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EFFECTS OF LOGGING RESIDUES AND SKID ROADS ON LITTER DECOMPOSITION RATE AND NUTRIENT RELEASE OF BLACK PINE (*Pinus nigra* Arnold) AND SCOTS PINE (*Pinus sylvestris* L.)

UČINAK DRVNIH OSTATAKA I TRAKTORSKOG PUTA NA STOPU RASPADANJA LISTINCA I OTPUŠTANJE HRANJIVIH TVARI CRNOGA BORA (*Pinus nigra* Arnold) I OBIČNOG BORA (*Pinus sylvestris* L.)

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SUMMARY

Needle litter decomposition rate and nutrient releases of pure stands of black pine and Scots pine under the three different micro-ecologic sites (skidding road, the logging residues and mineral topsoil) and the control site (non-harvesting site) were studied. The needle litters of Black pine and Scots pine were initially analysed for total carbon and nutrient concentrations (N, P, K, Ca, S, Mg, Mn, and Fe). The litter decomposition experiment using the litterbags method was carried out in the field for 18 months. The Scots pine needle litters decayed faster than the black pine litters. Both the Scots pine and Black pine needle litters showed higher mean mass losses under the mineral topsoil and the logging residues than under the skid road and the control site.

KEY WORDS: litter quality, micro-ecological areas, litter decomposition, nutrient, Black and Scots pine

INTRODUCTION
UVOD

Forest management, particularly harvesting activities creates a serious threat to soil physical, biological, and chemical properties (Venanzi et al., 2016; Armolaitis et al., 2018). Forest harvest generally degrades organic and mineral soil, remove organic matter and decaying debris layers, increases light intensity, temperature and soil water content at soil surface and consequently, causes nutrient loss and alters microbial community composition (Waldrop et al., 2003). Therefore, decomposition rates differ in microecological areas (Waldrop et al., 2003; Mott et al., 2021). Harvesting activities in forestry involve felling, crosscutting, primary transportation, and hauling phases and can cause high environmental disturbances (Janowiak and Webster, 2010; Picchio et al., 2020). Evaluation of harvesting activities by determining residual stand damage (sapwood and bark injury) (Gulci et al., 2016) and forest soil disturbance in terms of environmental aspects is very important.

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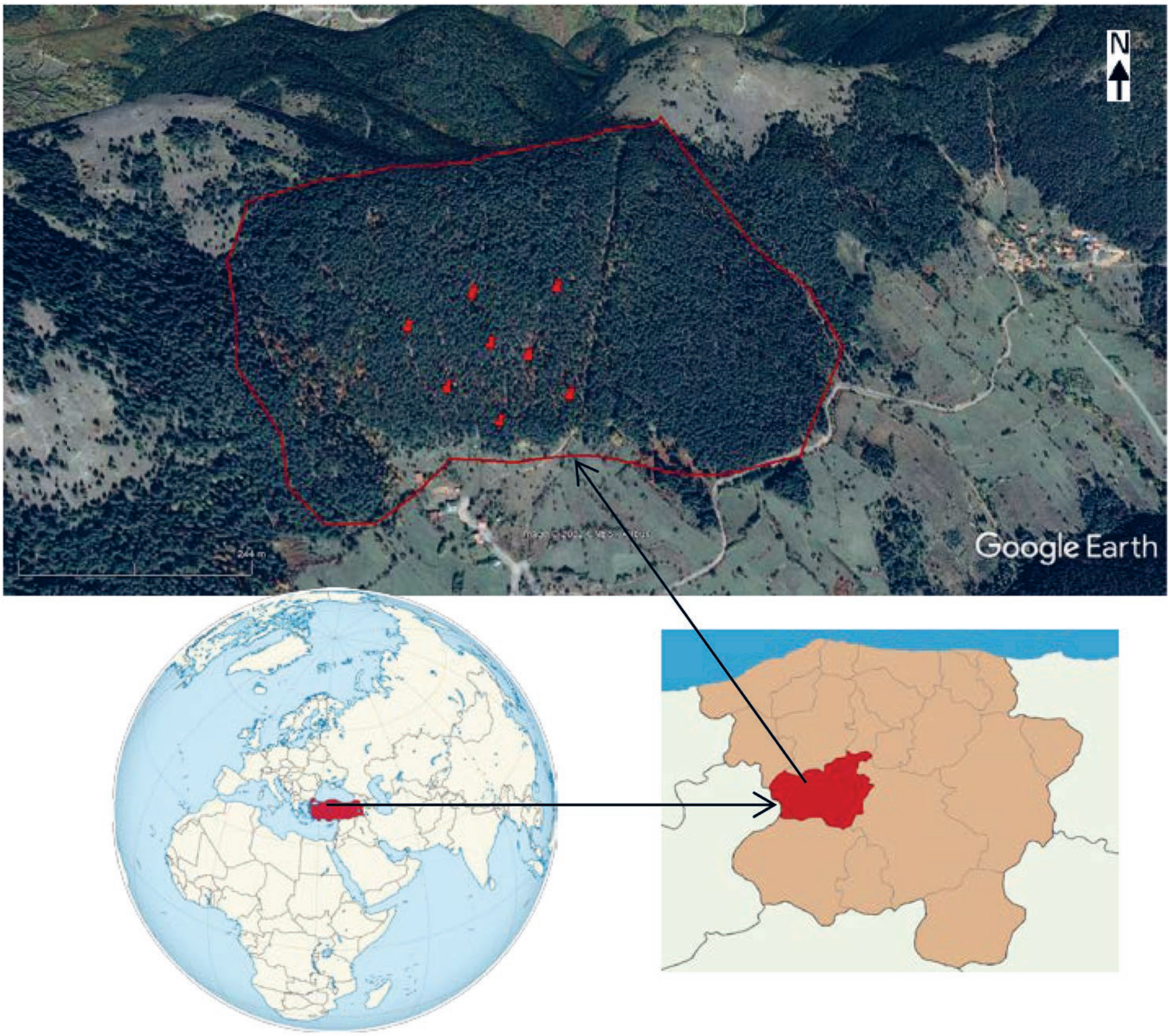

Figure 1 . Location of study area
Slika 1. Položaj područja istraživanja

Harvest residue biomass generate organic matter during decomposition (Elosegi et al., 2007). Litter decomposition is important for forest ecosystems in terms of providing nutrients and forming soil organic matter (Oades 1988; Sollins 1996). Impacts of forest stand and organic matter in the area on litter decomposition in different wood raw material production regimes were investigated by (Prescott 2005; Lado-Monserrat et al., 2016; Ferreira et al., 2018), while the impacts of soil erosion and compaction that stem from activities in a forest ecosystem in wood raw material production on biological characteristics of soil were studied by (Startsev et al., 1997; Andrade et al., 2017; Tassinari et al., 2019). Previous studies tried to identify the efficiency of sustainable forestry activities and interventions to cover the silvicultural requirements of forests following clear-cutting (Bird and Chatarpaul, 1988). Despite previous studies reported in the literature discussing litter decomposition mechanisms in micro-ecological areas after harvest in remaining stand (Kranabetter and Chapman, 1999; Bird and Chatarpaul, 1988; Jordon et al., 2003), few studies were detected discussing the effects of wood raw material production on litter decomposition (Enez et al., 2015, 2016; Cambi et al., 2015).

