated in soil water suspension (1:2.5) using the potentiometric method (Jackson, 1973) [26]. Similarly, the conductometric method was used to calculate electrical conductivity (Jackson, 1973) [26]. The organic carbon content of the soil samples was measured using the Wet oxidation technique (Jackson, 1973) [26]. Alkaline potassium permanganate technique was used to determine available nitrogen (Subbiah and Asija, 1956) [41]. Bray's method was used to estimate available phosphorus, while Ammonium acetate method was used to estimate available potassium (Jackson, 1973) [26]. The Versenate titration method was used to determine exchangeable calcium and magnesium (Black *et al.*, 1965) [8]. Sulphur was extracted using 0.15 per cent CaCl₂ solution, as described by Williams and Steinbergs (1959) [44] and its concentration was evaluated using the turbidimetric method described by Chesnin and Yein (1951) [13]. DTPA-extractable soil micronutrients were

used to assess soil micronutrients such as Fe, Mn, Zn and Cu (Lindsay, 1978) [27]. Soil physical and chemical parameters were statistically examined using three-factor factorial analysis and the results were interpreted based on the statistical analysis.

Results and Discussion

Soil Physical properties

Soils from moist deciduous forests have a lower bulk density (1.12 g/cc) and particle density (2.13 g/cc) with a higher porosity (49.72%). This could be attributed to higher organic matter content in moist deciduous forest soils compared to dry deciduous forest soils. Since the dry deciduous forest that was taken for the study had undergone more disturbances, it could have resulted in decreased organic matter content and increased bulk density. Also, the bulk density (1.14 g/cc) and particle density (2.26 g/cc) of soils under very dense canopy were reported to be lower while porosity was higher under very dense canopy (49.92%) (Table 1). This could be due to increased fine root turnover and litterfall. Similarly, Abera and Bekele (2019) [1] reported that the bulk density was lower under the *Acacia seyal* canopy than it was outside of the canopy. Soils that have been completely burned have a higher bulk density (1.23 g/cc) and particle density (2.28 g/cc), as well as a lower porosity (46.06%). This rise could be linked to clay mineral dispersion and aggregate collapse, which reduced soil permeability, porosity and blocked voids (Certini, 2005) [11].

Table 1: Influence of vegetation types, canopy density classes, fire disturbance levels on physical properties of soil

Treatments	Soil physical properties		
	Bulk Density (g/cc)	Particle Density (g/cc)	Porosity (%)
Vegetation types (V)			
V ₁	1.21	2.40	47.41
V ₂	1.12	2.13	49.72
S.Em±	0.002	0.004	0.126
CD @ 5%	0.006	0.011	0.368
Canopy Density (D)			
D ₁	1.14	2.25	49.92
D ₂	1.18	2.28	47.20
S.Em±	0.002	0.004	0.126
CD @ 5%	0.006	0.011	0.368
Fire Disturbance level (F)			
F ₁	1.23	2.28	46.06
F ₂	1.18	2.27	47.87
F ₃	1.08	2.24	51.76
S.Em±	0.002	0.005	0.154
CD @ 5%	0.007	0.014	0.451

Soil chemical properties

Soil pH is an important measure of soil fertility, as it influences the nutrients available to plants (Zhao *et al.*, 2012) [45]. The pH of the soil in the dry deciduous forest and moist deciduous forest studied was 6.11 and 6.36, respectively. The quality of the root exudates and litter differs across the two forest types, with species-specific effects on soil physical properties and microbiological activity (Chandra *et al.*, 2016) [12]. The canopy density had a significant effect on soil pH, with soils under very dense canopy having higher (6.31) soil pH. According to Isichei and Muoghalu (1992) [25], the pH of the soil is higher beneath tree canopies than in open grasslands. This could be due to less leaching and more organic debris accumulating beneath them. Soil pH ranged from 5.88 to 6.55 for soils exposed to varying levels of fire disturbance. Soil acidity was lower in fire-affected

soils than in non-fire-affected soils (Table 2). Acidic nature of soil pH in the study sites suggests that the fire-affected soils are recovering from the effect of fire. Adams and Sidle (1987) [2] and Robertson and Vitousek (1981) [36] discovered that natural forests with limited disturbance have lower pH levels than disturbed ecosystems. The accumulation and slow decomposition of organic material produced acids, which are responsible for the pH drop (De Haan, 1976) [16].

