T.R.
ONDOKUZ MAYIS UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION

HOW THE INTRODUCED TREE SPECIES SHAPES THE SORPTION PROPERTIES OF SOILS 30 YEARS AFTER THE FIRE?

Master's Thesis

Mukkaram EJAZ

I. Supervisor
Prof. Dr. Ridvan KİZİLKAYA

II. Supervisor
Assoc.Prof.Dr. Agnieszka JÓZEFOWSKA

SAMSUN
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ACCEPTANCE AND APPROVAL OF THE THESIS

The study entitled **"HOW THE INTRODUCED TREE SPECIES SHAPES THE SORPTION PROPERTIES OF SOILS 30 YEARS AFTER THE FIRE?"** prepared by **Mukkaram EJAZ**, and supervised by **Prof. Dr. Ridvan KİZİLKAYA** and **Assoc.Prof.Dr. Agnieszka JÓZEFOWSKA**, were found successful and unanimously accepted by committee members as Master thesis, following the examination on the date 14.8.2023 .

	Title Name SURNAME **University** **Department/Art**	**Final Decision**
Chairman	Prof. Dr. Rıdvan KIZILKAYA Ondokuz Mayıs University Department of Soil Science and Plant Nutrition	☒ Accept ☐ Reject
Member	Prof. Dr. Orhan DENGİZ Ondokuz Mayıs University Department of Soil Science and Plant Nutrition	☒ Accept ☐ Reject
Member	Assit. Prof. Dr. Ammar Ali ALBALASMEH Jordan University Science and Technology	☒ Accept ☐ Reject

This thesis has been approved by the committee members that already stated above and determined by the Institute Executive Board.

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Prof. Dr. Ahmet TABAK
Head of Institute of Graduate Studies

DECLARATION OF COMPLIANCE WITH SCIENTIFIC ETHIC

I hereby declare and undertake that I complied with scientific ethics and academic rules in all stages of my Master's Thesis , that I have referred to each quotation that I use directly or indirectly in the study and that the works I have used consist of those shown in the sources, that it was written in accordance with the institute writing guide and that the situations stated in the article 3, section 9 of the Regulation for TÜBİTAK Research and Publication Ethics Board were not violated.

Is Ethics Committee Necessary?

Yes ☐ (If it necessary, please add appendices.)

No ☒

12 /07 / 2023
Mukkaram EJAZ

DECLARATION OF THE THESIS STUDY ORIGINALITY REPORT

Thesis Title : HOW THE INTRODUCED TREE SPECIES SHAPES THE SORPTION PROPERTIES OF SOILS 30 YEARS AFTER THE FIRE ?

As a result of the originality report taken by me from the plagiarism detection program on 13 /07 /2023 for the thesis titled above;

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ÖZET

YANGINDAN 30 YIL SONRA YETİŞTİRİLEN AĞAÇ TÜRLERİ TOPRAKLARIN SORPSİYON ÖZELLİKLERİNİ NASIL ŞEKİLLENDİRİR?

Mukkaram EJAZ
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Yüksek Lisans, Haziran/2023
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Bu çalışmanın amacı, farklı ağaç türlerinin ve yönetim uygulamalarının toprakların absorpsiyon özelliklerini nasıl etkilediğini incelemek ve özellikle farklı tanıtılan ağaç türlerinin, özellikle döküntü kalitesi, rizosfer etkileri ve toprak özellikleri de dahil olmak üzere toprağın absorpsiyon özelliklerini nasıl değiştirdiğini araştırmaktır. Çalışmada, bu değişikliklerin yangından 30 yıl sonra ortaya çıkan uzun vadeli sonuçlarını ve çevrenin yönetimi ve restorasyonu için olan etkilerini değerlendirmiştir. Araştırmanın nihai hedefi, ağaç türlerinin toprak özelliklerini nasıl etkilediğine dair bilgiyi ilerletmek ve yangın sonrası alanlardaki ekosistem işleyişi ve hizmetler üzerinde olası etkileri hakkında içgörüler sunmaktır. Çalışma, meşe, çam, ladin ve huş olmak üzere dört farklı ağaç türünü içeren deneysel bir tasarım kullanmıştır ve karbonlu ve karbonsuz faktörleri dikkate almıştır. Toprak profilleri açılarak örnekler toplanmış ve her toprak katmanının morfolojik özellikleri tanımlanmıştır. Toprak pH değerleri su ve 1M KCl çözeltisinde ölçülmüş, absorpsiyon kompleksi özellikleri olan değiştirilebilir asidite (Hh), katyon değişim kapasitesi (CEC), baz doygunluğu (BS) ve baz kation konsantrasyonları (Ca2+, K+, Mg2+ ve Na+) belirlenmiştir.

Elde edilen sonuçlar, toprak katmanları ve ağaç türleri arasında pH değerlerinde farklılıklar olduğunu göstermiştir. CEC değerleri ağaç türleri arasında farklılık göstermiş ve karbonlu ladin örneğinde üst toprak tabakasında en yüksek değerler gözlenmiştir. Kalsiyum konsantrasyonları üst tabakada en yüksekken, potasyum ve magnezyum konsantrasyonları yüzey tabakasında alt tabakaya kıyasla daha yüksek bulunmuştur. Sodyum konsantrasyonları karbon içeriğinden önemli ölçüde etkilenmemiş, ancak derinlikle değişiklik göstermiştir. Baz doygunluğu yüzdesi, karbondan arındırılmış huş türünde en yüksek bulunmuştur. Absorpsiyon kompleksi özellikleri, daha çok derinlikten ziyade ağaç türlerinden etkilenmiştir. Temel bileşen analizi (PCA), toprak özellikleri arasındaki ilişkileri ortaya koymuş ve pH'nin diğer incelenen parametrelerle negatif bir korelasyona sahip olduğunu göstermiştir. Yüzey ve alt tabakalar arasında korelasyon desenlerinde farklılıklar gözlenmiştir. Genel olarak, bu çalışma farklı ağaç türlerinin ve yönetim uygulamalarının yangın sonrası alanlarda toprak absorpsiyon özelliklerini nasıl etkileyebileceğine dair anlayışımıza katkıda bulunmaktadır. Bulgular, sürdürülebilir orman yönetimi uygulamaları için değerli içgörüler sunarak ekosistem yönetimi ve restorasyon çabalarını bilgilendirebilir.

Anahtar Sözcükler: Yangın sonrası, Agaçlandırma, Toprak ıslahı, Reklamasyon

ABSTRACT

HOW THE INTRODUCED TREE SPECIES SHAPES THE SORPTION PROPERTIES OF SOILS 30 YEARS AFTER THE FIRE?

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The aim of this study was to examine the sorption characteristics of soils under various tree species and management practices, specifically investigating how different introduced tree species alter the sorption properties of soil, including changes in litter quality, rhizosphere effects, and soil properties. The study also assessed the long-term consequences of these alterations, 30 years after a fire, and their implications for managing and restoring the environment. The ultimate goal of the research was to advance knowledge on how imported tree species affect soil characteristics and offer insights into their possible impacts on ecosystem functioning and services in post-fire areas. The study employed an experimental design with four different tree species (oak, pine, larch, and birch) and considered carbon and non-carbon factors. Soil pits were dug to collect samples, and the morphological characteristics of each soil horizon were described. Soil pH was measured in water and 1M KCl, while the properties of the sorption complex, such as exchangeable acidity (Hh), cation exchange capacity (CEC), base saturation (BS), and concentrations of base cations (Ca2+, K+, Mg2+, and Na+), were determined.

Results showed variations in pH values across soil layers and tree species. The CEC values differed among tree species and were highest in the upper layer of soil, particularly in the case of larch with carbon. Calcium concentrations were highest in the upper layer, while potassium and magnesium concentrations were higher in the surface layer compared to the subsurface layer. Sodium concentrations were not significantly affected by carbon content but varied with depth. Base saturation percentages were highest in birch species with carbon removal. The sorption complex properties were influenced mainly by depth rather than tree species. Principal component analysis (PCA) revealed correlations between soil properties, indicating that pH had a negative correlation with other investigated parameters. The surface and subsurface layers showed differences in correlation patterns. Overall, this study contributes to our understanding of how different tree species and management practices can influence soil sorption properties in post-fire areas. The findings can inform ecosystem management and restoration efforts, providing valuable insights for sustainable forest management practices.

Keywords: Post-fire, afforestation, Soil remediation, reclamation.

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Sincerely,

Mukkaram Ejaz

CONTENTS

SYMBOLS AND ABBREVIATIONS

Hh	: Hydrolytic Acidity
AP	: Articular Process
DD	: Disc Degeneration

FIGURES LEGENDS

TABLES LEGENDS

1. INTRODUCTION

According to Alcañiz et al. (2018), soil is one of the most important natural resources used in socio-ecological and natural systems and is essential for nutrient cycling, mineral storage, carbon sequestration, and plant growth (Osman 2013). Due to its rapid degeneration and slow phase of creation, it is regarded as a non-renewable natural resource on a human timeline (Lal 2015). Therefore, the capacity of forest soils to function fully is reduced as a result of the degradation of their biological, chemical, and physical qualities, with such consequences being either transitory or long-lasting. Deforestation, fires, erosion, and soil contamination are the main causes of soil degradation in forest ecosystems (Ghazoul et al. 2015; Silvério et al. 2019).

In most tropical, temperate, and boreal forest ecosystems, fires are thought to be a harmful element (Fernandez-Garca et al. 2019a, b), and they are seen as a worldwide phenomenon that affects most land areas (Bento-Gonçalves et al. 2012). The Carboniferous period's 360 million-year-old fossil records are where the first signs of fire were found (Verma and Jayakumar 2012). By affecting species composition and regeneration, hydrophobicity, nutrient fluxes, and ecological biodiversity, fire influences the ecology and functioning of forests. While just a small portion of all flames worldwide occur spontaneously, wildfires are frequently caused by human activity (Knorr et al. 2016). According to Gómez-Rey et al. (2013), forest fires are a significant factor in soil deterioration and nutrient losses due to erosion and volatilization.

Higher temperatures and harsh droughts significantly enhance the risk of forest fires as a result of present global warming (Zhang and Biswas 2017). Recent predictions suggest that increasing temperatures could increase in frost length, intensity, and frequency in tropical and other wooded areas (Zhang and Biswas 2017; Auclerc et al. 2019; Addo-Fordjour et al. 2020). Therefore, increasing fire risk will affect soil's physical, chemical, and biological characteristics as well as forest flora (Romeo et al. 2020). Compared to the impact on vegetation, the effects of fire on forest soils are more complex and have not received as much research.

Whether they are man-made or natural, fire events have a variety of effects on the ecosystems they occur in. According to Certini (2005), soil qualities may change

as a result of a fire in a short-term, long-term, or permanent way that could have an ecosystem-wide influence effect for the stability and resilience of ecosystems. Fire-induced changes in soil characteristics could have detrimental effects in polluted soils where natural attenuation processes are hampered by the presence of large concentrations of pollutants. These modifications may have an impact on the sorption and attenuation capacities of the soil and may determine the remediation strategy to be used on fire-affected polluted sites. A wide range of reports suggest climate change would result in more fires worldwide, especially in areas affected by extreme weather (Beniston et al., 2007; Turco et al., 2018). Historically, forest fires have mainly affected the southern nations of Europe. The Mediterranean has been struck by fires more than 0.8 million times in the past two years (de Rigo et al., 2017). It's also true that there have been major fires in central and northern Europe, such as in Sweden (San-Miguel-Ayanz et al., 2018). Forest fire risk around Europe is expected to increase due to climate change (de Rigo et al., 2017).