The studies carried out in macro-scale areas have emphasized the importance of the climate factor (Sarginci et al. 2021), whereas the other studies have shown that the biochemical structure of the decomposing material is the most significant factor upon the decomposition under the small scale areas (Sarıyıldız 2002; Gao et al., 2019). Many studies have stated three fundamental factors that affected litter decomposition and nutrient release, which are; 1)- climate characteristics of the atmosphere (especially temperature and precipitation) where the decomposition of the litter occurs, 2)- number, variety and, the activity of the microorganisms and soil organisms and 3)- chemical components of the decomposing litter (Sariyildiz et al., 2010). Sariyildiz (2002) stated that various correlations between the quality of the decomposed material and decomposition rates have been comprehensively emphasized in more than one thousand studies. Among the soil biological processes, forest litter decomposition is known to be a fundamental biological soil process, and it is also important to many ecosystem functions such as the formation of soil organic matter, the mineralization of organic nutrients, and the carbon balance (Enez et al., 2019).

The storage of carbon in forest vegetation and forest soils is responsible for approximately 60% of the carbon stored on the land surface of the earth (Waring and Schlesinger 1985). The topic of the to which extent it has an impact on the amount of CO_2 is a very popular and trend topic especially in the research carried out in Canada, Europe, and America whereas little interest has been shown in Turkey. Nevertheless, our forests are diverse inhabit different varieties in different geographical fields and it is highly possible to carry out these studies (Sarıyıldız 2002; Sarıyıldız et al., 2005). The purpose of this study was to investigate the possible effects of harvesting activities on needle litter decomposition and nutrient release of black pine (*Pinus nigra* Arnold.) and scots pine (*Pinus sylvestris* L.) needles by comparing decay rates and nutrient concentrations under four different micro-ecologic areas: (1) non-harvesting activity areas (control - C), (2) skidding road (SD), (3) under logging residues (LR) and top-soil damaged in harvest, and (4) scalped mineral soil (MT).

MATERIALS AND METHODS
MATERIJALI I METODE

Study site description and sample collection – *Opis područja istraživanja i prikupljanje uzoraka*

This study was conducted in pure Scots pine and black pine-dominated stands in Kastamonu located in northwest Turkey (41°33′43″ N, –33°23′04″ E) (Figure 1). Mean elevation of the study sites was 1463 m a.s.l. The aspect was north (N) with a slope of 70%. The study site generally has a typical terrestrial climate with hot and dry summers, and cold and snowy winters. Based on the long term meteorological data (1960–2015) from Kastamonu meteorology station, mean annual precipitation was 499 mm and temperature was 9.8 °C. The bedrock type of the study area was schist and belonged to Triassic-Lower Jurassic geological period (Akbaş et al., 2016). According to the Food and Agriculture Organization's forest soil classification system, the soil is Lithic Leptosols (shallow hard rock with gravelly or highly calcareous nature) (Toth et al., 2008).

To test the effect of harvesting activities on litter decomposition in the black pine and Scots pine stands, three micro-ecological sites were defined: logging residues (LR), skid road (SD) and mineral topsoil (MT). In addition, a control (C) site was also taken adjacent to these micro-ecological sites. For each tree species and micro-ecological sites, two subplots (20 m × 20 m = 400 m^2) were identified, in total 8 subplots. The black pine and Scots pine litters were collected from the forest floor at the end of the fall season after the harvesting and brought to the laboratory in October/November 2015. At each subplot, fresh needle litter was collected (only the litter did not exhibit discoloration or fungal colonization), air-dried in laboratory and oven-dried at 40°C for 48 h, and stored in plastic bags at 6°C until litter decomposition experiment. Also, at each subplot, soil samples were collected, sieved (with a 2 mm mesh) to remove stone, root, and macro-fauna, and bulked to one representative soil sample for each site. The characteristics of soil samples are given in Table 1.

Laboratory analysis of needle litter and soil – *Laboratorijska analiza igličnog listinca i tla*

?ahe litter samples were oven-dried at 85°C, ground in mill to a mesh fraction less than 1 mm, and analysed for organic C, total N, P, K, Ca, Mg, S, Mn, and Zn concentrations. A CNH-S elementary analyzer (Eurovector EA 3000 V.3.0 single, Milano-Italy) was used to determine organic C and N concentrations in line with dry combustion method. Other nutrient concentrations (P, K, Ca, Mg, S, Mn, Zn) were analysed with an energy-dispersive X-ray Fluorescence Spectrometer (EDXRF Xepos II from Spectro -Analytical Instruments GmbH Boschstrasse- Kleve, Germany). Soil reference material (NIST srm 2709) that was certified was used to evaluate accuracy in EDXRF.

Soil pH (H_2O) was measured in a 1:2.5 mixture of deionized water using a glass calomel electrode (LaMotte pH 5 series meter) after equilibration for 1 h in solution (Jackson 1962). Bulk density was identified by weight loss following drying, and soil texture (i.e. sand, silt, clay) was determined using hydrometer method (Bouyoucos, 1962). Triplicate analyses were performed for each analysis.

Needle litter decomposition experiment – *Eksperiment razgradnje igličnog listinca*

Five g of needle litter was put into the litter decomposition bags with a mesh width of 1 mm and a size of 20 cm x20 cm. Sub-samples were taken to identify moisture contents after drying at 85°C. The litterbags were placed back to the area where needle litter was collected to determine the effects of the different micro-ecological sites dominated by black pine and Scots pine stands. Four treatments (C, SD, LR, MT) were evaluated on the basis of needle litter decomposition for 18 months. Total number of litter decomposition bags was 360 (2 tree species x 5 replicate litter samples x 3 sampling times x 3 replicate sites x 4 different environments =360). The litter decomposition experiment was followed for 18 months. Every 6 month, five litter bags were collected from the field, and litter mass loss rates were calculated after drying the samples at 85 °C.

The $Wt=W_0e^{-kt}$ formula was used to calculate litter decomposition constant (k) (Olson Decomposition Model; Olson, 1963). Wt= t is the remaining mass at t time and W_0 is the initial mass. The time for 50% mass loss was also calculated with $T_{50}=1/k$, and the time for 95% mass loss was calculated with $T_{95}=3/k$ formula (Olson, 1963).

At each sampling, the litter remaining, C, N, Ca, Mg, P, K, S, Fe, Zn, and Mn concentrations were given with percentages of initial values (P_{ij}), according to the equation:

$$P_{ij}=\frac{C_{ij}\times W_i}{C_{0j}\times W_0}\times 100$$

Here, C_{0j} is initial concentration of j^{th} parameter, W_0 is initial litter weight, C_{ij} is concentration of j^{th} parameter in i^{th} sampling, and W_i is litter weight at i^{th} sampling (Baldantoni et al., 2013).

Data Analysis – *Analiza podataka*

Mean and standard deviation values of the litter decomposition rates were calculated for each micro-ecological site. Two-way ANOVA (analysis of variance) was applied for the effects of micro-ecological sites and time on the litter quality parameters during the decomposition periods with SPSS program (version 17.0 for Windows). Based on the results of ANOVA, Tukey's HDS (Honestly Significant Difference) test ($\alpha = 0.05$) was employed for comparing multiple litter quality parameters at each litter sampling time in the micro-ecological sites.

