Environmental Engineering and Management Journal

July 2021, Vol. 20, No. 7, 1163-1172
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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IMPACT OF WINDTHROWS DISTURBANCE ON CHEMICAL AND BIOLOGICAL PROPERTIES OF THE FOREST SOILS FROM ROMANIA

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Abstract

The present study investigates the influence of windthrows on the chemical and biological characteristics and respiration processes of forest soils from Romania. Three pure Norway spruce, common beech, and sessile oak stands were chosen together with control plots, where the forest and soils were not affected by windthrows. Soil samples were taken from two soil layers: 0–10 cm and 10–20 cm. Soil carbon dioxide fluxes or soil respiration was monitored at 20 randomly selected points for each sample surface. Soil temperature and soil water content were also measured at these points. Furthermore, the total number of heterotrophic bacteria and the total number of fungi were also measured. We found that abiotic factors lead to the modification of the chemical and biological properties of forest soils: soil pH was higher in the areas affected by windthrows, while humus and nitrogen quantities were lower in these areas. However, these changes were observed only in the first 10 cm of the soil profile. Underground microclimatic conditions were found to influence soil respiration, with higher respiration values observed in the surfaces affected by windthrows. In the Norway spruce and common beech stands, aerobe heterotroph bacteria and fungus were more abundant in soils that were not affected by windthrows because the uprooted trees remove top horizons of soils and the creation of leaf litter, roots and fungal hyphae, stops. In this situation, organic matter, in the soil, begins to decay.

Key words: aerobe heterotroph bacteria, fungi, forest soils, soil properties, soil respiration, windthrows

Received: March, 2020; Revised final: November, 2020; Accepted: December, 2020; Published in final edited form: July, 2021

1. Introduction

Windthrows are a natural forest phenomenon. Windthrow is defined "*as the uprooting of a whole tree at the interface of the trunk with the soil, which may involve the lifting of roots, the snapping of roots or the failure of the trunk at the soil surface*" (Moore, 2014). In Romania, the windthrows which appear in *Norway spruce* stands is one of the biggest problem for the Romanian forestry (Vorovencii, 2014). However, the disturbances caused in forests by windthrows vary both spatially and temporally. Besides the changes they cause in forests, windthrows also significantly change soil characteristics. In addition, windthrows cause humidity and soil water content to increase, and also the soil temperature (Ulanova, 2000), leading to considerable alterations in the process of organic matter transformation because this process occurs under high temperature and humidity (Spârchez et al., 2013). Furthermore, the number of microorganisms in areas affected by windthrows increases, followed by an increase in soil CO_2 production (Gafrikova and Hanajik, 2016). Mayer et al. (2016) determined the respiration of the soil at the surfaces where the roots were removed and showed that it was significantly higher in the

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windthrow areas. Other studies revealed that windthrows did not influence the soil microbial community composition and microbial characteristics. Gömöryová et al. (2017) did not find differences between microbial properties but showed similarities in the composition of microbial populations of the extracted and not-extracted plots after 10 years of windthrow. Microbial characteristics at the „new" windthrow plot did not differ from the plots with different management. Damage caused by windthrows and associated changes in the soil regime can lead to the alteration of pedogenetic processes including bioaccumulation, humification, and eluviation-illuviation (Ulanova, 2000).

Mayer et al. (2015) studied a chrono-sequence of windthrows in the Austrian Alps to analyse the impact of windthrow damage on CO_2 emissions. By analysing a large variety of soil parameters (C and N stocks, temperature, and mycorrhiza activity) they established that climatic soil factors (temperature and moisture) and roots activity are the main factors that influence CO_2 emissions. Simon et al. (2011), among others, established that pH values in areas affected by windthrows and pH values in control surfaces are very similar. However, control surfaces presented the highest values for C and organic N content.

Windthrows change the decomposition process of organic matter in the soil, which can be reflected in the metabolic processes of organisms in these soils (Manzoni et al., 2012; Moyano et al., 2013; Schimel et al., 2007; Schjønning et al., 2003; Wardle and Ghani, 1995). The most important consequence of windthrows is the uprooting of trees, which is the most common form of soil disturbance (Mitchell, 1988). This natural phenomena appears in almost all forest type (Clinton and Baker, 2000). Uprooted trees bring nutrients and organic carbon from inside the soil to its surface, exposing them to atmospheric processes. Tree uprooting can increase the alteration processes of minerals and the availability of nutrients (Samonil et al., 2010). The positive effect caused by the increase of litter quantities due to the wood originating from windthrows is exceeded by the carbon loss which occurs through soil disturbances caused by tree uprooting (Lenart et al., 2010). Windthrows also create gaps of variable dimensions in the forest ecosystem. These cause changes in soil properties that depend on the gap's width and position (Kwit and Platt, 2014). In gaps with large surfaces, several changes may occur in the soil: the soil's pH increases; the basic cation's eluviation potential increases, leading to the depletion of soil's nutritive elements; and soil humidity is lower and temperatures are higher due to stronger soil radiation, causing a decrease in the density of soil microorganisms and biomass (Kooch and Haghverdi, 2014; Oneț et al., 2019a; Stark and Firestone, 1995).