It has been well documented that fire has abruptly affected soils. As a result of fire-burnt material, nitrogen (N) is volatilized, sooty and nitrogen are mobilized from organic matter in mineral soils (Certini, 2005), and less volatile nutrients (P, K, Ca, and Mg) that remain in the ash are intensified in ionic or labile fractions (Neary et al., 1999). A surface mineral soil typically develops as a result of increases in extractable (SO4-2), exchangeable (K+, NH+, Mg2+ and Ca2+) and pH levels. The combustion of organic matter in mineral soils is usually limited as the soil temperature isn't high enough unless there is an intense fire, so little change in organic carbon or nitrogen occurs in the soil. Lynham et al., 1998; Hauer et al., 1998; Carriera et al., 1996 determined how ortho-P availability changed with fire from organic materials and Ca2+ immobilization.

While forest fires are one of the most dangerous threats to ecosystems (Thonicke et al., 2001; Robinne et al., 2020), natural forces can also disrupt forest ecosystems and lead to the regeneration of many species in Central Europe, including Scots pines and common birches (Dzwonko et al., 2015). Large fires alter forest ecosystems negatively; (Knelman et al., 2015), which show up as altered soil characteristics and the "backflow" of forest ecosystems into secondary succession (Hume et al., 2016). Nitrogen is a key nutrient lost to soils at high temperatures (Neary et al., 2005; Mayer et al., 2020). It has been shown that fires increase soil

alkalinity (González-Pérez et al., 2004; Neary et al., 2005; Romeo et al., 2020). Several measures can be taken to prevent further forest fires, but revegetation of the burned area is the most important. Plant diversity, soil biological activity, and renewal processes are all affected by choosing the right tree species for reforestation (Pietrzykowski, 2019). Soil quality is affected differently by different tree species. Joly et al., 2017; Barbier et al., 2008) suggest that canopy closure has the effect of reducing light penetration onto the forest floor, resulting in a warmer microclimate. There is a possibility that a forest ecology may not be able to recover naturally after a fire or within a reasonable time period. For reforestation, it is important to consider fire frequencies in the area. A limited supply of propagules could boost the rates of secondary succession following fires (Ilisson & Chen, 2009).

The introduced tree species pine, birch, larch and oak will alter the soil properties, such as the content and type of clay minerals and iron oxides, which will affect soil pH, cation exchange capacity, and the availability of nutrients and contaminants, affecting the sorption properties of the soil.

Hypothesis Null hypothesis: The soil sorption properties of forest soils after 30 years of fire are unaffected by tree species.

Alternate hypothesis: Over a 30-year period, the soil sorption properties of post-fire forest soils are significantly affected by tree species.

The purpose of the study is to examine the sorption characteristics of soils under various tree species and management practices by which different introduced tree species alter the sorption properties of soil, such as changes in litter quality, rhizosphere effects, and soil properties. The study will also assess how these consequences are still being felt 30 years after the fire and what that means for managing and restoring the environment. The ultimate goal of the MSc thesis is to advance knowledge of how imported tree species affect soil characteristics and to offer insights into their possible impacts on ecosystem functioning and services in postfire areas.

2.LITERATURE REVIEW

The following pioneer species are often used in Central European postfire regeneration: common birch (Betula pendula Roth), Scots pine (Pinus sylvestris L.), and European larch (Larix decidua Mill.) (Bojarski & Kaczmarek, 2018; Dzwonko et al., 2015). Moreover, they are often prominent during natural secondary succession at forest sites that have been affected by fire or additional disturbances (Ellenberg, 2009). Low-fertility soils are well adapted to these tree species, which have a wide ecological spectrum and require a great deal of light. The types of trees that are planted in reforestation on postfire sites should be taken into account when examining the species composition of the regenerated forest soil. Different tree species can influence soil's organic carbon buildup, nutrient distribution, and availability, according to Vesterdal et al. (2008) and Hobbie et al. (2007). Certini (2005) concluded that fire can damage both factors.

By substituting more humus with mull, common birch increases soil fertility (Harrison *et al*., 1988; Dubois *et al*., 2020; Miles, 1981; Kanerva & Smolander, 2007). A study from Jonczak *et al*., 2020, reported that this species raised base saturation and soil pH, thereby altering nutrient contents and availability in favor of coniferous trees (Hansson *et al*., 2011). Additionally, birch has been shown to positively affect soil microbiome features, such as enzyme levels and microbial biomass (Priha *et al*., 1999; Chodak & Niklinska, 2010; Bradley & Fyles, 1995). On the other hand, Jonczak *et al*. (2020) concluded that birch had a ambiguous impact on carbon stock after conducting a literature review. The authors conclude that tree species are most helpful in redistributing carbon (C) between organic horizons and mineral horizons rather than affecting overall C stocks (between organic horizons and mineral horizons). The composition of mineral horizon C stocks in tree species with higher organic horizon C stocks is smaller compared to tree species with lower organic horizon C stocks (Wiesmeier *et al*., 2013; Gruba & Socha, 2019). As illustrated in figure (2.1.), Hüblová & Frouz (2021) found that soils undergoing early stages of development (such as post-mining areas) are dominated by tree species more than mature soils (such as post-agricultural and forest sites). Several soil textures and three trees species were tested for their effects on the chemical composition and carbon stock of fire-affected soils, including European larch (*Larix*

*decid*ua Mill.), Scots pine (*Pinus sylvestris* L.), and common birch (*Betula pendula* Roth).

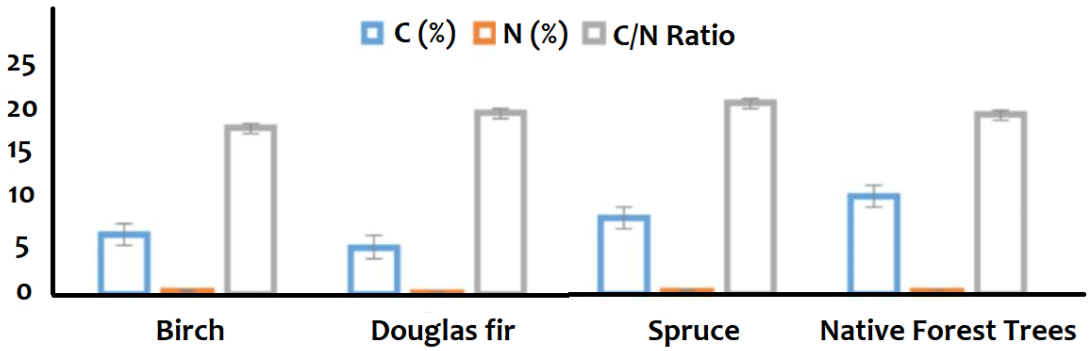


Figure 2.1. Characteristics of the fraction of A1 organo-mineral topsoil (0-5 cm)

2.1. Changes in soil properties induced by fire and how they affect soil sorption

Bhari *et al*. (2021) discovered the characteristics of chicken feather fibre and discussed how chicken feather can be utilized biologically for the formulation of hydrolysate which can further utilized as a biofertilizer. Feathers consist of three individual structures- (1) Rachis, (2) Barb, (3) and Barbules. Barb and Barbules primarily consist of α-helix confirmations and some β sheet structures. About 78% of β sheet and 18% of α-helical structure is found in rachis. High percentage of volatile solids are found in feather which contain 92% is crude protein, of which 82.8% is insoluble and chemically inactive keratin (Costa *et al*., 2012) Chicken feather can be found as an unique source of amino acid and this amount depends on age, food, environment, and breed. As well as carbon, hydrogen, nitrogen chicken feather also contain several macro and micronutrients such as phosphorus, calcium, magnesium, zinc, iron, sodium, potassium, manganese (Staron *et al.*, 2017) & (Nurdiawati *et al*., 2017).

2.2. Modification of soil texture caused by fire and how they impact soil sorption

It is estimated that finer soil particles can influence sorption of contaminants in soils by 37.1%, according to Falciglia *et al*. (2011). It has been shown that this effect is caused by cation exchange capacity (CEC) of soil particles, which ranges from 10

mmol/kg in sandy soil to 813 mmol/kg in fine clay, as described in Schulten and Leinweber (2000). It has been observed by various authors that wildfires affect soil particles and, thus, soil texture (Certini 2005; Mataix-Solera & Doerr 2004; Badia & Marti 2003), even though clay and sand have high melting points (460–980°C and 1414°C, respectively), even though clay and sand have high melting points of 460–980°C and 1414°C, respectivelyAfter 400°C clay particles start changing in structure because of hydroxylation and the collapsing of the lattice structure. At 700°C, clay particles are completely destroyed. As a result, soils' clay components contain a high amount of secondary minerals. Moreover, quartz has a melting point of 2577 °C and a high thermal conductivity, which makes it the most common component of sand and silt. Therefore, they are more thermally stable and are generally not affected by wildfire events because the soil temperatures are not extremely high. According to Neary *et al*. (2005), clayed soils are more susceptible to fire damage than sandy and silty soils. According to them, this is due to varying mineral contents between the soil types. The ability of soils to absorb moisture is likely to decrease following a fire, as sand-sized particles tend to accumulate in soils after a fire.

2.2.1. The effect of fire on soil mineral properties and how it affects sorption

A change in soil mineralogy caused by fire depends on the moisture level of the soil and depends on the type of soil, according to Reynard-Callanan et al. (2010). During Ngole's laboratory investigations, it emerged that uncontaminated soils underwent major mineralogy changes at about 300°C while mine tailings-contaminated soils underwent similar changes at 500°C. In both contaminated and uncontaminated soil, the mineralogy changes after four hours of 300°C heating and two hours of 500°C heating (Ngole-Jeme 2017). Possibly, secondary minerals are transformed into primary minerals due to dihydroxylation. Researchers have also demonstrated that fire events with temperatures as low as 200-600°C can affect soil mineral composition (Zihms et al., 2013 and Yusiharni and Robert, 2010). Tan et al. (Tan et al., 1986) show that soils do not change their mineral composition when they are burned below 500 °C. According to findings from studies on how variations in soil temperature affect soil mineralogy, fire occurrences have an impact on both primary and secondary soil minerals. Quartz, for instance, is unaffected by exposure to temperatures of 600 °C or higher, yet reduced quartz peak intensities have also

been seen at these temperatures. According to (Ketterings et al., 2000) quartz peak intensities were stable at 300 °C but decreased after 600 °C exposure to the subsoil. Additionally, it has been demonstrated that when soil temperatures rise, K-feldspar concentration in soil decreases while quartz content rises, as shown in Table 2 Ngole-Jeme (2017). Ngole-Jeme (2017) observed no changes in soil hematite concentration at temperatures of 750 °C, and calcareous soils have also been demonstrated to be resistant to alterations up to temperatures of roughly 1000 °C. According to (Cornell and Schwertmann, 2003), gibbsite can undergo phase transitions as low as 200 degrees Celsius, whereas goethite becomes hematite around 300 degrees. However, secondary minerals contribute more to the sorption capacity of soil than primary minerals (Table 2.1.), suggesting that alterations brought on by fire to basic minerals may not have much of an impact on the soil's total sorption capacity. However, the situation with secondary minerals is distinct.