RESULTS
REZULTATI

Soil characteristics – *Karakteristike tla*

Mean soil physical and chemical properties of the micro-ecological sites of black and Scots pine are shown in Table 1. Soil physical and chemical properties among the two tree species were significant ($p<0.001$). Soil characteristics could be highly affected by forest harvesting operations. In general, the control sites under the Scots pine had higher soil bulk density and sand content, but lower pH and silt content than the black pine (Table 1). Differences in soil sand, silt and clay contents were also significant between the micro-ecological sites for two tree species. While the contents of sand, silt and clay in the skid roads in the black pine stand differed compared to the other micro-ecological areas, the contents of sand, silt and clay in mineral top soil and logging resudial sites were similar (Table 1).

Mass losses of needle litters – *Gubici mase igličnih listinaca*

Figure 2a and 2b show the remaining mass of the black pine and Scots pine needle litters in 4 micro-ecological areas

Table 1: Soil characteristics under Scots pine and black pine stands for per microecological sites
Tablica 1. Karakteristike tla ispod sastojine običnog bora i crnog bora prema mikroekološkim područjima

Tree species	Microecological Sites/ *Mikroekološka lokacija*	Bulk Density/ Prirodna gustoća tla (g cm^{-3})	pH-values pH-vrijednost	Sand/*Pijesak* (%)	Silt/*Prah* (%)	Clay/*Glina* (%)
		Mean±SE *Srednja vrijednost± Std. Pogreška*				
Scots pine	LR	1.10±0.06^{a}	5.16±0.17^{a}	67.9±0.0^{a}	14.3±0.0^{a}	17.8±0.0^{a}
	SR	1.08±0.08^{a}	4.87±0.23^{a}	71.9±0.0^{b}	3.8±0.0^{b}	24.3±0.0^{b}
	MT	1.01±0.07^{a}	5.17±0.09^{a}	58.7±0.0^{c}	15.4±0.0^{c}	25.9±0.0^{c}
	C	1.14±0.07^{a}	5.28±0.09^{a}	62.7±0.0^{d}	17.0±0.0^{d}	20.3±0.0^{d}
	F values/*F vrijednosti*	0.592	1.306	2.43x10^{32}	1.24x10^{34}	2.11x10^{33}
	P/*P*	0.632	0.318	0.000	0.000	0.000
Black pine	LR	0.87±0.4^{a}	7.63±0.02^{b}	48.5±0.0^{a}	37.0±0.0^{a}	14.5±0.0^{a}
	SR	0,86±0.04^{a}	7.70±0.04^{b}	62.5±0.0^{b}	13.3±0.0^{b}	24.2±0.0^{b}
	MT	1.01±0.11^{a}	7.19±0.20^{a}	51.8±0.0^{c}	15.5±0.0^{c}	32.7±0.0^{c}
	C	0.87±0.03^{a}	7.48±0.05^{ab}	59.6±0.0^{d}	15.2±0.0^{d}	25.2±0.0^{d}
	F values/*F vrijednosti*	1.197	4.696	8.12x10^{32}	1.90x10^{32}	2.13x10^{33}
	P/P	0.352	0.022	0.000	0.000	0.000

Means with different alphabets in the column indicate a significant difference between the microecological areas $P < 0.05$.

SP_{-LR}: Obični bor$_{\text{-drvni ostaci}}$, BP_{-LR}: Crni bor$_{\text{- drvni ostaci}}$, SP_{-SR}: Obični bor$_{\text{-traktorski put}}$, BP_{-SR}: Crni bor$_{\text{-traktorski put}}$, SP_{-MT}: Obični bor$_{\text{-mineralno tlo}}$, BP_{-MT}: Crni bor$_{\text{-mineralno tlo}}$, SP_{-C}: Obični bor$_{\text{-kontrola}}$, BP_{-C}: Crni bor$_{\text{-kontrola}}$, BP: Crni bor, SP: Obični bor. Srednje vrijednosti s različitim slovima u stupcu upućuju na značajnu razliku između mikroekoloških područja $P < 0.05$.

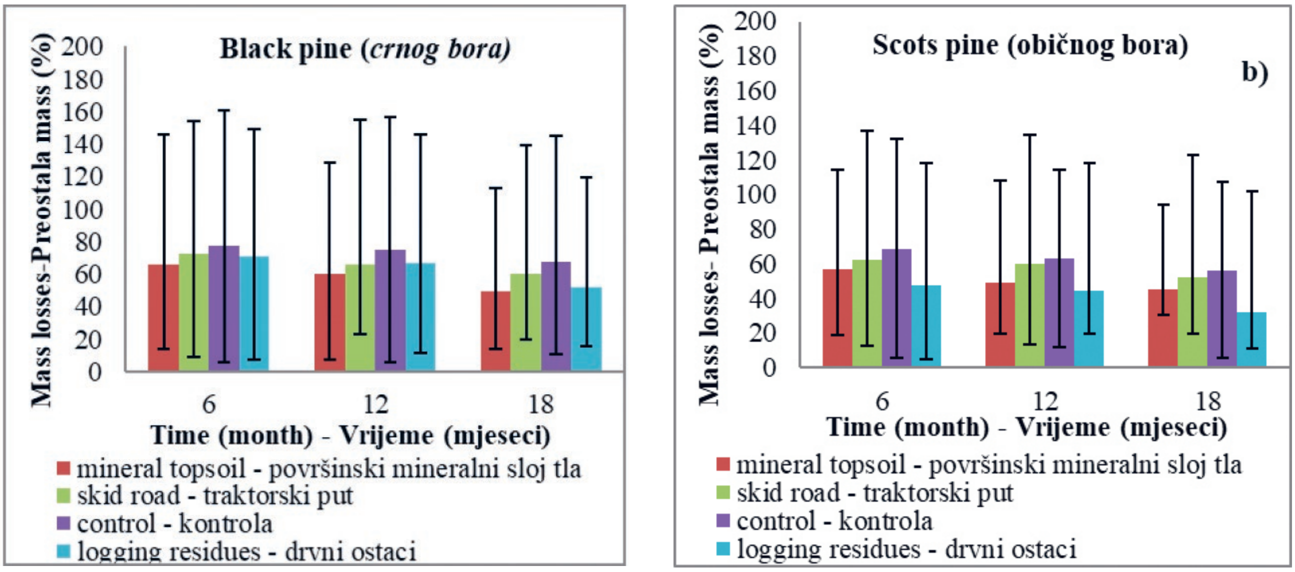

Figure 2. Mean mass losses of the black pine (a) and Scots pine (b) litters under the three different microecological and the control sites
Slika 2. Srednja vrijednost gubitka mase listinca crnog bora (a) i običnog bora (b) ispod tri različite mikroekološke lokacije i kontrolne lokacije

within 18 months. The main effects of time and interaction of time and micro-ecological areas on mass loss were significant in ANOVA results ($P<0.001$) (Figure 2).

In general, at all sampling intervals, the Scots pine needle litters decayed faster than the black pine needle litters. Both the Scots pine and black pine needle litters showed higher mean mass losses under the mineral topsoil and the logging residues than under the skid road and the control site. After 6 months, the Scots pine needle litters under the mineral topsoil and the logging residual showed higher mean mass remaining (43.4% and 52.4%, respectively). The black pine needle litters under control and skid road showed lower mean mass remaining (23% and 28%, respectively). After 12 months, the black pine needle litter under control and skid road areas still had the lowest mass losses (25% and 34%, respectively), while the Scots pine needle litter under the mineral topsoil and the logging residues had the highest mass losses (51% and 56%, respectively). At the end of the litter decomposition experiment in the field (after 18 months), the Scots pine needle litters under the logging residues had the highest mass loss (68%), followed by the mineral topsoil (55%), while the black pine needle litters under the control site had the lowest mass loss (33%).