The aim of our study was to evaluate the impact of the windthrows' effects on chemical and microbiological characteristics of the forest soil in three different forest ecosistem (spruce, beech and sessile oak). Our investigation was focused especially on soil CO_2 production and on evaluation of the total number of soil heterotrophic bacteria and fungi using traditional cultivation methods.

2. Material and method

2.1. Study area

In order to analyse the influence of windthrows on the characteristics of forest soils, three sample surfaces were chosen in areas with recent windthrows (within the past 2–4 years), situated in stands belonging to three different tree species: Norway spruce (*Picea abies* L. H. Karst), common beech (*Fagus sylvatica* L.) and sessile oak (*Quercus petraea* (Matt.) Liebl.).

The soil types of the three surfaces were eutric cambisol for Mihăeşti 1 and 2 and dystric cambisol for Rucar (Table 1, Fig. 1a). Dystric cambisol is the most widespread forest soil in Romania (Dincă et al., 2014) and has a rich humus content (Dincă et al., 2015), while eutric cambisol is the third-most common soil in Romania and is a typical common beech stand soil (Spârchez et al., 2017; Târziu et al., 2004). According to Koppen classification, the climate is temperate continental, whit mean annual temperature (MAT) of 4.9^{o}C and mean annual precipitation (MAP) of 980 mm, in Rucar forest region, and whit mean annual temperature of 7.6 ^{o}C and mean annual precipitation of 780 mm, in Mihaesti forest region (data according forest management plans of Rucar forest district and Mihaesti experimental forest district).

2.2. Soil sampling and analyses

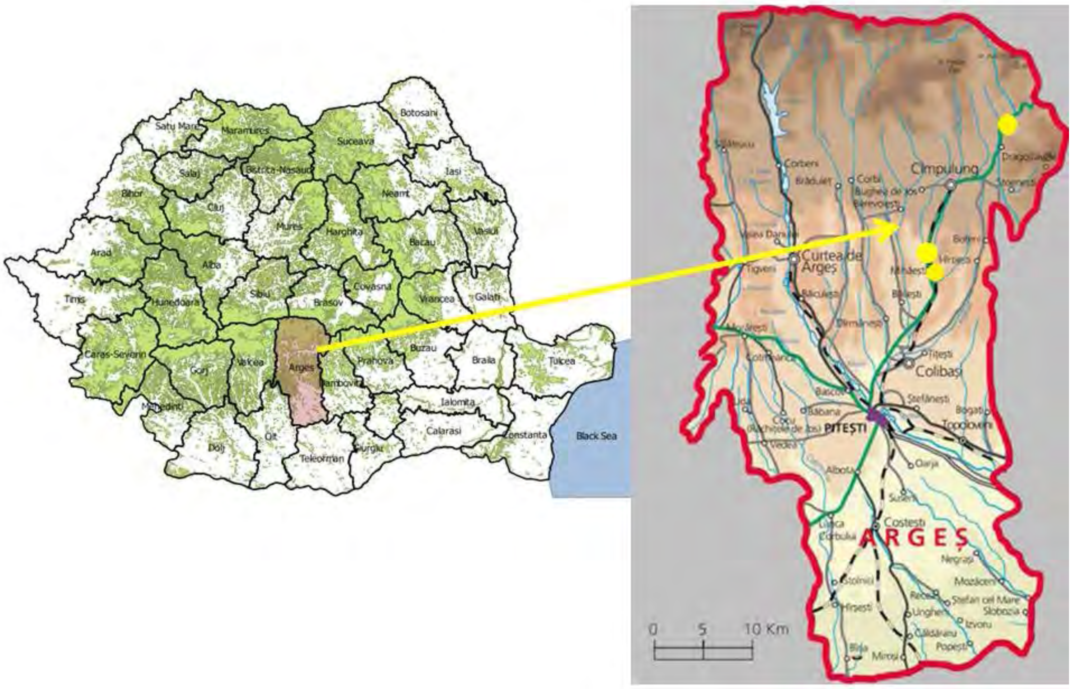
Soil samples from all the study surfaces were collected during fieldwork performed in 2016 and 2017. The surfaces were chosen so that each stand would contain areas affected by windthrows (D) as well as control areas (Ctrl) in which the initial stand and soil were unaffected by windthrows. A main soil profile (PP) was obtained in each sample surface affected by windthrows.

From this profile, samples were collected for each pedogenetic horizon. Samples were also collected for three secondary soil profiles with two standard horizons: 0–10 cm and 10–20 cm. Control areas were chosen based on their proximity to the affected areas. Sample surfaces were also placed in these areas, followed by three secondary profiles.