Table 2.1. Cation exchange capacity (CEC) of various soil minerals

Soil Minerals	Cation Exchange Capacity (Meq/100 g)
Vermicullite	100–150
Allophane	5–30
Gibbsite	0–4
Kaolinite	3–15
Montmorillonite (smectites)	80–50
Illite	20–40
glauconite	5–40
Hematite/goethite	4–100
Sesquioxides	0–1
Halloysite	5–50

Due to their reduced thermal conductivity, secondary minerals are affected by fire at considerably lower temperatures than primary minerals, and the consequences differ depending on the kind of clay mineral. (Reynard-Callanan et al., 2010) have demonstrated that although phyllosilicates like micas and vermiculite are impacted by fire episodes of high intensity, they are not totally destroyed. Dehydroxylation of most minerals occurs when soil temperatures are reached to roughly 500 °C.

Kaolinite was observed to vanish at 500 °C by (Araya et al., 2016 and Frost et al., 2003), and this was attributed to the loss of hydroxyl ions from the lattice structure of kaolinite and the production of metakaolinite. At soil temperatures exceeding 600 °C, kaolinite is claimed to be lost and a glassy phase to develop by Ketterings et al., 2000. These findings, however, go against those of Arocena and Opio (2003), who found that at comparable temperatures, kaolinite peaks (d-spacings) might move but not completely disintegrate. Richardson (1972) also noted the breakdown of kaolinite at 500–700 °C when the lattice water was lost. (Reynard-Callanan et al., 2010 and Ulery and Graham 1993) both documented fire-induced alterations in smectitic and vermicullite clay minerals and linked them to dihydroxylation. In the top 8 cm of soil, kaolinite completely decomposed as a result of fire events, according to (Ulery and Graham 1993), although Arocena and Opio (2003) found evidence of a decrease in 2:1 clay mineral in soils following fire events. One of the main sorbents in the soil environment is metal-(oxyhydr)oxides, which are also present in silicate clays. The structural layers of layer silicate clays, which are made up of stacks of aluminum-oxygen and silicon-oxygen sheets, are chemically replaced by ions of lower valence, giving them a mostly negative charge. As a result, these soil elements significantly contribute to soil sorption capacity. But their contributions differ depending on the sort of mineral. According to research by (Martin-Garcia et al., 1999), 2:1 clay minerals have a greater CEC than 1:1 type clay minerals, and even within the 2:1 type, smectites contribute to soil CEC more than Illite (Table 2.2.). This distinction is related to the fact that 2:1 clays have both an interior and exterior surface area, which raises the overall surface area and surface charge density of the clays. Due to changes in mineral assemblage and dihydroxylation of clay minerals found in fire-affected soils, its ability to immobilize both organic and inorganic molecules will be reduced.

Table 2.2 Mineralogical composition of soils as a function of heat duration and intensity

		Composition of Minerals (%)																					
Heating temperature (°C)	Heating time (in hours)	TC01				TC02					TC03								TC04					
		Goethite/ Hematite	K-Feldspar	Quartz	Kaolinite	Hematite/Goethite	K-Feldspar	Plagioclase	Quartz	Kaolinite	Hematite/Goethite	K-Feldspar	Plagioclase	Quartz	Mica	Kaolinite	Chlorite	Pyrophyllite	Hematite/Goethite	K-Feldspar	Quartz	Mica	Kaolinite	Pyrophyllite
0	0	1	-	97	2	1	-	-	97	2	1	-	1	89	2	-	4	1	1	-	96	1	2	-
150	2	1	1	96	3	1	1	-	96	2	1	1	-	89	3	-	5	2	2	1	95	-	2	-
	4	1	-	96	3	1	-	1	96	2	1	-	-	90	2	-	5	2	2	-	96	-	2	-
	6	1	-	97	2	1	-	-	98	1	1	-	-	94	1	4	-	-	1	-	97	-	2	-
300	2	1	-	96	3	1	-	-	97	2	1	-	1	89	2	-	5	2	2	-	96	-	2	-
	4	2	-	95	3	1	-	-	97	2	1	-	-	94	2	3	-	-	2	-	95	-	2	1
	6	1	-	97	2	1	-	-	99	-	1	-	-	96	-	3	-	-	1	-	98	-	1	-
500	2	2	-	98	-	1	-	-	99	-	1	-	-	93	2	-	2	2	2	-	98	-	-	-
	4	2	-	98	-	1	-	-	98	1	1	-	-	94	2	3	-	-	1	-	99	-	-	-
	6	1	-	99	-	1	-	-	99	-	1	-	-	95	1	2	-	1	1	-	99	-	-	-
750	2	2	1	97	-	1	-	-	99	-	2	-	-	97	1	-	-	-	3	-	97	-	-	-
	4	2	-	98	-	1	-	-	99	-	1	-	-	99	-	-	-	-	1	-	99	-	-	-
	6	1	-	99	-	1	-	-	99	-	1	-	-	99	-	-	-	-	2	-	98	-	-	-

Additionally, soil sorption capacity is significantly influenced by iron (Fe) and aluminum oxides, which often form as coatings on clay particles (Rieuwerts et al., 1998). These metal-oxyhydroxides have a changeable charge because water causes their surfaces to hydroxylate. Depending on how much protonation they undergo, which is in turn influenced by the current pH circumstances, they may be anionic (-MO), neutral (-MOH), or cationic (-MOH2+). When the pH is circumneutral, they are neutral, but when the pH is low or high, they have a net positive surface charge and a net negative surface charge, respectively (Hyun et al., 2003). Metal oxides have very high melting points, which the soil may not reach during fire outbreaks. SiO2, Al2O3, and Fe2O3 concentration variations in soil heated at various temperatures for various amounts of time are shown in Figure 1Fire events with low intensity are not expected to affect these oxides, as no noticeable changes were observed when soils were scorched at temperatures below 500 degrees Celsius. During studies on contaminated and uncontaminated soils conducted by Ngole-Jeme (2017), few changes were observed in the concentrations of major and trace elements between temperatures of 0-700 °C, except that MgO, CaO, MnO, and K2O concentrations increased with increasing temperature and heating duration. The rise in these oxides that was detected may have resulted from their release during the transformation of organic matter as a result of rising soil temperature. Since major

and trace element oxides are not very important to soil sorption, fires would have little effect on the percentage of sorption capacity contributed by these oxides. However, heating soils above 600 °C would probably increase the content of SiO2, Al2O3, and Fe2O3 in the soil, which would increase their contribution to the soil sorption complex.

2.3. Afforestation effects of different tree species after fires

Globally, forest fires contribute nearly 5-10% to greenhouse gas emissions, with more than 84% of these emissions coming from tropical regions (1830 Tg C year-1) (Boden et al., 2017; Van Den Werf et al., 2017). There is also the possibility of changing species composition, flooding and erosion risks, change in nutrient and water cycles, and threats to rural livelihoods as a result of these changes (Shlisky et al., 2009; Scheper et al., 2021), these factors have disastrous impacts on the environment. In order to restore the ecosystem following a fire, various approaches can be used, depending on the topographic characteristics, severity, disruptions frequency, technical capability, availability of funds and knowledge (FAO, 2019). To ensure sustained forest recovery, enriched planting is among the commonly employed strategies (Montagnini et al., 1997). This involves presenting valuable species to wild lands without removing the valuable species previously there. When a forest is ravaged by fire, revegetation of the postfire area is the most important counteracting step, and selecting the right tree species for reforestation affects both soil biodiversity and biological activity (Šnajdr et al., 2013; Pietrzykowski, 2019). The soil properties of trees are affected in a variety of ways, including the regulation of light reaching the forest floor, which impacts microclimatic conditions (Joly et al., 2017), and the disruption of inputs and outputs of essential nutrients, particularly C, and the cycling of nutrients (Vesterdal et al., 2013; Angst et al., 2019).

There have been studies carried out using betula pendula Roth, larix decidua Mill., and Scots pine (Pinus sylvestris L.) to reforest postfire forests in central Europe (Bojarski and Kaczmarek, 2018). According to Ellenberg, 1988; Dzwonko et al., 2015, these species are most likely to emerge as a result of secondary succession after fire events or other disturbances in forests. The plants growth rapidly at a young age, are unfazed by low fertility soils, and have a large ecological amplitude, making them weed competition strong (Woś et al., 2021). The common birch plays an essential role in soil 'improvement' by replacing humus with mull, thereby improving soil fertility (Dubois et al., 2020). In addition to increasing soil pH and base

saturation, it also improves soil microbial biomass and enzyme activity (Chodak and Niklińska, 2010). Several studies have shown that the tree species selected for post-fire regeneration of forest sites are essential in terms of the soil's regenerating properties and in restoring its ecological functioning. An additional study by Enriquez-de-Salamanca (2022) investigated post-fire vegetation changes in two Mediterranean pine forests and used pine species to reforest them. A summer drought exacerbated the problems faced by young seedlings during survival of the pines during regeneration, causing difficulty during regeneration for the pines. Even for the same species, pine species suffer significant regeneration difficulties after fire, and it is primarily due to difficulties faced by young seedlings. Resprouter species (those that reproduce from their own seeds) have been highlighted as a way to increase biodiversity and maintain ecosystem resilience to disturbances such as wildfires throughout pine forests (Granados et al., 2016).

2.3.1. Interaction Between Organic Matter And Sorption Properties

Dissolved organic matter (DOM) is a naturally occurring organic substance which sinks many organic and inorganic compounds. Functional groups commonly found in DOM include carboxyls, phenolic hydroxyls, and alcoholic hydroxyls (De Witt *et al*., 1993). It is common for several of these groupings of natural waters to have pH levels that can cause deprotonation. As a result of the resulting anionic charge on the molecules, the DOM has many characteristics, including water solubility, metal binding capability, and buffer capacity. The presence of DOM in subsurface water is thought to facilitate the transmission of related pollutants in the subsurface environment (McCarthy and Zachara 1989). As DOM binds to soil during transportation, the related contaminants become less mobile. Furthermore, the adsorbed DOM can alter soil surface physicochemical properties (e.g., electrophoretic mobility, colloidal stability, and transport, which may be influenced by the adsorbed DOM (Kretzschmar *et al*., 1997). Adsorption of DOM coatings may increase the organic matter content of soil as well as its ability to sorb additional organic pollutants (Torrents and Jayasundera 1997) DOM adsorbs on mineral surfaces primarily by hydrogen bonding, (v) entropic effects, (vi) cation bridging, and (iii) contact. Ligand exchange, anion exchange, and hydrophobic interaction are the three primary surface complexation mechanisms.