Decay rates (k) and the time for 50% [T_{50} (y)] and 95% mass loss [T_{95} (y)] for the needle litters of the three micro-ecological and the control sites are shown in Table 2. The decay rates of Scots pine needle litters were highest under the logging residues (0.66) compared to the other sites. The calculated times required for 50% litter mass loss were the highest in BP-$_{C}$ (4.69 y) and the lowest in SP-$_{LR}$ (1.62 y). For example, while this period was between 1.62-4.84 years for the logging residual of Scots pine, it was 3.16-9.48 years in the control area. For black pine, this period was 2.62-7.87 years in the mineral topsoil microecological field, it increased to 4.69 and 14.07 in the control area. Similar results were found in the time needed for 95% mass losses. The results showed that the Scots pine needle litters under the LR site needed approximately 5 years to lose 95% of its initial mass

Table 2. Annual decay rate constants (k), coefficients of determination (r2 describing the fit of the decay model (P, 0.001), and mean percentage of the needle, time (year) needed for 50% [T50 (y)] and 95% mass loss [T95 (y)] under different micro-ecological areas.
Tablica 2.?????prijevod Godišnja konstanta stope raspadanja (k), koeficijent determinacije (r2 opisuje prikladnost modela raspadanja (P, 0,001) i srednji postotak igličnog listinca, vrijeme (godine) potrebno za gubitak mase od 50% [T50 (y)] i 95% [T95 (y)] ispod različitih mikroekoloških područja

Tree species	Microecological and control sites – Mikroekološka i kontrolna lokacija	$k(yr^{-1})$	r^2	F	T_{50} (y)	T_{95} (y)
Scots pine	LR	0.66	0.963	P<0.001	1.62	4.84
	SR	0.38	0.860	P<0.001	2.85	8.54
	MT	0.47	0.924	P<0.001	2.40	7.21
	C	0.32	0.988	P<0.001	3.16	9.48
Black pine	LR	0.37	0.888	P<0.001	2.84	8.51
	SR	0.29	0.892	P<0.001	3.75	11.26
	MT	0.40	0.969	P<0.001	2.62	7.87
	C	0.22	0.963	P<0.001	4.69	14.07

compared to the black pine needle litters, which needed much time (~8.5 y). The calculated times required for 95% litter mass loss were the highest in BP-$_{C}$ (14.07 y) and the lowest in SP-$_{LR}$ (4.84 y). In general, the decomposition rate of the species was affected in LR, SR, and MT in three different microecological areas. There was the highest decomposition rate in the field of LR by Scots pine and MT by black pine.

For the two tree species, initial C, Mg, P, K and S concentrations in the needle litter decreased with the decomposition time (Figure 3a, d, e, f and g respectively). Initial N concentration increased for the two tree species at 6 months, but at 12 months it decreased for the Scots pine, whereas it increased for the black pine. At 18 months, it sharply decreased for the black, whereas it increased for the Scots pine

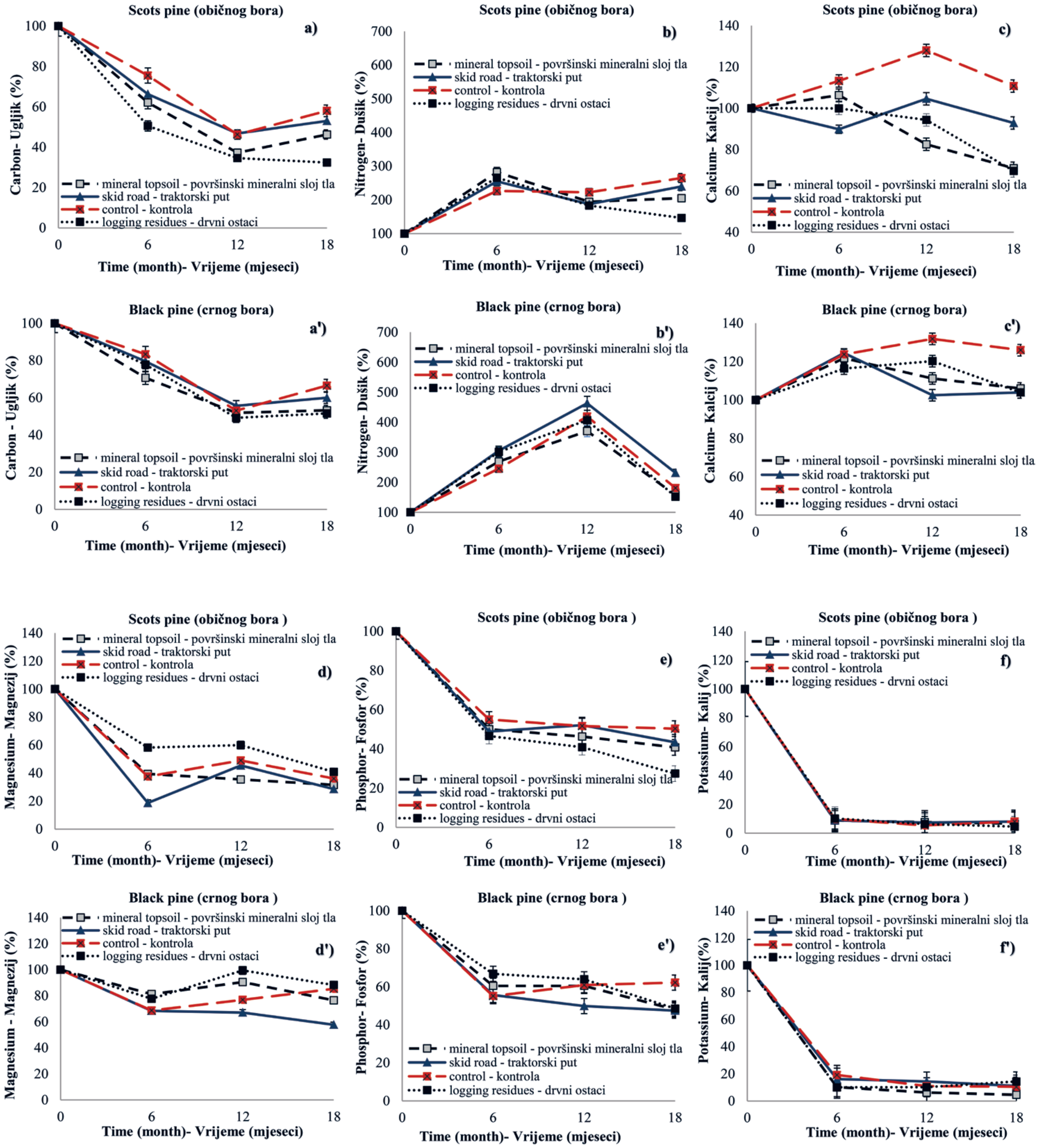

Figure 3. Dynamics of C, N, Ca, Mg, P, K, S, Mn, and Zn, as a percent of the initial value, in P. sylvestris and P. nigra leaves from four different microecological sites, during the litter decomposition. Vertical bars represent the standard error of the means.