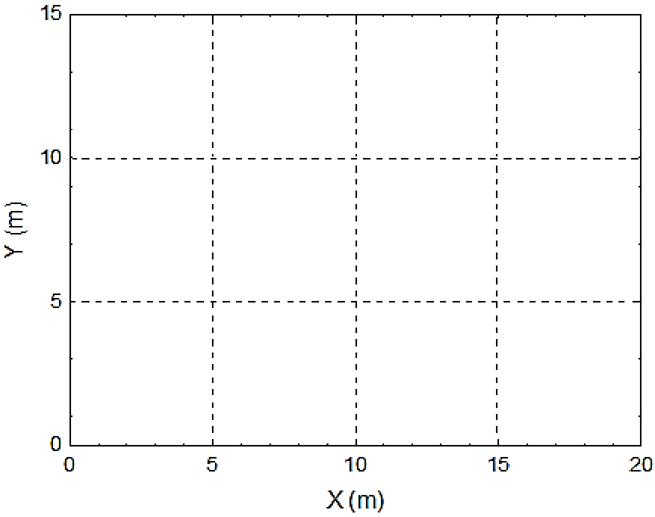
The samples were kept in the laboratory for drying for a maximum of 72 hours (ISO 18400-206:2018). In order to use samples for microbial counts, it is necessary to eliminate fragments of unwanted material like pieces of roots or leaves. As such, the soil samples were sieved through a sieve with a diameter of 2 mm. Next, to perform microbiological analysis the wettable soil samples were incubated at 37^{0}C for five days. The analysis of the chemical properties of the soil samples (pH, humus, total nitrogen, total cationic exchange capacity, base saturation degree) was performed with internationally recognized methodologies.

Table 1. General characteristics of sites locations

Site	*Geographic coordinates*		*Altitude (m)*	*Stand age (years)*	*Dominant specie of stand*	*Slope of terrain (°)*	*Exposition of terrain*	*Soil type*
	Latitude	*Longitude*						
Rucar	45°29'01"	25°10'13"	1250	90	Spruce	25	SW	Dystric cambisol
Mihaesti 1	45°03'29"	25°02'04"	550	110	Beech	15	W	Eutric cambisol
Mihaesti 2	45°04'24"	25°01'44"	520	130	Sessile oak	15	SE	Eutric cambisol



(a)



(b)

Fig. 1. Location of the studied forest stands (a) (Zarnesti, 2020) and sampling design of plots (b)

The pH was determined in water - soil suspensions, with a soil : water ratio of 1 : 2.5 by the potentiometric method with the laboratory pH meter. The humus content was determined by the Walkley-Black method which consists of wet oxidation of carbon from soil organic matter. For content of total nitrogen was used the Kjeldahl method. This method is performed in two steps, namely: (1) release of nitrogen from organic compounds (by digestion or mineralization) and (2) titrimetric nitrogen dosing.

The total cation exchange capacity is given by the total exchangeable cations in the soil and is determined by calculation, being the sum between the exchange capacity for bases (Sb) and the exchange capacity for hydrogen (Sh), both determined by the Kappen method. As well as the total cation exchange capacity, base saturation degree results also by calculation, as a ratio between the exchange capacity for bases (Sb) and the total capacity of cation exchange (T). All this method are consistent with international methodology in force (Cools and De Vos, 2010).

2.3. Installing the experimental device and measuring forest soil respiration (Rs)

In order to detect the effect of windthrows on CO_2 emissions, soil respiration (Rs) was measured during several periods of the year: spring (April), summer (June, August) and fall (October). Soil CO_2 effluxes were measured with a portable infrared gas analyser (IRGA), which was connected to a soil respiration standard chamber (EGM-4 and SCR-1, PP Systems, USA). The volume of the commercial chamber (1171 cm^3) was supplemented by the extra volume generated by the collars installed in the first centimetre of the soil layer. The increase of CO_2 in the chamber was finished within two minutes. To avoid disturbing the soil and thus causing errors in Rs determination, 20 PVC collars (11 cm in diameter and 8 cm in height) were installed randomly at a depth of 3 cm in each location (Perturbation and Control plots) one week before the measurements started (Fig. 1b). The collars were placed considering the following factors: field characteristics, stand location, possible wood remains, and stones. The collars' purpose was to retain the initial measurement position as well as contingent gas contaminations through the gas diffusion effect. Furthermore, Rs was not measured during rain events and measurements were always taken between10 a.m. and 5 p.m., following various past protocols (Buchmann, 2000; Pumpanen et al., 2010). Meteorological conditions (e.g. daily precipitation > 15 mm) were taken into account to avoid overestimating soil CO_2 emissions due to the "Birch effect". Soil CO_2 was measured simultaneously with environmental characteristics of the soil (temperature and moisture). During soil respiration measurements, the soil temperature (3 cm depth) was continuous recorded using a specific soil temperature sensor (STP-1, PP System), attached to the EGM-4 device. Also, a device that uses the time-domain reflectometry technique (TDR 300, Sensotech, USA) was used to measure soil moisture by determining the volumetric water content at a soil depth of 20 cm. Furthermore, we performed two different measurements of SWC around each collar and recorded the average value (data not shown).