2.4. Fire-Induced Soil pH Changes and Effects on Soil Sorption

There are conflicting reports on the impact of fire on soil pH. While (Certini 2005), (Bada and Mart 2003) have shownand other researchers (Xue et al., 2014; Ponder et al., 2009) have observed that heating between 250 and 500 C lowers soil pH, (Arocena and Opio 2003) have observed that fire-induced increases in soil pH. However, the majority of research that noted a drop in pH was conducted in laboratories and did not account for the impact of the ashes that result from burning plant residues in the soil, which is why some studies showed a drop in soil pH. But according to laboratory research on polluted soil done in South Africa, the pH of the soil rises with temperature up to 150 ℃, after which there is no discernible impact of fire on the pH of the soil (Ngole-Jeme 2017). These alterations were noticed up to 4 hours after the heating process began at varied temperatures. The results of this investigation are consistent with those found in scorched soils reported by (Arocena and Opio 2003). These findings emphasize the impact of fire intensity and duration on soil pH variations seen during fire episodes. Increasing fire intensity and duration is accompanied by an increase in pH values due to the combustion of organic matter, which produces ash, which releases calcium (Ca), magnesium (Mg), and potassium (K) ions that form bases during combustion. According to Etiégni and Campbell (1991), soil pH changes brought about by fires last for around three years, but higher temperatures (Granged et al. 2011), longer fire durations (Arocena and Opio 2003), and smaller fire durations (Ubeda et al. 2005) suggest that soil pH changes brought about by fires should last up to 50 years.

The soil pH plays a major role in soil sorption complexes. Based on the fact that specific charges in soils depend on pH, their contribution to soil sorption capacity changes as a result. It is pH-dependent that organic matter and some clay minerals, such as kaolinite, carry negative charges; they increase with increasing pH and vice versa. Therefore, an increase in soil pH may enhance the density of negative charges there and, as a result, their sorption capacity. The density of its surface charge is due to the kaolinite. The portion of soil CEC that is provided by organic matter may be little affected by pH changes because of the destruction or transformation of the functional groups caused by fires. In a lab study by (Ngole-Jeme 2017) who found no correlation between pH and CEC of soils, the reduction in CEC may have been caused by changes in the lattice structure of minerals in the soil particles rather than by pH-dependent charges on soil organic matter fractions. Even more complex is soil sorption as a result of this. Minerals with hydroxyl groups on their outside edges,

such as kaolinite, would become negative charged as pH increases, altering the soil's CEC and, eventually, its sorption capacity. In this scenario, the soil temperature would have to be too low to alter kaolinite's structural makeup and, consequently, its surface charge density. If kaolinite is converted to primary minerals during high-intensity fires, pH variations caused by the fire may also have no impact on the portion of soil sorption that is contributed by the kaolinite's pH-dependent charges. Therefore, changes in soil pH brought about by fire episodes could either decrease or increase soil sorption capacity, depending on the amount of organic matter and the presence of minerals with pH-dependent charges in the soil.

3. MATERIAL AND METHODS

3.1 An overview of the study area's characteristics

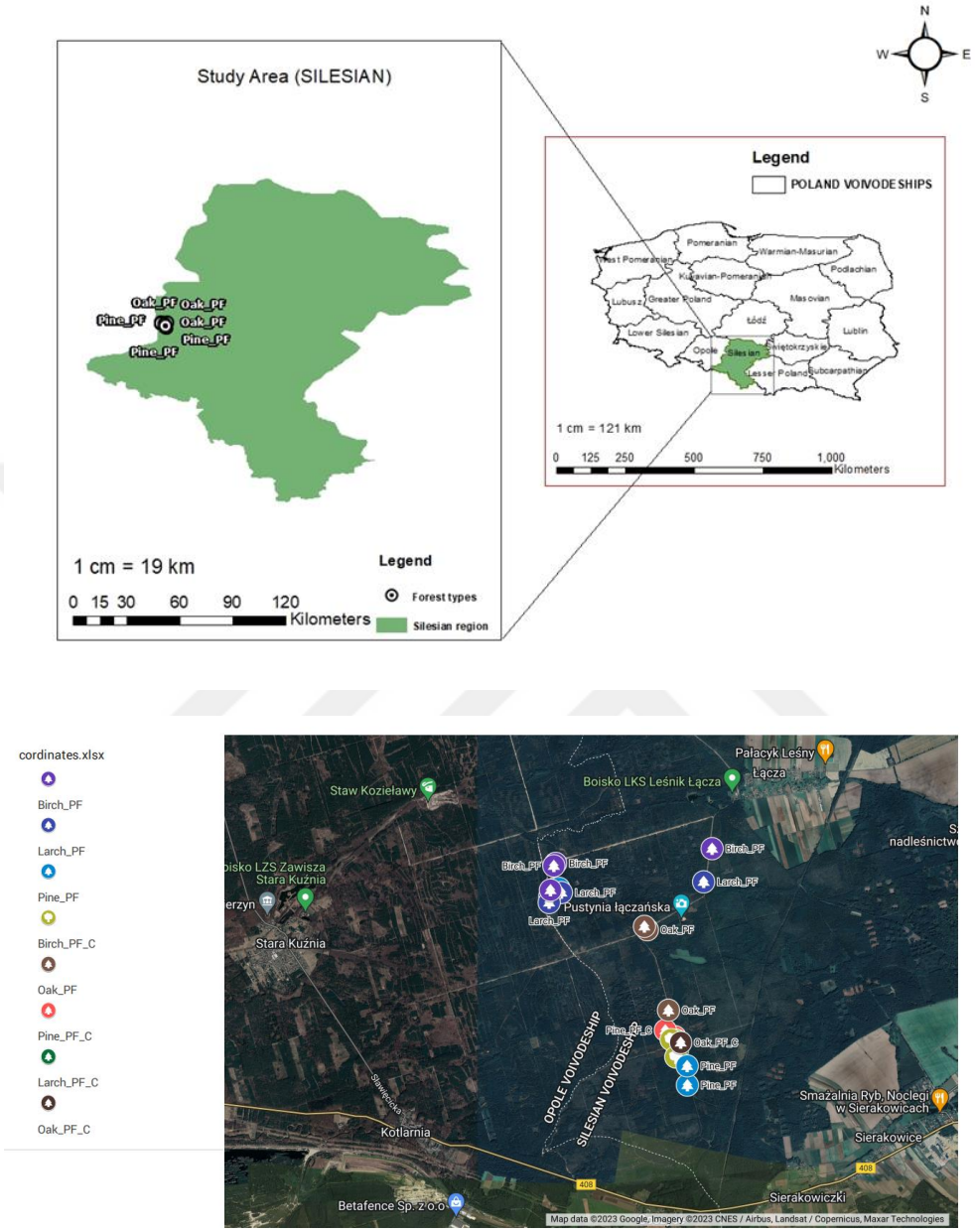


Figure 3.1. Satellite image of the experimental area in Rudziniec Forest.

In Rudziniec Forest District, south of Poland, 30 years after a fire, a newly-reforested post-fire site was selected for the study. Post-fire conditions at Rudziniec were found to be 9.7 °C, 586 millimeters of precipitation annually, 168 days of rain, 45 days of snow on average (data collected from meteorological station for 1992–2022; source: www.tutiempo.net (accessed on February 2, 2023). One of the largest fires in Central Europe after World War II occurred in this area in August 1992. During the fire's 18-day span, 9062 hectares were destroyed, including 8461 hectares

of forest. It is estimated that over 75% of trees were destroyed by the fire as well as damaging mineral soil. There were more than 5000 mature pine-oak stands in the burned area before the fire, with a moderately moist and humid environment. The Rudziniec Forest District has suffered a forest fire that has burned 2254.30 hectares. The remainder of the trees were felled within three years of the fire, their stems and unburned parts were removed, the wood extracted, and the post-fire site was replanted with trees (Szabla ,1994; Orczewska et al., 2016; Woś et al., 2023).

Figure 2.2. Images from the field post fire Rudziniec Forest District on the left site Larch stand on the right site Birch stand

3.2 Design of experiment

The field experiment was conducted we selected area with four different tree species and had 4 repeations among them 3 were used for cores sampling and one for profile in soils with carbon and without carbon that were named as C0 (without carbon) and C1(with carbon) . The different tree species such as oak, pine, larch, and birch was assigned as the main plot factors and charcoal and non-charcoal were considered as subplot factors.

3.3 Field Sampling

Soil pits were dug and the morphological characteristics of each soil horizons were described according to the requirements of FAO (Amerling *et al*., 2006 Amerling *et al*., 2006). Soil samples were collected using tube sampler and soil profile samples were also drawn using the same techniques, other composite samples were taken from the all the locations as designated in the Fig. (3.1.) in map.

3.4 Laboratory preparation

Soil Samples were prepared for further analysis in the lab for soil physical and chemical properties. Sample preparation included air drying, grinding, sieving and crushing of soil samples. As soon as the samples have been dried, they are ground with a wooden pestle and mortar and clods and large aggregates are crushed and mixed in the preparation room (which is separate from the main laboratory). A 2-mm sieve is used to screen the soil after grinding. Later these samples were used for soil texture, pH, and sorption properties analysis.

3.4.1 Determination of soil pH

pH was measured potentiometrically in H2O and 1 M KCl (at 1 soil: 2.5 solution ratio). Instrument with combined electrodes for measuring pH, Measuring cylinder with saturated KCl electrode as a reference electrode, Plastic wash bottle with interval timer Glass rod Glass beaker, Reagents; A buffer solution of pH 7.0 and pH 4.0 made from de-ionized water.

3.4.2 Soil Sorption properties

Properties of the sorption complex (exchangeable acidity (Hh) was measured using the Kappen method (extraction with 1N Ca(CH3COO)2), Exchangeable Ca2+, K+, Mg2+, and Na+ were extracted with 1M CH3COONH4 and determined using the spectrometer CP OES ICAP 6000 Series. The cation exchange capacity (CEC) was calculated as the sum of hydrolytic acidity and base exchangeable cations. The base saturation (BS) was defined as percentage of the sum of base cations in CEC.

3.5 Data analysis

The obtained results were collected in a table using the Excel program. The mean value and standard deviation were calculated for each variant. Statistical interpretation was performed in Statisticx 10.1 and Canoco 5.1. The significance difference between treatments were determined with factorial ANOVA using "Statisticx" software. Post-hoc testing was conducted later. An analysis of principal components (PCA) was carried out using Conoco 5.

4. RESULTS AND DISCUSSION

4.1 Soil Profile description in Field

For each tree species, soil samples were collected in the area with or without carbon removal after the forest fire.