Slika 3. Dinamika C, N, Ca, Mg, P, K, S, Mn i Zn kao postotak početne vrijednosti u listovima P. sylvestris i P. nigra s četiri različite mikrobiološke lokacije tijekom raspadanja listinca. Vertikalne trake predstavljaju standardnu pogrešku srednje vrijednosti.

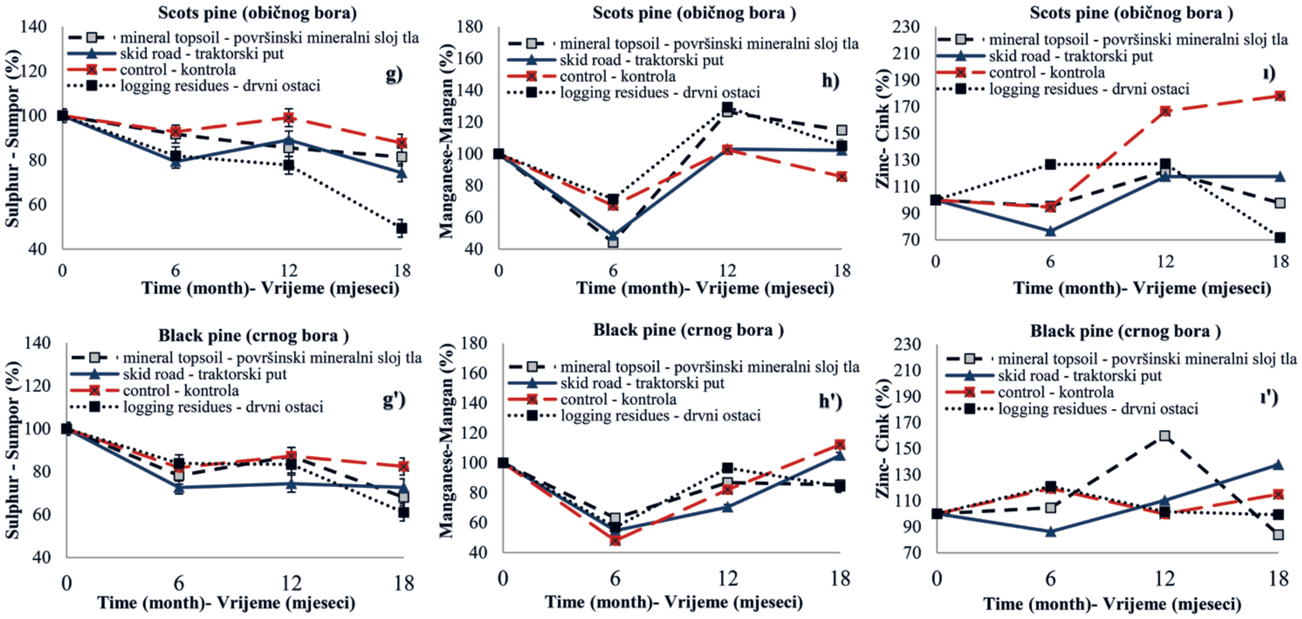

Figure 3. Continued.

(Figure 3b), but, it had a sharp decrease at the 18 moths (Figure 3b′). Initial Mn and Zn concentrations firstly showed a decrease and then increased (Figure 3h and i).

DISCUSSION
RASPRAVA

In this study, it was determined that clay, silt, sand and pH changed due to the harvesting activities in microecological areas where as soil density did not. In other studies for different tree species, harvesting activities especially at skid roads compared to control areas were effect has been reported the physical properties of the soil (Jourgholami et al., 2014; Picchio et al., 2019; Solgi et al., 2019).

Variation in mass losses and nutrients during litter decomposition with micro-ecological areas – *Varijacija u gubitku mase i hranjivih tvari tijekom raspadanja listinca s obzirom na mikroekološka područja*

The decomposition rates in the microecological areas with the highest decomposition in both species were approximately twice higher than in the control areas. In addition, microecological areas were evaluated among themselves, it is seen that there is always higher decomposition in Scots pine than black pine as a parallel to the control group, in logging residual, skid road, and mineral topsoil. Post harvesting alters litter decomposition processes (Kohout et al. 2018). At the same time these processes depend on remain duration in the forest and the time of year (Törmänen et al., 2018; Mott et al., 2021). The differences in microecological areas were caused by the time required for the estimated 50 and 95 percent mass reduction of these species to differ. This situation also reveals that it gives similarity to the studies conducted in the same region (Enez et al., 2015, 2016).

Previous studies show that nutrient concentrations change in litter residue during decomposition period. A decrease in litter C content (Figure 3a and Figure 3a') followed by a decline at 12th months, as observed in all micro-ecological areas, is similar to previous study reports (Dore et al., 2010, Baldantoni et al., 2013; Savaci and Sariyildiz, 2020; Ganatsios et al., 2021). An increase in Scots pine litter N concentration (Figure 3b) was followed by a decline in time whereas there was a rapid increase in black pine litter over 12 months and decreased sharply at the end of the 18th month (Figure 3b') due to nitrogen immobilization by microorganisms (Melillo et al., 1982; McClaugherty et al., 1985). Magill and Aber (1998) have assumed that the initial stage of litter decomposition by microbes is limited by nitrogen availability and that increases in available nitrogen will increase decay rates.

Forest disturbance, such as harvesting causing nutrient release (Phillips and Watmough, 2012; Crossman et al., 2016) cause a decrease in the amount of Ca and P in a long time (O'Brien et al., 2013; Watmough et al., 2003). In nutrients, initial litter potassium and phosphorus (Figure 3e, Figure 3e', Figure 3f, and Figure 3f', respectively) were lost in decomposing litter in first 18 months, which shows initial leaching potassium loss because of solubility. The relative elemental transition from dissociated litter generally indicates that potassium is highly mobile and nitrogen is the

Table 3. Decomposition studies in Turkey
Tablica 3. Istraživanja raspadanja u Turskoj

Classifying Trees – *Razvrstavanje stabala*	Species – *Vrsta*	Decay Rate – *Stopa raspadanja* (k)	Region – *Regija*	Experimental Period (month) – *Eksperimentalni period (mjeseci)*	References – *Reference*
Conifers – *Crnogorice*	*Pinus sylvestris* L.	0.236	Eskişehir	41	Cömez et al. 2017
	Pinus sylvestris L.	0.375	Ankara	12	Sarıyıldız et al., 2008b
	Pinus sylvestris L.	0.346	Artvin	12	Sarıyıldız et al., 2008b
	Pinus sylvestris L.	0.425	Kastamonu	18	Enez, et al., 2015; 2016
	***Pinus sylvestris* L.**	0.458	Kastamonu	18	This study
	Pinus nigra Arnold.	0.304	Ankara	12	Sarıyıldız et al., 2008b
	Pinus nigra Arnold	0.261	Artvin	12	Sarıyıldız et al., 2008b
	Pinus nigra subsp. pallasiana	0.017	Çankırı	5	Tunç, 2019
	***Pinus nigra* Arnold.**	0.320	Kastamonu	18	This study
	Picea orientalis (L.) Link	0.383	Artvin	12	Sariyildiz et al., 2008a
	Abies nordmanniana subsp. equi-trojani	0.254	Bartın	21	Kara et al., 2014
	Abies nordmanniana subsp. equi-trojani	0.353	Kastamonu	18	Enez, et al., 2015; 2016
Deciduous – *Listopadni*	*Castanea sativa* Miller	0.496	Ankara	12	Sarıyıldız et al., 2008b
	Castanea sativa Miller	0.636	Artvin	12	Sarıyıldız et al., 2008b
	Castanea sativa Miller	0.398	Düzce	27	Sargıncı, 2014
	Castanea sativa Miller	0.412	Kastamonu	18	Enez, et al., 2015; 2016
	Fagus orientalis Lipsky	0.159	Bartın	21	Kara et al., 2014
	Fagus orientalis Lipsky	0.817	İstanbul	12	Çakır and Makineci, 2020
	Fagus orientalis Lipsky	0.248	Düzce	27	Sargıncı, 2014
	Quercus petrea	0.375	Ankara	12	Sarıyıldız et al., 2008b
	Quercus petrea	0.426	Artvin	12	Sarıyıldız et al., 2008b
	Quercus petraea	0.680	İstanbul	12	Çakır and Makineci, 2020
	Populus nigra L.	3.427	Amasya	6	Erdem 2016
	Juglans regia L.	2.239	Amasya	6	Erdem and, Karavin, 2016