2.4. Determining two groups of soil microorganisms

The harvested soil samples were treated with decimal dilutions. The plate count method was used to evaluate the total number of heterotrophic bacteria as well as the total number of fungi. To determine the aerobic bacteria we used the Plate Count Agar (7.5 pH). The plate were incubated three days at 37^0C (Atlas, 2004). For total number of fungi was used the Sabouraud Agar with 0.5% chloramphenicol (5.4 Ph). The plate were incubated 4-5 days at 25^0C. (Dehghan et al., 2014). The colonies were counted with the POL EKO LKB2002 colony counter. To obtain the number of colony-forming units (C.F.U.) per gram of soil the number of colonies were multiplied with the dilution factor (10^9 for aerobic bacteria and 10^4 for fungi) (Bölter et al., 2002).

2.5. Statistical analyses

A classic univariate ANOVA analysis (one-way ANOVA, N = 3, P = 0.05) was used to determine the differences between the parameters values measured in each experimental area. This analysis tests a single variable (quantitative parameter) to perform a multiple comparison of the samples (post hoc Tukey test). The data was processed with the GraphPad Prism software tool, version 5.00 (GraphPad Software, San Diego). Based on this statistical method can be highlighted the influence of the abiotic stress factor on the soil properties variation. The correlations between the various parameters measured in this study were obtained by calculating the Pearson coefficient using the same software. Values are expressed as mean ± standard deviation. The average multiple comparisons were achieved with a three-way ANOVA (P = 0.05) followed by Tukey's post hoc test (P = 0.05).

3. Results

3.1. Chemical properties of forest soils from areas affected by windthrows

The centralized data obtained for all chemical analyses are rendered in Table 2.

The soil's pH was higher in areas affected by windthrows (probably due to the appearance of herbaceous flora, replacing the more acidic specific stand litter), while the humus quantity was smaller in windthrow areas (a logical result identified in the literature). The total nitrogen quantity follows the same decreasing trend in the areas affected by windthrows (due to the disappearance of the humus layer), while the total cationic exchange capacity (T) and the base saturation degree (V) is higher in windthrow areas (in correlation with the pH increase). These trends were observed regardless of the stand's nature.

3.2. Influence of windthrows on soil respiration and soil environmental conditions

Soil CO_2 emission rates varied greatly with each time period's microclimatic conditions, including soil temperature (Ts) and soil moisture

(SWC), as well as with the state of the surfaces affected by windthrows, which could be perturbed (P) or control (C) (Figs. 2–4). The values were determined for tree forest species (Norway spruce, beech, and sessile oak) and for four time periods, both for the surfaces affected by windthrows (perturbed) as well as for the unaffected ones (control) (Fig. 2). The Norway spruce sample surfaces (Fig. 2) reveal that the soil temperature at a depth of 3 cm has varied from 3.66°C (±0.46) in April (C) to 15.20°C (±1.16) in August (C). In addition, the soil moisture was lowest in August (C), at 10.50 (±3.96)%, in comparison with June (P), when the highest value was recorded, 26.84 (±4.19)%. The highest CO_2 emission rates were recorded in August, being 4.05 (±1.30) µmol m^{-2} s^{-1}, and also were insignificantly different between plots (control and perturbation area). The minimum value for Rs was observed in the affected area (C), in April, namely 1.28 (±0.67) µmol.m^{-2} s^{-1}.

In the experimental common beech site (Fig. 3), the lowest soil temperature, 8.94 (±0.31) °C, was recorded in April (P), while the highest value, 18.76 (±0.53) °C, was observed in August (C), though the differences recorded for this date were insignificant between plots. Soil moisture was lowest in August (C), at 6.42 (±1.37)%, and highest in June (P), at 31.67 (±9.42)%. This value can be compared with the value recorded in the control surface in April, 30.63 (±5.06) %. Soil CO_2 emissions were highest in June (C), at 4.09 (±2.64) µmol m^{-2} s^{-1}, and lowest in April, at 1.60 (±0.42) µmol m^{-2} s^{-1}.

As for the sessile oak surfaces (Fig. 4), the lowest soil temperature values occurred during April, 10.42 (±0.23)°C and October, 10.80 (±0.23)°C, for the same type of surface (C). As expected, the highest soil temperature, 23.78 (±2.17)°C, was recorded in August for the surface affected by windthrows (P). The minimum soil moisture value, 9.25 (±2.27)%, was measured in the control surface (C) in August, while the maximum value, 36.01 (±3.49) %, was recorded in April in the affected surface (P). This value is similar to the values recorded for the same time period in the perturbed surface (P), namely 36.99 (±8.73)%. Insignificant differences between surfaces (P, C) were recorded for Rs during April, with minimum values of 1.97 (±0.57) µmol m^{-2} s^{-1} (C), and 1.99 (±1.36) µmol m^{-2} s^{-1} (P). Furthermore, the maximum Rs value, 3.57 (±1.11) µmol m^{-2} s^{-1}, was recorded in June (C).