SOILS WITH CHARCOAL REMOVAL (C0)

PINE (*Pinus sylvestris)*

Albic PODZOL (Arenic)

0-5 A: 10YR 2/1; SL; SA-WE; M; CL; pH_{KCl} 3.5

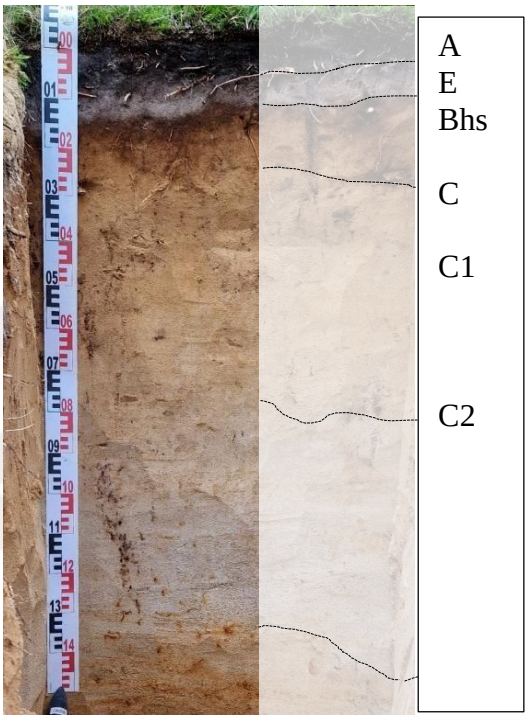
5-12 E: 7.5YR 4/1; S; SG; F; CL; pH_{KCl} 3.6

12-25 Bhs: 7.5YR 4/6; S; SG; C; CL; pH_{KCl} 4.2

25-80 BC: 10YR 6/8; S; SG; VF; G; pH_{KCl} 4.4

80-130 C1: 10YR 7/3; S; SG; N; G; pH_{KCl} 4.7

130-180 C2: 5YR 6/8; S; SG; N; pH_{KCl} 4.6



LARCH *(Larix decidua)*

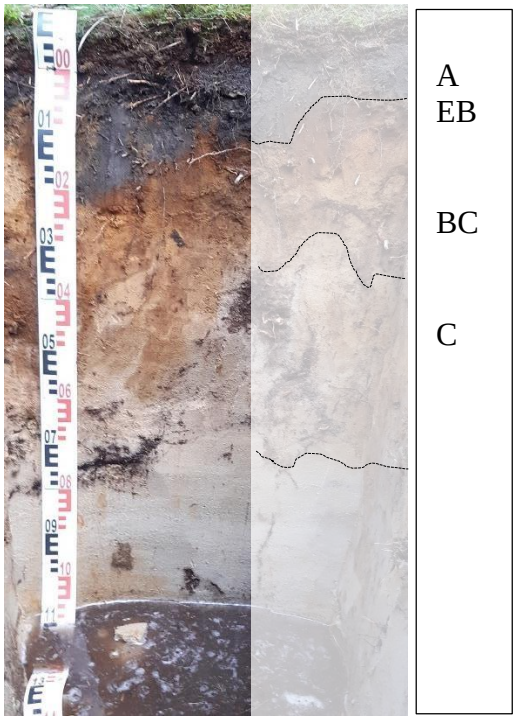
Stagnic Albic PODZOL (Arenic)

0-6 A: 10YR 2/1; LS; WE; M; A-W; pH_{KCl} 3.8

6-32 EB: 7.5YR 5/8+ 10YR 5/1; S; WE; C; CL-W; pH_{KCl} 4.2

32-70 BC: 10YR 6/8; S; WE; F; CL; pH_{KCl} 4.5

70-150 C: 10YR 7/4; S; SG; N; pH_{KCl} 4.6



BIRCH (*Betula pendula)*

Albic PODZOL (Arenic)

0-4 A: 10YR 2/2; LS; SA-WE; C; CL; pH_{KCl} 2.7

4-12 E: 10YR 5/2; S; SG; F; CL-W; pH_{KCl} 3.1

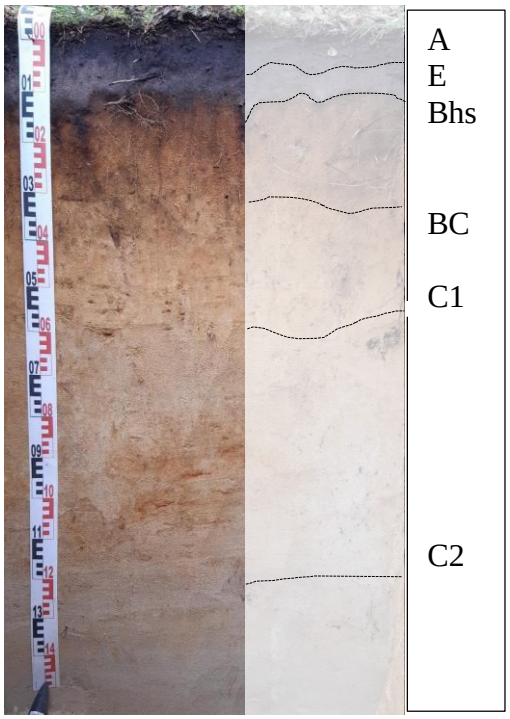
12-30 Bhs: 7.5YR 4/6; S; SA-WE; C; CL; pH_{KCl} 4.0

30-60 BC: 10YR 6/8; S; SG; F; CL; pH_{KCl} 4.0

60-125 C1: 10YR 7/4+ 5YR 6/8; S; SG;

VF; G; pH_{KCl} 4.4

125-160 C2: 10YR 7/3; S; SG; N; pH_{KCl} 4.2



OAK *(Quercus robus)*

Albic PODZOL (Arenic)

0-10 A: 7.5YR 3/1; S; SA; M; A; pH_{KCl} 3.3

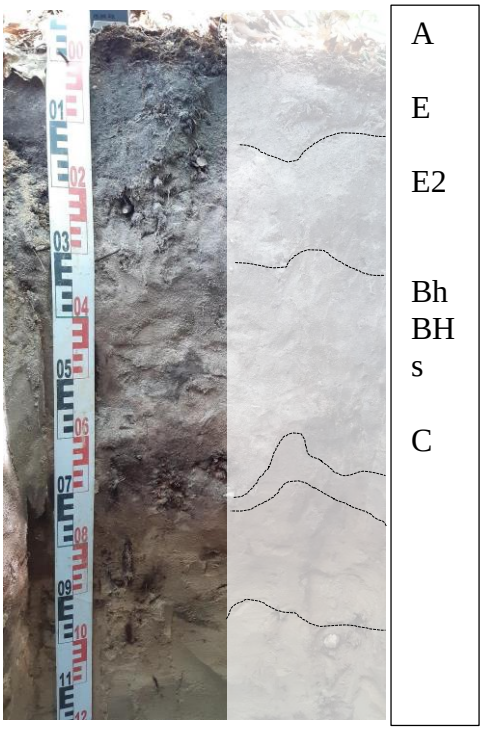
10-30 E: 7.5YR 4/1; S; SA; M; A-W; pH_{KCl} 3.5

30-62 E2: 7.5YR 6/1; S; SA/SG; C; G-W; pH_{KCl} 3.9

62-77 Bh: 7.5YR 4/3; SL; SA; F; CL-W; pH_{KCl} 4.0

77-97 Bhs: 7.5YR 4/4; S; SA/SG; VF; G- W; pH_{KCl} 5.3

97-150 C: 10YR 6/4; S; SG; N; pH_{KCl} 4.3



WITHOUT CHARCOAL REMOVAL (C1)

PINE (*Pinus sylvestris)*

Albic PODZOL (Arenic)

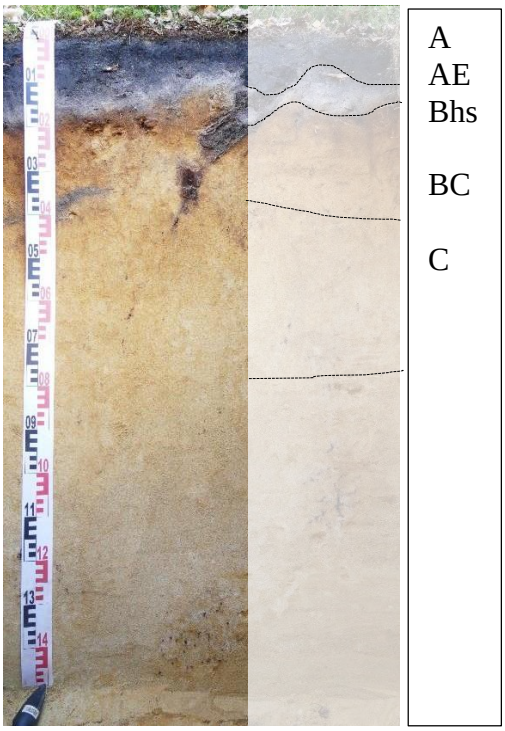
0-12 A: 10YR 2/1; LS; SA-MO; C; CL; pH_{KCl} 3.6

12-22 AE: 10YR 5/2; S; SG; F; CL/A; pH_{KCl} 3.9

22-34 Bhs: 7.5YR 5/6; S; SA-WE; F; G; pH_{KCl} 4.3

34-65 BC: 10YR 6/8; S; SG; VF; G/CL; pH_{KCl} 4.4

65-160 C: 10YR 6/8+ 5YR 4/8; S; SG; N; pH_{KCl} 4.6



LARCH *(Larix decidua)*

Albic Ortsteinic PODZOL (Arenic)

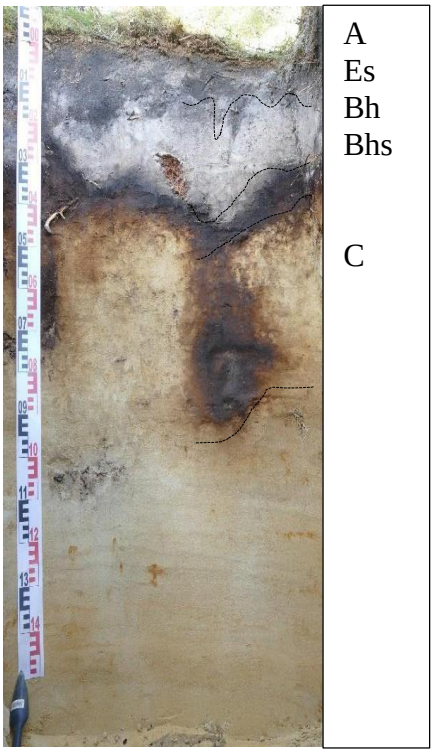
0-15 A: 10YR 2/1; LS; SA-WE; C; CL; pH_{KCl} 3.3

15-30 Es: 10YR 4/1; S; SG; F; CL; pH_{KCl} 3.7

30-40 Bh: 5YR 2/;3; LS; Ped-Fe; F; G; pH_{KCl} 3.8

40-85 Bhs: 5YR 2/3+ 10YR 6/3; S; SG; N; CL; pH_{KCl} 4.2

85-150 C: 10YR 6/3; S; SG; N; pH_{KCl} 4.6



BIRCH (*Betula pendula)*

Albic PODZOL (Arenic)