least mobile (Savaci and Sariyildiz, 2020). Similarly, conducted studies determined that an initial rapid decrease in K concentration (Berg et al., 1987; Baldantoni et al., 2013; Brais et al. 1995). Armolaitis et al. (2018) declared that the mean concentrations of N, K, Ca and Mg were decreased four years following clear-cutting activities. Also, Berg et al. (1987) stated that decreased from the litter in Mg concentration (Figure 3d, Figure 3d'). In similar to phosphorus concentrations in our study, Edmonds (1980) reported that phosphorus was lost in the first 3-month period, and absolute weights did not exceed initial weights in *A. rubra* and *A. nepalensis* litter. In this study, we reported an increase in absolute calcium and zinc concentrations in Scots pine and black pine litters during the first year of decomposition (Figure 3c, Figure 3c', Figure 3ı and Figure 3ı', respectively). Initial Mn concentration also decreased over time but had highest point at the 12-month under Scots pine and 18-month intervals under black pine (Figure 3g, Figure 3g'). Davey et al. (2007) stated that Mn concentration was with the degradation of lignin or humification products already important in the early stage of decomposition. Also, the relationship between the initial decomposition rate and Mn may be due to the role of Mn as a cofactor in Mn-peroxidase, an enzyme in the ligninase system (Davey et al., 2007). The S concentration in Scots pine and black pine litters were initially lowered at the 6-month but then slowly increased at the 12-month and then decreased at the 18-month (Figure 3h, Figure 3h'). This is similar to the value reported for decomposing litter (Blair, 1988). We did not investigate the differences in soil nutrient status of different microecological areas of the Scots pine and black pine species, but the results show that these factors must be considered to understand the difference in decomposition process among the different microecological areas.

Variation in mass losses among tree species – *Varijacija u gubitku mase među podvrstama drveća*

Litter decay rates of various tree species in different habitat conditions in Turkey are given in Table 3. In this study carried out the Scots pine needles have a higher decomposition rate than the black pine. Compared to other studies with black pine and Scots pine needles in different growing habitats, it is seen that the decomposition is higher in the Kastamonu region. It is known that climate, soil organisms, initial chemical content of litter, and soil properties are effective on the decomposition of litter (Sarıyıldız et al., 2008a). At the same time, stand types affect the rate of litter decomposition (Cömez et al., 2017).

CONCLUSION
ZAKLJUČAK

Forest management activities are needed in forestry, and humans might show minimum control over the conditions under which these are performed. This study has shown that litter decomposition rates are significantly influenced by the site disturbance activities from the forest harvesting, but the degree of variation in litter decomposition rates shows differences with tree species. The results show that there are significant variations in the litter mass loss, the nutrient concentrations, soil physical and chemical properties among the two tree species, and different micro-ecologic areas due to the site disturbance activities from the forest harvesting. These results demonstrate that the litter mass remaining of black pine and Scots pine varied at significant levels among sampling time and micro-ecological areas. These results make it mandatory to specify the operation plans and especially the skidding routes with its inspection for the harvesting activities.

Declarations

⇒ Ethics approval and consent to participate

Not applicable

⇒ Consent for publication

Not applicable

⇒ Availability of data and materials

Not applicable

⇒ Competing interests

The authors declare that they have no competing interests

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REFERENCES
LITERATURA

- Akbaş, B., N. Akdeniz, A. Aksay, I. Altun, V. Balcı, E. Bilginer, T. Bilgiç, M. Duru, T. Ercan, I. Gedik, Y. Günay, I.H. Güven, H.Y. Hakyemez, N. Konak, I. Papak, S. Pehlivan, M. Sevin, M. Senel, N. Tarhan, N. Turhan, A. Türkecan, U. Ulu, M.F. Uğuz, A. Yurtsever: 2016. Geological map of Turkey. General Directorate of Mineral Research and Exploration Publication, Ankara, Turkey (in Turkish).
- Andrade, M.L.C., D. Tassinari, M.S. Dias Junior, R.P, Martins, W.W. Rocha, Z.R. Souza, 2017: Soil compaction caused by harvest and logging operations in eucalyptus forests in coarse-textured soils from northeastern Brazil, Cienc Agrotecnologia, 41(2): 191–200. https://doi.org/10.1590/1413-70542017412036216
- Armolaitis, K., V. Stakénas, I. Varnagiryté-Kabašinskiené, A. Gudauškiené, P. Žemaitis, 2018: Leaching of organic carbon and plant nutrients at clear cutting of Scots pine stand on arenosol, Baltic For, 24: 50-59.
- Baldantoni, D., A. Bellino, F. Manes, A. Alfani, 2013: Ozone fumigation of *Quercus ilex* L. slows down leaf litter decomposition with no detectable change in leaf composition, Ann For Sci, 70: 571-578. http://doi.org/10.1007/s13595-013-0297-5
- Berg, B., H. Staaf, B. Wessen, 1987: Decomposition and nutrient release in needle litter from nitrogen-fertilized Scots pine (*Pinus sylvestris*) stands, Scand J For Res, 2(1-4): 399-415. https://doi.org/10.1080/02827588709382478
- Bird, G.A., L. Chatarpaul, 1988: Effect of forest harvest on decomposition and colonization of maple leaf litter by soil microarthropods. Can J Soil Sci, 68: 29–40.
- Blair, J. M. 1988: Nitrogen, sulfur and phosphorus dynamics in decomposing deciduous leaf litter in the southern Appalachians. Soil Biol and Biochem, 20(5): 693-701. https://doi.org/10.1016/0038-0717(88)90154-X
- Bouyoucos, G.J., 1962: Hydrometer method improved for making particle size analyses of soils 1, Agronomy J, 54: 595-622.
- Brais, S., C. Camiré, Y. Bergeron, D. Paré, 1995: Changes in nutrient availability and forest floor characteristics in relation to stand age and forest composition in the southern part of the boreal forest of northwestern Quebec, Forest Ecol Manag, 76: 181-189. https://doi.org/10.1016/0378-1127(95)03541-H
- Çakır, M., E. Makineci, 2020: Litter decomposition in pure and mixed Quercus and Fagus stands as influenced by arthropods in Belgrad Forest, Turkey, J For Res, 31: 1123-1137. https://doi.org/10.1007/s11676-019-00915-y
- Cambi, M., G. Certini, F. Neri, E. Marchi, 2015: The impact of heavy traffic on forest soils: A review, For Ecol Manag, 338: 124-138. https://doi.org/10.1016/j.foreco.2014.11.022
- Cömez, A., D. Tolunay, Ş.T. Güner, 2017: Determination of carbon sequestration in Scots pine (*Pinus sylvestris* l.) stands on Sündiken Mountain. In, T.C. ESK-09 (6303)/ 2010-2016 numbered project supported by the Ministry of Forestry and Water Affairs, Istanbul.
- Crossman, J., M.C. Eimers, S.A. Watmough, M.N. Futter, J. Kerr, S.R. Baker, P.J. Dillon, 2016: Can recovery from disturbance explain observed declines in total phosphorus in Precambrian Shield catchments? Can J Fish Aquat Sci, 73: 1202–1212. https://doi.org/10.1139/cjfas-2015-0312
- Davey, M. P., B. Berg, B. A. Emmett, P. Rowland, 2007: Decomposition of oak leaf litter is related to initial litter Mn concentrations. Botany, 85:16-24. https://doi.org/10.1139/b06-150
- Dore, S., T.E. Kolb, M. Montes-Helu, S.E. Eckert, B.W. Sullivan, B.A. Hungate, J.P. Kaye, S.C. Hart, G.W. Koch, A. Finkral, 2010: Carbon and water fluxes from ponderosa pine forests disturbed by wildfire and thinning, Ecol Appl, 20(3): 663-683.https://doi.org/10.1890/09-0934.1
- Edmonds, R.L., 1980: Litter decomposition and nutrient release in Douglas-fir, red alder, western hemlock, and Pacific silver fir ecosystems in western Washington, Can J For Res, 10 (3): 327-337. https://doi.org/10.1139/x80- 056
- Elosegi, A., J. Diez, J. Pozo, 2007: Contribution of dead wood to the carbon flux in forested streams, Earth Surf Proc Land, 32: 1219–1228.https://doi.org/10.1002/esp.1549
- Enez, K, T. Sariyildiz, B. Aricak, G. Savaci, 2016: Initial litter quality variables and disturbed site characteristics by forest harvesting practices influence litter decomposition rates of scots pine,