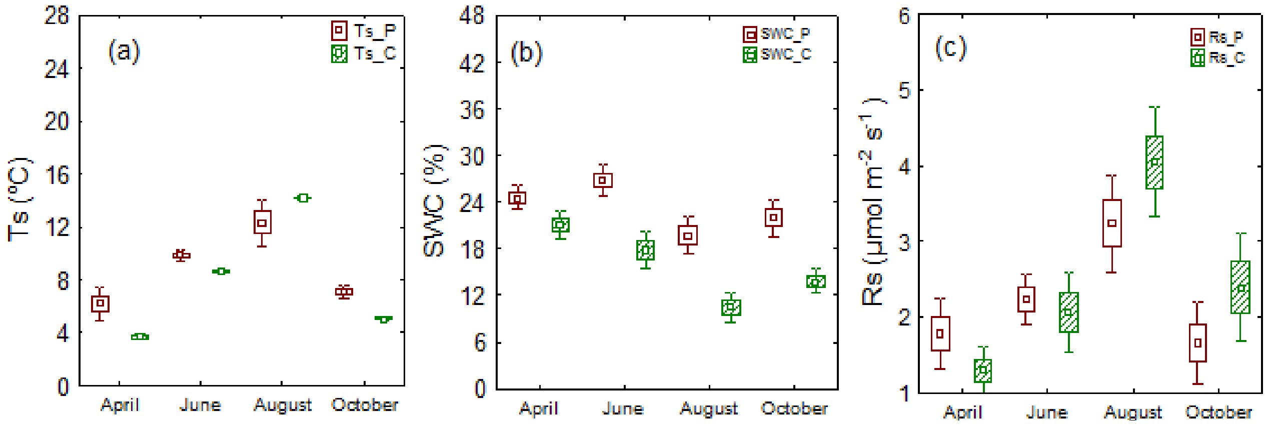


Fig. 2. Seasonal evolution of the soil temperature (a), soil moisture (b) and soil respiration (c) The box-plots represent the means, standard errors and coefficient of variation from each period of the year (April, June, August, October) for each plots (perturbation -P and control - C) in Spruce site

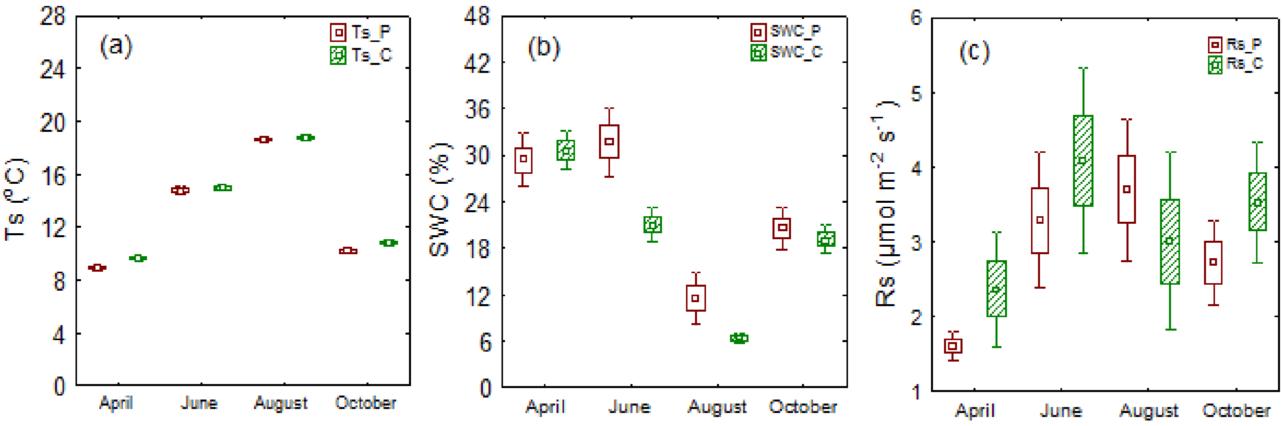


Fig. 3. Seasonal evolution of the soil temperature (a), soil moisture (b) and soil respiration (c).The box-plots represent the means, standard errors and coefficient of variation from each period of the year (April, June, August, October) for each plots (perturbation -P and control - C) in Beech site