Soil electrical conductivity (EC) is a measure of salt concentration. It is an excellent predictor of soil texture, available water capacity, nutrient availability, and loss. The electrical conductivity of the study site ranged from poor to normal. Too low EC indicates a lack of available nutrients, while high EC indicates an abundance of nutrients. The influence of vegetation types and canopy density classes was non-significant for soil electrical conductivity (Table 2). This finding is aligned with Mishra *et al.* (2017) [30]. While the effect of fire disturbance on soil electrical conductivity was significant, it was higher in fire-affected soil. The assimilation of soluble salts produced by the combustion of soil organic matter could be the source of this significant increase in soil electrical conductivity (Ciampa *et al.*, 2009; Debano *et al.*, 1977) [15, 18].

Organic carbon (1.77%) was found to be greater in moist deciduous forests. This could be attributed to increased disturbances in the dry deciduous forest. According to Chhabra *et al.* (2003) [14], tropical moist deciduous forest soil has a carbon density of 73.2 t/ha, while dry deciduous forest soil has a carbon density of 37.5 t/ha. Furthermore, for a depth of 50cm, the soil carbon pool in moist deciduous and dry deciduous forests is 1.73 PgC and 0.73 PgC, respectively. The amount of organic carbon in the soil may be affected by the location or physiography of

the soil profile under consideration. Soils under very dense canopy had greater organic carbon (1.98%), which could be attributed to enhanced litter decomposition under such a canopy. Chhabra *et al.* (2003) [14] reported that canopy density and elevation from mean sea level have a substantial influence on soil organic carbon in their study.

Organic carbon and organic matter in soil were reduced considerably in fire-affected areas. Fire lowered the amount of organic carbon due to heat-induced pyrolysis of organic materials (Almendros *et al.*, 1990) [4]. Some of the consequences of fire on soil organic matter include volatilization, charring and oxidation. Significant organic matter loss occurs between 200°C and 460°C (Giovannini *et al.*, 1988) [21]. Depending on the intensity of the fire, organic carbon burns partially or completely (Simard *et al.*, 2001) [39]. Litter generation (both above and below ground), litter quality and other factors all have an impact on soil organic carbon (Shapkota and Kaffle, 2021) [38]. Changes in forest types affect the species and biomass output of natural vegetation and cultivated plants, as well as soil water balance, soil erosion and geologic deposition processes (Tan *et al.*, 2004) [42].

Soil organic matter content varied significantly as a result of vegetation types, canopy density classes, fire disturbance levels and their interactions. It followed a similar pattern as that of soil organic carbon. It was found to be higher (3.05%) in moist deciduous forests (V₂). It was found to be higher (3.41%) beneath a very dense canopy (D₁). Increased fire disturbances were found to diminish soil organic matter. The greatest (4.09%) was found in non-fire-affected (F₃) soils, while the lowest (1.92%) was found in completely fire-affected soils (F₁).

Table 2: Influence of vegetation types, canopy density classes, fire disturbance levels on soil pH, electrical conductivity, organic carbon and organic matter

Treatments	pH	Electrical conductivity (dS/m)	Organic carbon (%)	Organic matter (%)
Vegetation types (V)				
V ₁	6.11	0.08	1.60	2.77
V ₂	6.36	0.07	1.77	3.05
S.Em±	0.024	0.009	0.019	0.033
CD @ 5%	0.069	NS	0.056	0.095
Canopy Density (D)				
D ₁	6.31	0.07	1.98	3.41
D ₂	6.17	0.08	1.39	2.40
S.Em±	0.024	0.009	0.019	0.033
CD @ 5%	0.069	NS	0.056	0.095
Fire Disturbance level (F)				
F ₁	6.55	0.11	1.12	1.92
F ₂	6.28	0.06	1.57	2.70
F ₃	5.88	0.06	2.37	4.09
S.Em±	0.029	0.011	0.023	0.04
CD @ 5%	0.084	0.032	0.068	0.117

Soil Macronutrients

Soils from moist deciduous forests (V₂) have more available N kg/ha), but the differences were not statistically significant. Similarly, while fire disturbance levels had no effect on available N, they decreased in fire-affected soils (F₁ and F₂) as compared to non-fire-affected soils (F₃). The increase in available N levels is transient and it may diminish after six months due to fast immobilization. Since this study was conducted two years after the fire, the effect of fire on available N became non-significant. Since N has a temperature threshold as low as 200 °C, it is considered a sensitive element (Hosking, 1938) [23].