trojan fir and sweet chestnut in northwest of Turkey, Fresenius Environ Bull 25: 4732-4741.

- Enez, K., B. Arıcak, T. Sariyildiz, 2015: Effects of harvesting activities on litter decomposition rates of scots pine, trojan fir, and sweet chestnut, Sumar List, 78: 361-368.
- Enez, K., T. Sariyildiz, G. Savaci, 2019: Effects of timber harvesting activities on needle litter decomposition rates and nutrient concentrations of black pine. 2nd International symposium of forest engineering and technologies, Agricultural University of Tirana, Faculty of Forestry Science, 111-116, Tirana
- Erdem E., N. Karavin, 2016: Effect of litter placement to decomposition rate of *Juglans regia* L leaf litter, Sch Acad J Biosci, 4 (9): 778-781. https://doi.org/10.21276/sajb.2016.4.9.15
- Erdem, E., 2016: Investigation on leaf litter decomposition in *Populus nigra* L. and *Juglans regia* L. **(Master's thesis),** Amasya University, Amasya (in Turkish with English summary)
- Ferreira, G.W., J.V. Roque, E.M. Soares, I.R. Silva, E.F, Silva, A.A. Vasconcelos, R.F. Teófilo, 2018: Temporal decomposition sampling and chemical characterization of eucalyptus harvest residues using NIR spectroscopy and chemometric methods, Talanta 188: 168-177. https://doi.org/10.1016/j.talanta.2018.05.073
- Ganatsios, H.P., P.A. Tsioras, A.G. Papaioannou, C.R. Blinn, 2021: Short term impacts of harvesting operations on soil chemical properties in a mediterranean oak ecosystem, Croat J For Eng, 42: 3463-476 https://doi.org/10.5552/crojfe.2021.1100
- Gao, J., H. Han, F. Kang, 2019: Factors controlling decomposition rates of needle litter across a chronosequence of chinese pine (*Pinus tabuliformis* Carr.) Forests, Pol J Environ Stud, 28(1): 91-102 https://doi.org/10.15244/pjoes/84770
- Gulci, N., A.E. Akay, O. Erdas, 2016: Investigation of timber harvesting operations using chainsaw considering productivity and residual stand damage: The Case of Bahçe Forest Enterprise Chief. J Fac For-Istanbul University. http://dx.doi.org/10.17099/jffiu.11250
- Jackson, M.L. 1962: Soil chemical analysis, constable and company Ltd., 42-47., London, England.
- Janowiak, M.K., C.R. Webster, 2010: Promoting ecological sustainability in woody biomass harvesting, J For, 108:16-23.
- Jordon, D., JrF, Ponder, JrF, V.C. Hubbard, 2003: Effects of soil compaction, forest leaf litter and nitrogen fertilizer on two oak species and microbial activity, Appl Soil Ecol, 23: 33-41. https://doi.org/10.1016/S0929-1393(03)00003-9
- Jourgholami, M. B. Majnounian, M. Etehadi Abari, 2014: Effects of tree-length timber skidding on soil compaction in the skid trail in Hyrcanian forests, For. Syst, 23. 288–293.
- Kara, O., I. Bolat, K. Cakıroglu, M, Senturk, 2014: Litter decomposition and microbial biomass in temperate forests in Northwestern Turkey, J Soil Sci Plant Nutr, 14: 31-41. http://dx.doi.org/10.4067/S0718-95162014005000003
- Kohout, P, M. Charvátová, M. Štursová, T. Mašínová, M. Tomšovský, P. Baldrian, 2018: Clearcutting alters decomposition processes and initiates complex restructuring of fungal communities in soil and tree roots. The ISME journal, 12: 692-703.
- Kranabetter, J.M., B.K. Chapman, 1999: Effects of forest soil compaction and organic matter removal on leaf litter decomposition in central British Columbia, Can J Soil Sci, 79: 543–550. https://doi.org/10.4141/S98-081
- Lado-Monserrat, L., A. Lidón, I.Bautista, 2016: Litterfall, litter decomposition and associated nutrient fluxes in *Pinus halepensis*: influence of tree removal intensity in a Mediterranean forest, Eur J For Res, 135(1): 203-214. http://dx.doi.org/10.1007/s10342-015-0893-z
- Magill, A.H., J.D. Aber, 1998: Long-term effects of experimental nitrogen additions on foliar litter decay and humus formation in forest ecosystems, Plant Soil, 203: 301-311.
- McClaugherty C.A., J. Pastor, J.D. Aber, J.M. Melillo, 1985: Forest litter decomposition in relation to soil nitrogen dynamics and litter quality, Ecology, 66: 266-275.
- Melillo, J.M., J.D. Aber, J.F. Muratore 1982: Nitrogen and lignin control of hardwood leaf litter decomposition dynamics, Ecology, 63: 621-626.
- Mott, C.M., R.W. Hofstetter, A.J. Antoninka 2021: Post-harvest slash burning in coniferous forests in North America: A review of ecological impacts, For Ecol Manag, 493: 119251. https://doi.org/10.1016/j.foreco.2021.119251
- O'Brien., H.D., M.C. Eimers, S.A. Watmough, N.J. Casson, 2013: Spatial and temporal patterns in total P in south-central Ontario streams, the role of wetlands and past disturbance. Can J Fish Aquat Sc. 70: 766–774. https://doi.org/10.1139/cjfas-2012-0474
- Oades, J.M. 1988: The retention of organic matter in soils. Biogeochemistry 5:35–70. https://doi.org/10.1007/BF02180317
- Olson, J.S. 1963: Energy storage and the balance of producers and decomposers in ecological systems, Ecology, 14: 322-331. https://doi.org/10.2307/1932179
- Phillips, T., S. Watmough, 2012: A nutrient budget for a selection harvest, implications for long-term sustainability, Can J For Res, 42, 2064–2077. https://doi.org/10.1139/cjfr-2012-0224
- Picchio, R, F. Tavankar, M. Nikooy, G. Pignatti, R. Venanzi, A. Lo Monaco, 2019: Morphology, growth and architecture response of beech (*Fagus orientalis* Lipsky) and maple tree (*Acer velutinum* Boiss.) seedlings to soil compaction stress caused by mechanized logging operations, Forests, 10 (9): 771. https://doi.org/10.3390/f10090771
- Picchio, R, P.S. Mederski, F Tavankar, 2020: How and how much, do harvesting activities affect forest soil, regeneration and stands? Curr For Rep, 6:115-128.
- Prescott, C.E. 2005: Do rates of litter decomposition tell us anything we really need to know? Forest Ecol Manag, 220: 66-74. https://doi.org/10.1016/j.foreco.2005.08.005
- Sargıncı, M., 2014: Litter dynamics in western blacksea forest ecosytems. (PhD thesis), Duzce University, Duzce (in Turkish with English summary)
- Sarginci, M., O. Yildiz, D. Tolunay, B. Toprak, Ş. Temür, 2021: Leaf litter dynamics in Western Black Sea mountainous forest ecosystems. Can J For Res, 51: 1821-1832.
- Sariyildiz T (2002). An overview of studies on the importance of litter decomposition and the effect of litter components on litter decomposition. II. National Black Sea Forestry Congress 2: 807-819 (in Turkish with English summary), Artvin
- Sariyildiz, T., A. Tüfekçioğlu, M. Küçük 2005: Comparison of decomposition rates of beech (*Fagus orientalis* Lipsky) and spruce (*Picea orientalis* (L.) Link) litter in pure and mixed stands of both species in Artvin, Turkey, Turk J Agric For, 29: 429-438.
- Sariyildiz, T., E. Akkuzu, M. Küçük, A. Duman, Y. Aksu 2008a: Effects of *Ips typographus* (L.) damage on litter quality and decomposition rates of oriental spruce [*Picea orientalis* (L.) Link.] in Hatila Valley National Park, Turkey, Eur J of For Res, 127: 429-440. https://doi.org/10.1007/s10342-008-0226-6
- Sariyildiz, T., S. Varan, A. Duman, 2008b: Effects of litter quality and enviromental factors on litter decomposition rates: a case