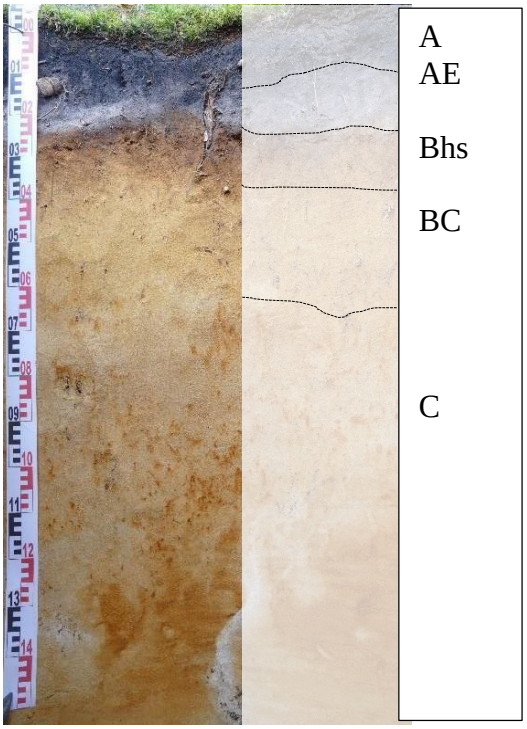
0-8 A: 7.5YR 1.7/1; LS; SA-WE; C; G; pH_{KCl} 4.1

8-16 AE: 7.5YR 4/2; S; SG; F; CL; pH_{KCl} 3.7

16-35 Bhs: 5YR 4/6; S; SA; F; CL; pH_{KCl} 4.5

35-80 BC: 10YR 6/8; S; SG; VF; G; pH_{KCl} 4.8

80-150 C: 10YR 7/6; S; SG; N; pH_{KCl} 4.7



OAK (*Quercus robus)*

Albic PODZOL (Arenic)

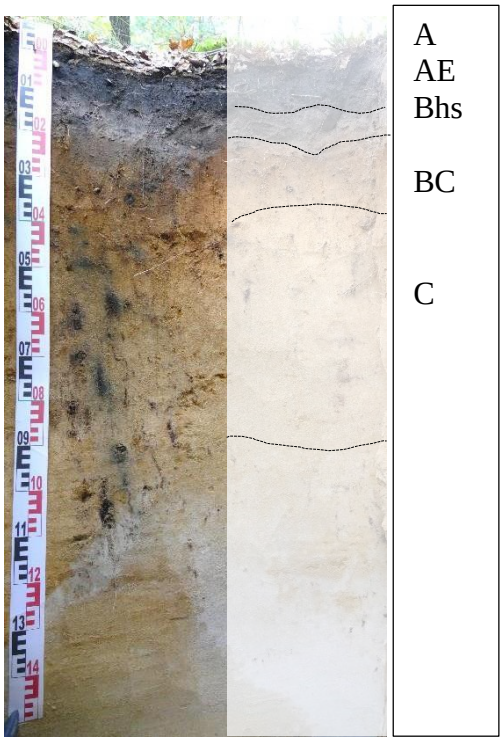
0-10 A: 10YR 2/2; LS; SA-MO; C; A; pH_{KCl} 4.3

10-18 AE: 10YR 5/2; S; SG; F; CL; pH_{KCl} 3.7

18-35 Bhs: 5YR 3/4; S; SA-MO; C; G; pH_{KCl} 4.4

35-85 BC: 10YR 6/6; S; SG; F; CL; pH_{KCl} 4.6

85-150 C: 10YR 7/3; S; SG; VF; pH_{KCl} 4.8



Texture LS: loamy sand	Structure SG: single grain	MO: moderate	Roots M: many	Boarder A: abrupt
S: sand	SA: subangular	WM: weak to moderate	C: common	CL: clear
SL: sandy loam	WE: weak	Ped: pedogenic	F: few VF: very few N: none	G: gradual W: wavy

4.2 Properties of soil under investigation

4.2.1 Soil pH

The pH value for different layers of soils for the pine with carbon measured in H2O ranged from 3.47 to 4.49 while those measured in KCl ranged from 3.17 to 4.43. So the pH of the tested soils ranged from 5.7 to 3.4 highest pH was observed in C0 pine and lowesr was observed in C1 pine. The values for depth between 0-30 were characterized strongly acidic while the soil under pine trees was very acidic among others as seen in (Fig 4.1.). Larger differences between the pH values measured in water and potassium chloride may suggest a lower abundance of minerals in these soils.

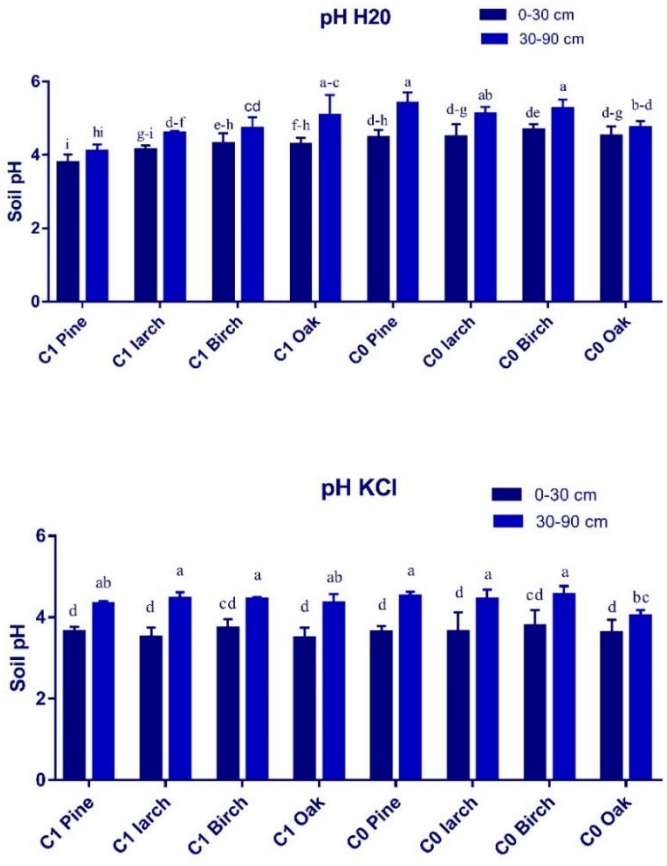


Figure 3.1. Soil pH value under H20 and KCl in different tree species at 0-30cm and 30-90 cm; the differ letters indicate the significance. Bars show means of pH values, error bars show 95% confidence intervals. Species significantly different at 0.05 level are mark

Similarly for Larch C1kind of similar trend was seen. Here as well the top layer in two of the places 0-30 was strongly acidic. The range of pH measured in

H_2O was 3.79 to 5.04 whereas in KCl it was 2.9 to 4.9. As for the Birch tree with carbon the soils had a range 3.8 to 5.24 in H_2O and in KCl it was 3.02-4.6. Furthermore the next tree species was Oak where the range was 3.82-5.87 in H2O and 2.84-4.73 in KCl.

4.2.2 Soil Sorption Properties

Cation exchange capacity (CEC)

Differences between the CEC values of different tree species have been noted (Fig. 5). CEC value was highest in C1 Larch tree species in the upper layer of soil as compared to C0 Oak which was significantly lower. The top soil 0-30 cm has higher CEC as seen in (Fig.4.2.) below. The subsurface soils has significantly lower values for CEC. Highest values of CEC were observed in treatment (C1Birch) birch tree species with carbon. Whereas the lowest values were seen in treatments shown with letter "f". From the trend in the graph we can see that pools of exchangeable cations are highest in pine species in the top layer whereas subsurface layer has least values for CEC.

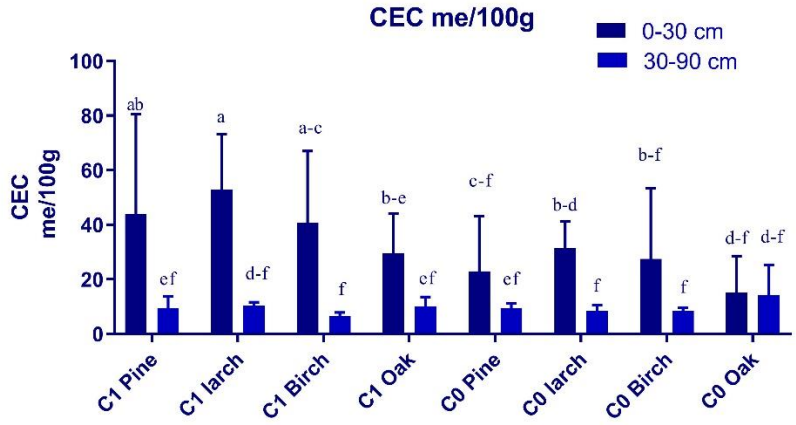


Figure 4.2. Cation exchange capacity of soils under different tree species surface and subsurface layers of soil 0-30 and 30-90 cm measured in meq/100g. The bars represent means in me/100g and the error bars represent 95% confidence intervals.

Base Cations Content

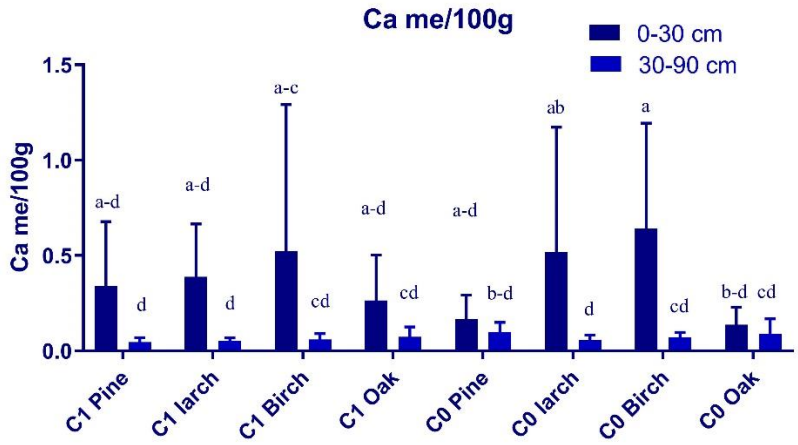


Figure 4.3. Calcium content of soils under different tree species surface and subsurface layers of soil 0-30 and 30-90 cm measured in meq/100g. The bars represent means in me/100g and the error bars represent 95% confidence intervals.

Calcium concentrations were highest in the upper layer in all the tree species except for the case of oak trees where carbon had been removed. However the results for subsurface soils very drastically low and was non-significant. Highest values were observed in the treatment (C0 Birch) birch trees species without carbon in the soil and the lowest were observed in the treatments marked with “d” letter in the (Fig. 4.3.)as shown above. There were significant differences observed within the all the treatments in the surface soils as compared to subsurface soils.

Similar to this the potassium k content had quite similar results having higher concentration in the surface layer then subsurface layer as can be seen in the (Fig. 4.4.) highest values were observed in birch with carbon in the soil and significantly higher values then the subsurface soil.