The soil of the moist deciduous forest had a maximum available

P₂O₅ value of 26.15 kg/ha (Table 3). Mani *et al.* (2006) [28] found such higher available P₂O₅ in shola forest soils as well as in the moist deciduous forests in the Western Ghats (Bhuvanesh, 2017) [7]. The available P₂O₅ in dry deciduous forest soils was determined to be 23.64 kg/ha. Phosphorus content was similar in the Dharmapuri forest circle's dry deciduous forests (Dhinesh *et al.*, 2019) [19]. Available P₂O₅ appears to increase in completely fire-affected areas, followed by partially fire-affected and non-fire-affected soils. Fire converts the organic pool of soil phosphorus to orthophosphate, the only readily available form of P (Cade-Menun *et al.*, 2000) [10].

The available K₂O content was 200.82 kg/ha in dry deciduous forest and 210.78 kg/ha in moist deciduous forest, respectively

(Table 3). The presence of potassium-containing minerals such as illite, muscovite, gluconite, biotite, phlogopite, sanidine and orthoclase in Indian soil may account for the higher amounts of available K₂O in the soils of the study site (Naidu *et al.*, 2011)

^[31]. When compared to non-fire-affected areas, available K₂O reduced in completely and partially burned soils. Verma and Jayakumar (2018) ^[43] found lower potassium levels in the fire-affected soils of the Mudumalai Tiger Reserve in Tamil Nadu.

Table 3: Influence of vegetation types, canopy density classes, fire disturbance levels on available Nitrogen, P₂O₅ and K₂O of soil

Treatments	Available Nitrogen (kg/ha)	Available P ₂ O ₅ (kg/ha)	Available K ₂ O (kg/ha)
Vegetation types (V)			
V ₁	182.11	23.64	200.82
V ₂	203.50	26.15	210.78
S.Em±	4.896	0.127	0.503
CD @ 5%	14.36	0.372	1.476
Canopy Density (D)			
D ₁	193.72	25.56	211.73
D ₂	191.89	24.23	199.88
S.Em±	4.90	0.127	0.503
CD @ 5%	NS	0.372	1.476
Fire Disturbance level (F)			
F ₁	184.25	25.12	188.49
F ₂	196.17	23.76	205.15
F ₃	198.00	21.19	223.76
S.Em±	6.00	0.155	0.616
CD @ 5%	NS	0.456	1.808

The results showed how vegetation types, canopy density classes, fire disturbance levels, and their relationships influence exchangeable calcium (Table 4). The exchangeable calcium of both vegetation types differed significantly, with moist deciduous forests having the highest exchangeable calcium (4.86 meq/100g) (V₂). The influence of canopy density on exchangeable calcium was found to be significant, with soils under the very dense canopy (D₁) having higher exchangeable calcium (4.55 meq/100g). While the impact of fire on exchangeable calcium was non-significant. According to Hough (1981) ^[24], due to the high threshold temperatures of Ca (1107 °C), this nutrient was unaffected by varying amounts of fire disturbances.

The moist deciduous forest has the most exchangeable Mg (2.15 meq/100 g) (V₂). Similarly, canopy density had a significant effect on exchangeable Mg, with the very dense canopy having

the highest (2.14 meq/100 g) (D₂). However, the effect of fire disturbance levels on exchangeable Mg was found to be non-significant. According to Hough (1981) ^[24], due to the high threshold temperatures of Mg (1484 °C), this nutrient was unaffected by varying amounts of fire disturbances.

The effects of vegetation types, canopy density classes, fire disturbance levels and their relationships on available S is given in the table 4. The available S in soils of various vegetation types did not vary significantly. Although the influence of canopy density and fire was significant. Soils under very dense canopy (D₁) had more available S (18.61 kg/ha). Among the three fire disturbance levels, soils with total fire incidence (F₁) had the lowest available S (15.21 kg/ha). Available S dropped as the intensity of fire disturbance increased because they had a low threshold temperature of 375 °C (Hough, 1981) ^[24].

Table 4: Influence of vegetation types, canopy density classes, fire disturbance levels on exchangeable Calcium, Magnesium and available Sulphur in soil

Treatments	Exchangeable Calcium (meq/100 g)	Exchangeable Magnesium (meq/100 g)	Available Sulphur (kg/ha)
Vegetation types (V)			
V ₁	3.63	1.54	16.52
V ₂	4.86	2.15	18.12
S.Em±	0.134	0.182	0.702
CD @ 5%	0.393	0.534	NS
Canopy Density (D)			
D ₁	4.55	2.14	18.61
D ₂	3.94	1.54	16.03
S.Em±	0.134	0.182	0.702
CD @ 5%	0.393	0.534	2.059
Fire Disturbance level (F)			
F ₁	4.55	2.17	15.21
F ₂	4.19	1.84	16.40
F ₃	4.00	1.53	20.36
S.Em±	0.164	0.223	0.86
CD @ 5%	NS	NS	2.522

Soil micronutrients

The impact of vegetation types, canopy density classes, fire disturbance levels, and their interactions on soil micronutrients such as manganese, iron, copper, and zinc were given in the

table 5. Soils from the moist deciduous forest (V₂) had more manganese (31.49 ppm) than those from the dry deciduous forest (26.71 ppm). Soils under dense canopy (D₁) had higher manganese levels (30.73 ppm), however the influence of fire

disturbance levels on soil manganese was revealed to be non-significant.