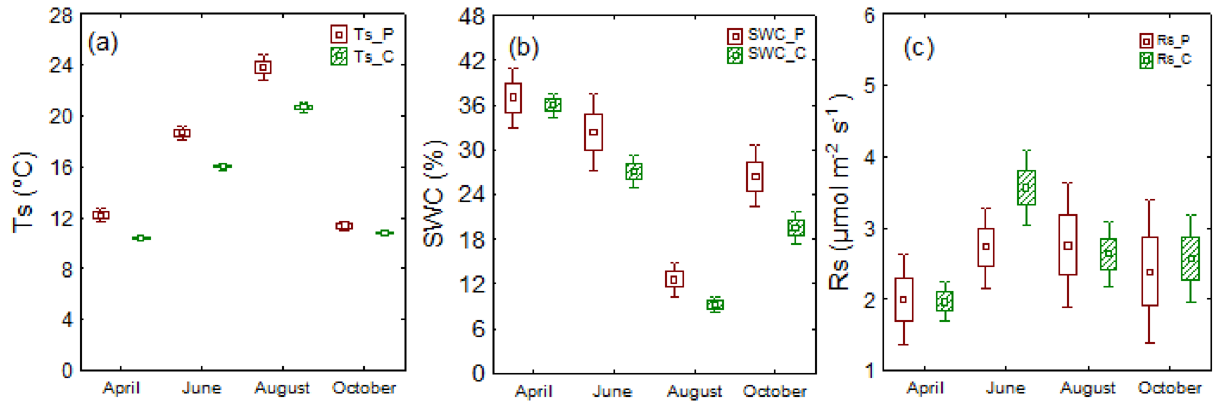


Fig. 4. Seasonal evolution of the soil temperature (a), soil moisture (b) and soil respiration (c).The box-plots represent the means, standard errors and coefficient of variation from each period of the year (April, June, August, October) for each plots (perturbation -P and control - C) in Sessile oak site

Table 2. Analytical soil properties data for all experimental sites

Nr. crt.	*Site*	*Plot*	*pH*	*Humus (%)*	*Total nitrogen (%)*	*T (me %)*	*V (%)*
1	Norway spruce	Windthrows (Wd)	4.681	10.782	0.553	23.106	41.746
2		Control (Ctrl)	4.394	13.303	0.682	21.138	32.214
3	Beech	Windthrows (Wd)	4.959	2.974	0.153	16.543	59.612
4		Control (Ctrl)	4.735	3.114	0.16	15.960	48.682
5	Sesille oak	Windthrows (Wd)	5.003	2.897	0.149	16.338	61.406
6		Control (Ctrl)	4.732	2.915	0.149	16.146	55.980

3.3. Influence of windthrows on the abundance of aerobe heterotroph bacteria and fungi from forest soils

Tables 3-6 present the observed biological parameters of the soil samples in the form of average ± standard deviation. Statistically significant differences in the abundance of aerobic heterotroph bacteria were observed between locations. Abundance values were significantly higher in the Mihăeşti area than in the Rucar area (Table 3). We compared all microorganism abundance values obtained for both windthrow-affected and non-affected areas across all three stands to emphasise the variation of microorganisms in forest soils. Statistically significant differences were observed between the abundance of aerobic heterotroph bacteria in the three tree species. The bacteria were more abundant in soils from common beech and sessile oak stands than in soils from Norway spruce stands (Table 4).

Fungi were more abundant in the controlled soil variants that were not affected by windthrows than in the soil variants that were affected by windthrows, demonstrating significantly higher values in surfaces not affected by windthrows (Table 5). The microbiological parameter values determined in the control variants were compared with the values for the windthrow variants within the same tree species and in the same location. Fungi abundance in the sessile oak forest from the Mihăeşti area was affected by windthrows, as significant lower values were recorded in comparison with the control surface. In the soils from the common beech and Norway spruce forests, the total number of fungi did not vary significantly (Table 6). Fig. 5 emphasises the differences between the average values of the monitored microbiological parameters in the control soil variants and the variants affected by windthrows, based on the studied areas and the main tree species. In the Mihăeşti area, sessile oak soil affected by windthrows had a significantly lower total number of fungi than control areas (Fig. 5), with an average value 93.24% lower than the average value in the control area. Aerobic heterotrophic bacteria were also less abundant, with an average value 59.13% less than the control variant, but the difference was statistically insignificant.

The situation is different, however, for the common beech forest in the Mihăeşti area. Here, the microorganisms were more abundant in the surface affected by windthrows, though the difference is statistically insignificant. In this case, the total number of aerobic bacteria was 266.67% higher than the control surface, while the total number of fungi was 71.27% higher. In the Ivan Valley (Rucar site), the variations were insignificant in the Norway spruce forest, with aerobic bacteria values 124.90% higher in the variant affected by windthrows in comparison with the control variant, while the total number of fungi was 82.86% lower than the control variant.

4. Discussions

4.1. Chemical characteristics of the studied forest soils from areas were they took place the windthrows

Taking into account the data from the two depth categories, it is clear that in the soil profile 0-10 cm the same dynamics of the chemical indicators was registered.