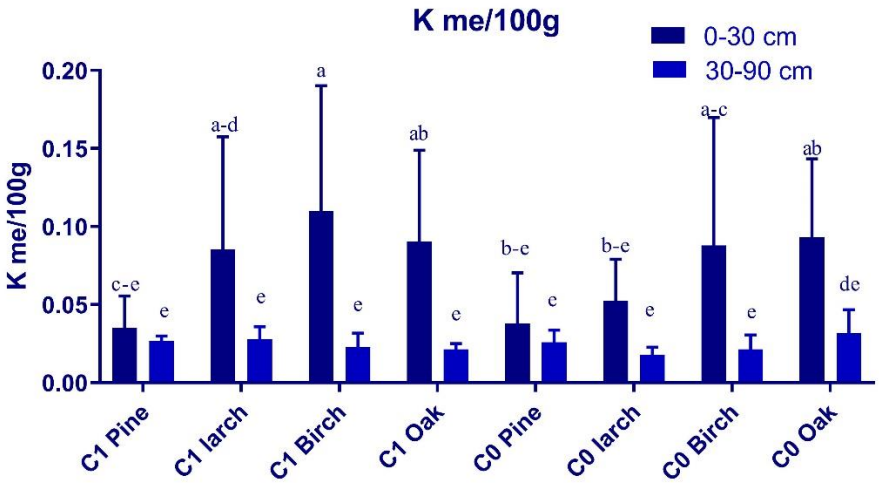


Figure 4.4. Potassium content of soils under different tree species surface and subsurface layers of soil 0-30 and 30-90 cm measured in meq/100g. The bars represent means in me/100g and the error bars represent 95% confidence intervals.

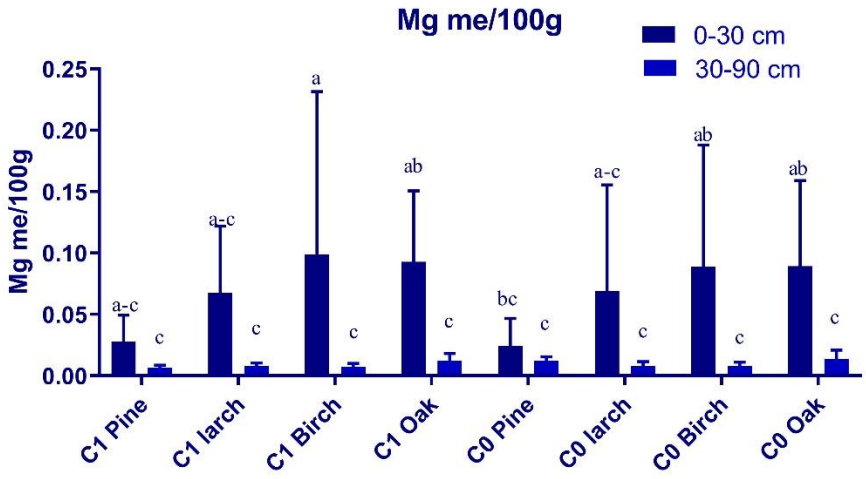


Figure 4.5. Magnesium contents of soils under different tree species surface and subsurface layers of soil 0-30 and 30-90 cm measured in meq/100g. The bars represent means in me/100g and the error bars represent 95% confidence intervals.

Mg content was higher in surface layer than subsurface layer the letters in graph represent the significant differences between the species highest content of Mg was observed in birch with carbon. Pine specie had the lowest mg content the subsurface soil had the least concentration are non-significant as seen in (Fig. 4.5.).

The surface soils have significantly higher content of Mg then subsurface layers of soils.

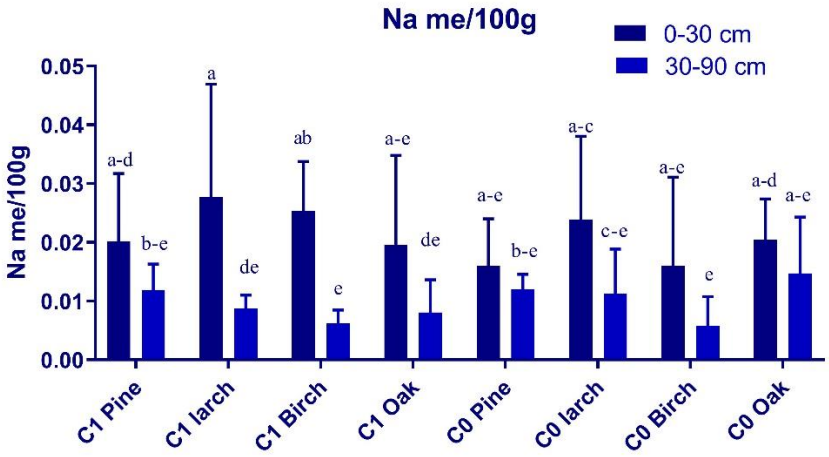


Figure 4.6. Sodium contents of soils under different tree species surface and subsurface layers of soil 0-30 and 30-90 cm measured in meq/100g. The bars represent means in me/100g and the error bars represent 95% confidence intervals.

Similarly, the Na concentrations were different than Mg as carbon content had no significant effect on these concentration except for depth that effected the concentration of these content there can be seen in table the significant differences within the means represented by lower case letters in the bars. Highest values were observed in the Larch specie with carbon not removed from the soil similar trends were observed for surface and subsurface layers observed in (Fig. 4.6.).

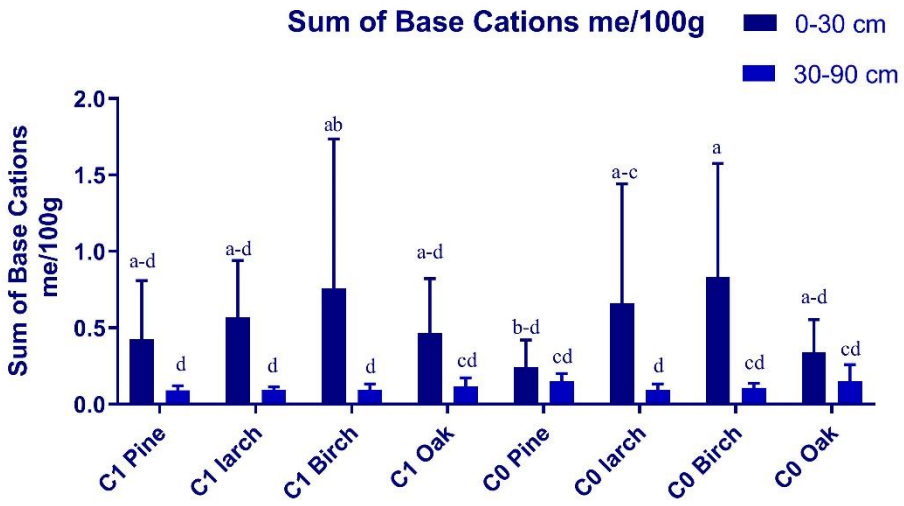


Figure 4.7. Sum of base cation (K, Ca, Mg and Na) pools of soils under different tree species surface and subsurface layers of soil 0-30 and 30-90 cm measured in meq/100g.

The sum of base cations (Mg, K, Ca and Na) were observed to highest in birch species with and without carbon significantly to other species in the surface layer 0-30 cm while lowest in the subsurface layer in all the species however it is worth noticing that the surface layer for all the species did not have highest content of base cations like can be observed in the (Fig. 4.7.) where the surface layer with pine tree without carbon has significantly lower contents of base cations.

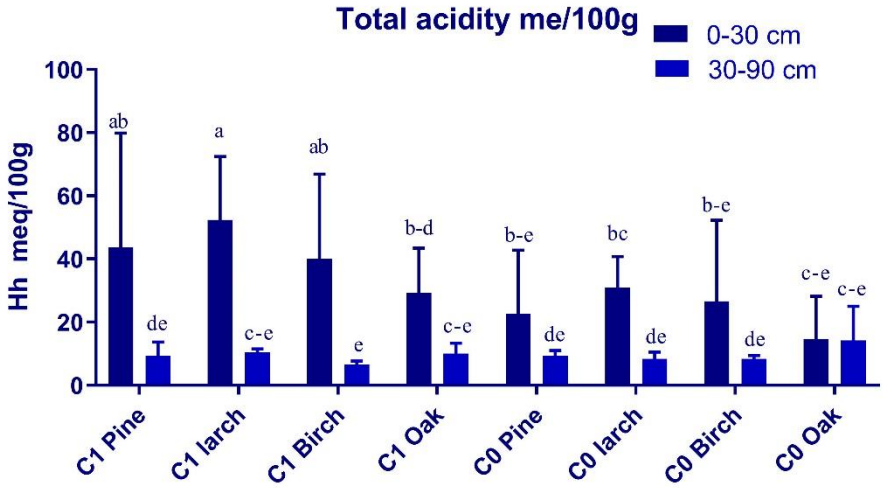


Figure 4.8. Pools of hydrolytic acidity in upper layer (0-30 cm) and 30-90 cm) of the forest soils in presence of different tree species. The bars indicate the mean in grams, and the error bars show the 95% confidence interval.

In case of total acidity the acidic cations were highest in larch species with carbon in the surface layer and the significantly lower in the Oak species in the top layer and subsurface layer respectively (Fig. 4.8.).

The trends can be observed in the figure to see the maximum and minimum values.

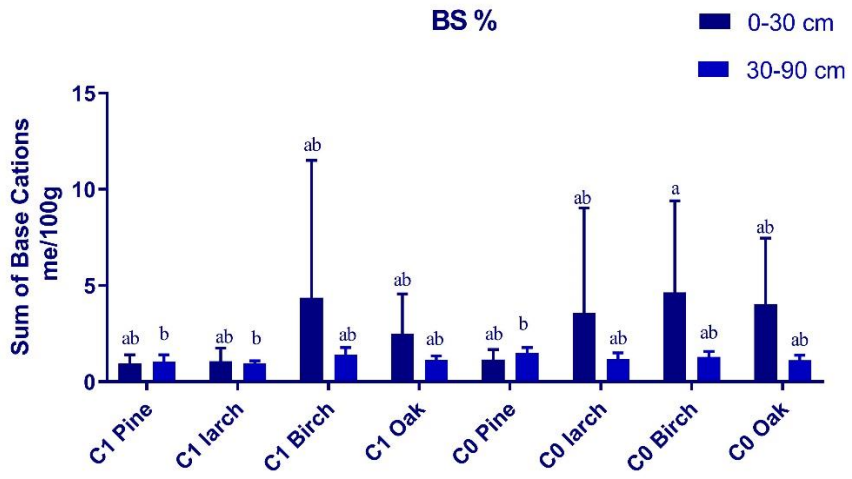


Figure 4.9. Base saturation percentage in upper layer (0-30 cm) and 30-90 cm) of the forest soils in presence of different tree species. The bars indicate the mean in grams, and the error bars show the 95% confidence interval.

The base saturation percentage results were striking the highest values were observed in the birch species with carbon removal and not significantly different from soil with carbon. However the surface layer did not have same base saturation for all the species as it can been seen from the figure there were not much difference between surface 0-30cm and subsurface 30-90cm soil (Fig. 4.9.).

Among the sorption complexes, the ions that form the Hh value were dominant (base saturation [BS] 0.240184%–15.06581 %).In the study of sorption complex properties (Hh, CEC, and BS), tree species had no significant effect. These properties were only affected by depth in the top soil 0-30 cm. A significant difference in the Hh and CEC was observed in species with carbon on the top layer, while the BS was significantly lower in species with carbon and higher in species without carbon.