study from Artvin and Ankara Regions, Kastamonu Univ J Foresty Faculty, 8: 109-119 (in Turkish with English summary)

- Sariyildiz, T., M. Acar, M. Küçük, 2010: Effect of tree species and topography on root secomposition, oral presentation II. National Black Sea Forestry Congress, Turkey: 20-22 (in Turkish with English summary), Artvin
- Savaci, G., T. Sariyildiz, 2020: Effects of stand age on litter quality, decomposition rate and nutrient release of Kazdagi fir (*Abies nordmanniana* subsp. *equi-trojani*), iForest-Bioge Forestry, 13: 396-403. https://doi.org/10.3832/ifor3306-013
- Solgi, A., R. Naghdi, E. Marchi, A. Laschi, F.K. Behjou, V. Hemmati, A. Masumian, 2019: Impact assessment of skidding extraction: effects on physical and chemical properties of forest soils and on maple seedling growing along the skid trail, Forests, 10: 134.
- Sollins, P., 1996: Stabilization and destabilization of soil organic matter: mechanisms and controls, Geoderma, 74: 65–105 https://doi.org/10.1016/S0016-7061(96)00036-5
- Startsev, N.A., D.H. McNabb, A.D. Startsev, 1997: Soil biological activity in recent clearcuts in west-central Alberta, Can J of Soil Sci, 78: 69–76.
- Tassinari D., M.L.D.C. Andrade, M.D.S. Dias Junior, R. P. Martins, W.W. Rocha, P.S.A.M. Pais, Z.R. de Souza, 2019: Soil compaction caused by harvesting, skidding and wood processing in eucalyptus forests on coarse-textured tropical soils, Soil Use Manag, 35(3): 400-411. https://doi.org/10.1111/sum.12509
- Törmänen., T, V. Kitunen, A.J. Lindroos, J. Heikkinen, A. Smolander, 2018. How do logging residues of different tree species affect soil N cycling after final felling? For Ecol Manag, 427: 182-189. https://doi.org/10.1016/j.foreco.2018.06.005
- Tóth, G., L. Montanarella, V. Stolbovoy, F. Máté, K. Bódis, A. Jones, P. Panagos, M.V. Liedekerke 2008: Soils of the european union. JRC scientific and technical reports, Office for Official Publications of the European Communities, 1-100, Luxembourg
- Tunç, T., 2019: Litter decomposition in different development stage of anatolian black pine stands in Çankırı-Eldivan region. (Master's thesis), Çankırı Karatekin University, Cankırı (in Turkish with English summary)
- Venanzi., R., R. Picchio, G. Piovesan, 2016:. Silvicultural and logging impact on soil characteristics in Chestnut (*Castanea sativa* Mill.) Mediterranean coppice, Ecol Eng, 92: 82–89. https://doi.org/10.1016/j.ecoleng.2016.03.034
- Waldrop., M.P., J.G. McColl, R.F. Powers, 2003: Effects of forest postharvest management practices on enzyme activities in decomposing litter, SSSAJ, 67(4): 1250-1256. https://doi.org/10.2136/sssaj2003.1250
- Waring,. R.H. W.H. Schlesinger, 1985: Forest Ecosystems: conceptions and management. Academic, Press, INC. (London) LTD.
- Watmough., SA, J. Aherne, P.J. Dillon, 2003: Potential impact of forest harvesting on lake chemistry in south-central Ontario at current levels of acid deposition, Can J Fish Aquat Sci, 60: 1095–1103. https://doi.org/10.1139/f03-093

SAŽETAK

U istraživanju se proučavao učinak drvnih ostataka i traktorskih puteva na raspadanje igličnog listinca i otpuštanje hranjivih tvari čistih sastojina crnog bora i običnog bora na tri različite mikroekološke lokacije (traktorski put, drvni ostaci i mineralni površinski sloj tla) i na kontrolnoj lokaciji (područje neiskorištavanja šume). Prvo je analizirana ukupna koncentracija ugljika i hranjivih tvari (N, P, K, Ca, S, Mg, Mn i Fe) u igličnim listincima crnog bora i običnog bora. Eksperiment raspadanja listinca proveden je pomoću metode vreća na otvorenom u periodu od 18 mjeseci. Iglični listinci običnog bora raspali su se brže od listinca crnog bora. Obje vrste igličnog listinca pokazali su veće prosječne gubitke mase ispod mineralnog površinskog sloja i drvnih ostataka nego ispod traktorskog puta i na kontrolnoj lokaciji.

KLJUČNE RIJEČI: kvaliteta listinca, mikroekološko područje, raspadanje listinca, hranjive tvari, vrste drveća