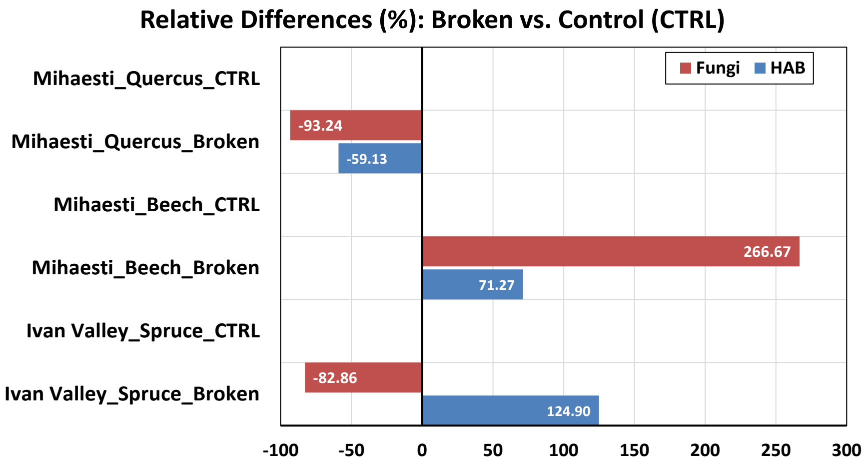


Fig. 5. Heterotrophic aerobic bacteria and fungi comparison between the soil variants affected by windthrows and control variant based on the interaction factor Location*Species*Status

Table 3. Results of the heterotrophic aerobic bacteria and fungi soil properties for the Location factor

Factor: Location	*Heterotrophic aerobic bacteria (HAB) (UFC/g sol)*	*Fungi (UFC/g sol)*
Rucar (N=6)	1.527E+11b ±9.515E+10	8.200E+05a ±7.255E+05
Mihaesti (N=12)	4.383E+11a ±2.153E+11	1.454E+06a ±1.847E+06

Note: In each column are different letters which shows the differences between the averages (Tukey's post hoc test (P = 0.05)). Values are expressed as mean ± standard deviation. N represents the samples number

Table 4. Results of the heterotrophic bacteria and fungi soil properties for the Species factor

Factor: Species	*Heterotrophic aerobic bacteria (HAB) (UFC/g sol)*	*Fungi (UFC/g sol)*
Beech	4.485E+11a ±2.276E+11	9.333E+05a ±1.511E+06
Sessile Oak	4.280E+11a ±2.234E+11	1.975E+06a ±2.137E+06
Spruce	1.527E+11b ±9.515E+10	8.200E+05a ±7.255E+05

Note: In each column are different letters which shows the differences between the averages (Tukey's post hoc test (P = 0.05)). Values are expressed as mean ± standard deviation

Table 5. Results of the heterotrophic aerobic bacteria and fungi soil properties for the Status factor

Factor: Status	*Heterotrophic aerobic bacteria (HAB) (UFC/g sol)*	*Fungi (UFC/g sol)*
Control	3.441E+11a ±2.348E+11	1.833E+06a ±1.686E+06
Windthrow	3.420E+11a ±2.347E+11	6.522E+05b ±1.261E+06

Note: In each column are different letters which shows the differences between the averages (Tukey's post hoc test (P = 0.05)). Values are expressed as mean ± standard deviation

Table 6. Results of the heterotrophic aerobic bacteria and fungi soil properties for the Species*Status interaction factor

*Factor: Species*Status*	*Heterotrophic aerobic bacteria (HAB) (UFC/g sol)*	*Fungi (UFC/g sol)*
Beech*Windthrow	5.663E+11ab ±2.890E+11	5.663E+11ab ±2.890E+11
Beech*Control	3.307E+11b ±6.638E+10	3.307E+11b ±6.638E+10
Sessile Oak* Windthrow	2.483E+11b ±1.020E+11	2.483E+11b ±1.020E+11
Sessile Oak* Control	6.077E+11a ±1.323E+11	6.077E+11a ±1.323E+11
Spruce* Windthrow	2.113E+11b ±1.100E+11	2.113E+11b ±1.100E+11
Spruce* Control	9.397E+10ab ±1.404E+10	9.397E+10ab ±1.404E+10

Note: In each column are different letters which shows the differences between the averages (Tukey's post hoc test (P = 0.05)). Values are expressed as mean ± standard deviation

For areas affected by windthrows, these changes include an increase in pH, an increase in the base saturation degree and total cationic exchange capacity, and a decrease of humus and total nitrogen quantities. However, differences between the quantities of humus and total nitrogen appear at higher depths for both areas affected and not affected by windthrows. In some cases, these quantities can even disappear (common beech and sessile oak stands). Windthrows change the amount of the humus and total nitrogen only in the 0-10 cm of the soil's profile for broad-leaved species, while these properties are also affected at depths of up to 20 cm for resinous species (Fig. 6). In another study about other soil disturbance – fire, the results show that the values of soil pH are bigger in the areas affected by this disturbance and the humus content is smaller (Oneț et al., 2019b).