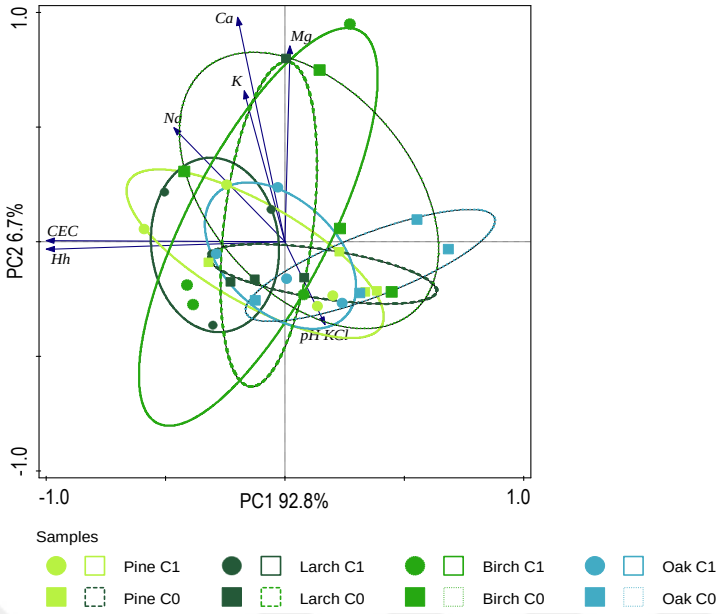


Figure 4.10. "Multivariate Analysis of Tree Species and Soil Properties: A PCA Approach to Calcium, Magnesium, Sodium, Potassium, CEC, Hh and pH" for 0-30cm surface layer

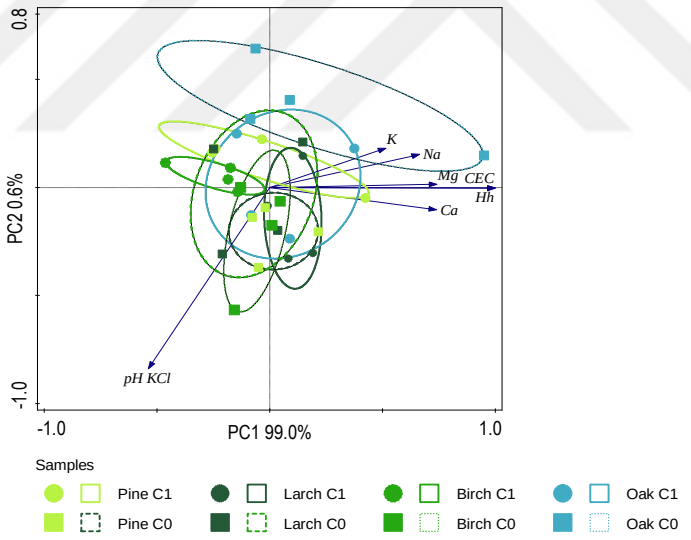


Figure 4.11. "Multivariate Analysis of Tree Species and Soil Properties: A PCA Approach to Calcium, Magnesium, Sodium, Potassium, CEC, Hh and pH for 30-90cm subsurface layer

An analysis of principal components (PCA) is a multivariate statistical technique used to clarify relationships between many variables and a small set of objects. These tree species are the objects in this study, and the variables are soil characterization components (such as pH, Calcium content, magnesium content, CEC and Hh etc.).

Principal components (PC) are variables that explain the relationship between the two (Esbensen, 2010).The PCA analysis clearly shows us the relationship within the components. (Fig. 4.10.) shows the correlation between the soil properties in the surface horizon. From PCA we can see that pH is negatively correlated with other investigated parameters. And that investigated variants in 0-30 cm layers are similar, taking into consideration presented soil properties. On the other hand (Fig. 4.11.) shows the sub surface layer K+, Na+, Mg2+ and Hh are strongly correlation positively whereas pH is negatively correlated to other parameters and it can be noted that Oak c0 is different from the other plots as there is no overlap on others except for Oak C1 and Larch C0.

5. DISCUSSION

Under birch, higher contents of cations were observed in the top soil in comparison to other species, particularly at the macronutrient level. Under oak, CEC and total acidity were the highest, and under pine, they were the lowest. In the mineral horizon, tree species had little effect on CEC or total acidity. Because tree species' effects on soil properties are largely determined by litterfall chemistry, tree species' effects are usually more pronounced in the organic horizon and decrease rapidly in deeper soil horizons (Chodak *et al*., 2015; Hansson *et al*., 2011). As a result, organic material accumulated in the litter layer of deciduous trees may possess chemical properties influenced by higher concentrations of N, K, Ca, and Mg (Augusto *et al*., 2002). Researchers Bradley & Fyles (1995) found that soils containing paper birch seedlings, such as *Betula papyrifera* Marsh., showed greater carbon availability and higher rates of nitrogen mineralization than soils containing seedlings of five other types of trees. Based on our results, the properties of the mineral soil beneath litter horizons affect their chemical composition. Binkley & Giardina, 1998 report that litter horizons in more fertile sites are richer in nutrients than those in less fertile sites (Augusto *et al*., 2002). Significantly more exchangeable magnesium was found in soil mineral horizons. Due to this, the top layer also contained significantly higher amounts of magnesium. In contrast to the mineral horizon, the humic horizon's concentration of exchangeable K, Ca, and Na did not differ. In terms of chemical properties (CEC, Hh, and exchangeable cations), there were no significant differences. The study soils could have been affected by the fire as well by affecting their clay minerals. There is evidence that kaolin levels were reduced in California severely burned soil layers because d 001 spacings of clay-sized vermiculite, chlorite, chlorite-vermiculite, and hydroxy interlayered vermiculite collapsed towards 1.0 nm or decomposed (Ulery *et al*., 1996). Litter from birch trees has a higher pH than litter from other types of trees. In contrast, birch-dominated mineral soils had higher exchangeable acidity and a lower pH KCl than pine-dominated mineral soils. Several studies have suggested that coniferous trees acidify soils (Augusto *et al*., 2002; Mueller *et al*., 2012; Oostra *et al*., 2006). In spite of this, there is conflicting information regarding the effects of deciduous and coniferous trees on soil acidity The pH in birch and pine horizons was higher than in mineral horizons under birch in Reich *et al*. (2005)'s common garden experiment in Central

Poland. A study conducted by Chodak & Niklinska (2010) on sandy mine soils afforested with different tree species found the pH of the O-horizon was significantly higher under birch than pine or larch. A slightly lower pH was found under larch and slightly higher pH under birch in the uppermost mineral horizon. The higher SOC content in the uppermost minerals under birch might explain the lower pH and exchangeable acidity under this species.

As a consequence of the topsoil's high organic matter content, the pH values in topsoil are generally lower than those in the surrounding soil. As organic matter decomposes, it produces organic acids that lead to a precipitation of these acids, thereby resulting in a lower pH (Hong *et al*. 2019). Surface and subsurface soil pH values are affected by tree species present in an ecosystem. Larch trees are pH-tolerant, birch trees cause soil acidification, pine trees cause soil salinization, and oak trees are moderately pH-sensitive. Other environmental factors, such as climate, geology, and land management practices, can also affect soil pH. Understanding pH values under different tree species is essential for effective land management, afforestation, and soil health promotion. An efficient afforestation strategy and sustainable soil health require the ability to understand these pH differences between different tree species. There are many factors that influence the soil pH, such as soil formation process and soil colloids' quantity and quality. It was found that leaching and organic matter content played a dominant role in regulating pH in sandy soils (Gruba and Mulder, 2015; Jozefowska *et al*., 2019).

A majority of the BS was formed by ions that contributed to the Hh value in the sorption complexes of the soils studied (0.946 - 1.05%) (Table 5). Forest soils with acidic conditions have this characteristic (Blaser *et al*., 2008; Gruba and Mulder, 2015). In 1991, Manrique *et al*. identified two factors that determine CEC values: soil texture and pH. There was a positive correlation between the CEC and pH KCl in the post-fire soils. Ca^{2+}, K+, and Mg^{2+} contents were higher in soils under birch and larch than in soils under pine. In the post-fire area, larch and pine soils had higher CEC values than oak and birch soils (Table 5), where the influence of tree species was more noticeable. This is mainly due to the higher Hh values in the soils under pine (Cole *et al*., 1990; Mueller *et al*., 2012).

The differences in CEC can be attributed to litter quality, decomposition rate, and root exudates. The CEC values are effected by various factors such as organic matter, pH and mineral compositions of soils. CEC effects the soil sorption by controlling

nutrient availability, ion retentions and water holding capacity. The ability to retain and exchange cations, including potassium (K+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), is increased in soils with a higher CEC value. The higher the CEC, the more effectively the soil holds on to these nutrients, reducing the chance of nutrient leaching and making them more accessible to plants. The soil has a greater ability to retain ions on exchange sites as a result of a higher CEC value.

Among the pollutants that can be retained by this property are heavy metals (e.g., lead, cadmium), or pesticides. By reducing their mobility and potential to leach into groundwater or be taken up by plants, soils with a higher CEC have a greater ability to bind and hold onto these contaminants.

When the species were compared in terms of sum of base cation pools and total acidity in the upper soil layer, pine had the most acidifying effect in surface layer followed by larch and other species oak was least acidifying in condition without carbon. Whereas subsurface layer was almost the same and non-significant. In case of base cations the highest concentration was seen in birch trees followed by larch in the surface layer whereas subsurface layer had almost similar type of results that are non-significant.

6. CONCLUSION

As a result of the study, it was found that oak, birch, pine, and larch did not significantly affect soil sorption after 30 years of post-fire forest growth. These species of trees may differ substantially in their soil sorption properties within the timeframe of 30 years, however. However it was worth noticing that some trends were clearly evident like base saturation percentage was significantly higher in birch specie and hydrolytic acidity was significantly higher in larch. There are several factors that affect soil sorption, including tree species composition, litter quality, nutrient uptake, and root system characteristics. Even though longer-term observations are likely to reveal more significant impacts on soil sorption than those observed within the 30-year timeframe, the study failed to identify significant effects within the 30-year timeframe. After a fire, various tree species can establish and grow and interact with soil nutrients, thereby affecting soil properties and biogeochemical processes over time, including base saturation. Consequently, it seems reasonable to predict that the selected tree species may eventually have a significant impact on soil sorption. A long-term study and research on soil sorption beyond the 30-year mark will be necessary to elucidate the potential impacts of these tree species on soil sorption. By examining soil properties and the composition of trees in post-fire forests, we will be able to gain a better understanding of how forest areas evolve and how soil properties are influenced by tree species composition. Reforestation and ecosystem management strategies based on such knowledge will assist land managers and forest ecologists.

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2. Duan, K., Zhao, B., Zhang, S., Li, Y., Ma, Y., Liu, H., Ejaz, M., Peng, X., Yang, P., 2022. Toxic metals and metalloids in farmland soil and cereals in an industrial agricultural interaction region of china: contamination, sources and risks. Environmental Engineering and Management Journal 21(9): 1493-1504.
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Won Awards, Incentives and Scholarships

1. University Gold Medal 2017 University of Agriculture Faisalabad
2. Erasmus Mundus Masters scholarship
3. PEEF Scholarship for masters at University of Agriculture Faisalabad