Soil Cu was significant at the $p \leq 0.05$ level for all factors and their interactions. Cu was greater (3.75 ppm) in the moist deciduous forest (V_2) than in the dry deciduous forest (V_1). Similarly, among the canopy densities, soils under the very dense canopy (D_2) had greater Cu (3.37 ppm). Cu was significantly affected by fires. The soils that had not been affected by fire (F_3) had higher Cu (3.09 ppm). Soils from moist deciduous forests (V_2) were shown to have higher (3.17 ppm) Zn, but canopy density classes and fire disturbances had a non-significant effect.

Table 5: Influence of vegetation types, canopy density classes, fire disturbance levels on available micronutrients in soil

Treatments	Soil Micronutrients			
	Manganese (ppm)	Iron (ppm)	Copper (ppm)	Zinc (ppm)
Vegetation types (V)				
V_1	26.71	50.66	1.99	1.65
V_2	31.49	64.32	3.75	3.17
S.Em $\pm$	0.915	0.85	0.038	0.094
CD @ 5%	2.683	2.50	0.112	0.277
Canopy Density (D)				
D_1	30.73	57.65	3.37	2.54
D_2	27.47	57.33	2.37	2.27
S.Em $\pm$	0.915	0.85	0.038	0.094
CD @ 5%	2.683	NS	0.112	NS
Fire Disturbance level (F)				
F_1	28.92	51.63	2.71	2.29
F_2	29.04	55.22	2.82	2.45
F_3	29.34	65.63	3.09	2.48
S.Em $\pm$	1.12	1.05	0.047	0.115
CD @ 5%	NS	3.07	0.137	NS

Fire had an impact on soil micronutrients such as iron and copper. As the fire disturbance intensified, there was a slight reduction in iron and copper. Influence of fire on soil micronutrients is a poorly studied area. According to a study conducted by Norouz and Ramezani (2013) [33], fire drastically reduced soil iron status while having no effect on the other soil micronutrients. Blank *et al.* (1995) [9] reported that fire had a non-significant effect on soil manganese. Larger amounts of Cu were identified in the unburned soil at the Lakan site, which could be attributed to lower pH, because acidity makes these elements more easily available (Pivello *et al.*, 2010) [35]. According to DeBano (1990) [17], Mn is comparatively less sensitive to high threshold temperatures of 1962°C, which could explain why fire has no major influence on Mn. The behaviour of Fe, Mn, Cu, Zn, B, and Mo in relation to fire is not well understood due to a lack of specific studies (Certini, 2005) [11]. Understanding how fire impacts micronutrient availability is critical for understanding how plants and soils recover after a fire (Garcia-Marco and Gonzalez-Prieto, 2008) [20]. According to studies, micronutrients decreased after a forest fire. According to Marafa and Chau (1999) [29], micronutrients such as Mn (14%), Fe (12%) and Zn (4%), were reduced following the fire. Garcia-Marco and Gonzalez-Prieto (2008) [20] investigated the short- and medium-term effects of fire on soil micronutrient availability and found an increase in Mn and Zn availability, a decrease in Fe and Co availability and no change in Cu availability.

Conclusion

The physical and chemical properties of the soil are affected by forest fire. Forest fires were found to have a stronger impact on

the soils of dry deciduous forests. Severe fires contribute significantly to overall nitrogen and carbon losses in the atmosphere. Since nitrogen is a critical soil nutrient that is required by soil flora and fauna, its loss as a result of a forest fire should be considered. While certain nutrients are lost during combustion, others become more available to plants after a fire. It was revealed that fire has a negative impact on soil micronutrients. When completely fire-affected areas were compared to partially fire-affected areas, the latter showed less loss of nutrients and other negative impacts. Changes in soil physical and chemical properties caused by forest fires were discovered to follow a similar pattern in both forest types. Moist deciduous forest soils were shown to have a greater concentration of soil macro and micronutrients. Similarly, soils under a very dense canopy were found to store more nutrients than soils under a moderately dense canopy.

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