Fig. 6. Area affected by windthrows in a *Picea abies* stand

4.2. Respiration of forest soils from areas affected by windthrows

This study's results show that the level of CO_2 soil emissions is higher in disturbed surfaces, with the exception of June (common beech) and August (Norway spruce and sessile oak). Others studies (Orchard and Cook, 1983; Köster et al., 2011; Mayer et al., 2014) corroborate the observation that Rs rates recorded in a Norway spruce forest were higher in areas partially or completely affected by windthrows or in plots where the wood was entirely harvested after the phenomenon, in comparison with the unaffected (control plot) surfaces.

Furthermore, the variability of CO_2 soil fluxes was mainly affected by microclimatic factors (Ts, SWC). Soil temperature was the main parameter that explains the differences recorded between the analysed surfaces. This fact is confirmed by a study (Amiro et al., 2010) that demonstrates the importance of soil temperature in explaining the windthrow impact on Rs. As we expected, the lowest level of soil moisture was recorded in August, based on the increase in soil temperature, in Norway spruce and sessile oak forests Reduced CO_2 soil emissions were observed in the disturbed surface (P), compared with the control surface (C), even though the situation was different for the common beech forest (Rs was higher in the P surface in comparison with the C surface). Indirectly, the lower humus and nitrogen content observed in the P surfaces (Table 2) can explain subsequent changes in the quantitative and qualitative distribution of heterotrophic populations from the experimental sites, likely to spatiotemporally change the CO_2 soil production.

This possibility is reflected in the present study through the majority presence of moulds in control surfaces, in comparison with the surfaces affected by windthrows. Undoubtedly, differences in the level of decomposition in the superior soil layer can explain these tendencies concerning the CO_2 soil production from the C and P surfaces. The wood debris from the soil originating from trees affected by windthrows can contribute to the enrichment of the soil's organic matter, with possible short-term and long-term effects on soil carbon effluxes (Amiro et al., 2010; Deyn et al., 2011; Jones et al., 2009; Yuste et al., 2005).

4.3. The influence of windthrows on aerobic heterotroph bacteria and fungi from forest soils

In Slovakia, Gömöryová et al. (2011) observed the changes caused by windthrows in forest soils from the Tatra Mountains (Velka Lomnica calamity from November 2004) by analysing their physio-chemical and biological properties over time (2006–present). Their results showed a gradual recursion of microbial communities in the surfaces affected by windthrows.

Regarding the abundance of microorganisms from soils affected by windthrows, this study has emphasised that aerobic heterotroph bacteria vary based on the studied area. For example, mesophilic bacteria were more abundant in soils from common beech and sessile oak forests than in Norway spruce soils. Comparing the control areas from both locations with the areas affected by windthrows reveals that fungi are more abundant in the control surfaces than in surfaces affected by windthrows. The dominant tree species and the stress factor represented by windthrows influenced the abundance of fungi, as significantly lower fungi values were recorded in the sessile oak soils affected by windthrows in Mihăești than in the control plot. Microorganisms did not vary significantly in the soils from common beech and Norway spruce soils.

5. Conclusions

Abiotic factors and windthrows may lead to the alteration of the physical, chemical, and biological properties of forest soils.

Soils' pH is higher in areas affected by windthrows. The total quantity of humus and nitrogen is smaller in windthrow areas, while the total cationic exchange capacity and the base saturation degree are higher. In this study of how various stands are affected by windthrows, the first 10 cm of the soil showed the same variation in the soil's chemical properties for all stand categories. On the other hand, these differences do not occur anymore at higher depths in broad-leaved stands. The stand's nature does not influence the variation of the chemical properties of soils affected by windthrows.

It was observed that microclimatic soil factors (Ts and SWC) influence the production of CO_2 from the soil, as higher CO_2 production values were observed in the surfaces affected by windthrows. The highest CO_2 fluxes in a given season were observed in the common beech stand. Furthermore, the correlation between SWC and Rs was higher for the Norway spruce stand. For the other sites (common beech and sessile oak), the rate of CO_2 emissions was significantly correlated with the temperature only for perturbed areas. This is likely explained by these sites' low elevation and consequent higher mean temperature compared to the spruce site's higher elevation.

Acknowledgments
This work was implemented by the National Institute of Research and Development in Forestry „Marin Dracea", project number 19070506 „Modelling the action of some extreme climatic factors upon forest ecosystems", within the BIOSERV programmed financed by the Romanian Ministry of Education and Research. The research was possible by equal scientific involvement of all authors.

References

Amiro B.D., Barr A.G., Barr J.G., Black T.A., Bracho R., Brown M., Xiao J., (2010), Ecosystem carbon dioxide fluxes after disturbance in forests of North America, *Journal of Geophysical Research: Biogeosciences*, **115**, 1-13.

Atlas R.M., (2004), *Handbook of Microbiological Media*, 3rd Edition, CRC Press, New York.

Bölter M., Bloem J., Meiners K., Möller R., (2002), Enumeration and biovolume determination of microbial cells – a methodological review and recommendations for applications in ecological research, *Biology and Fertility of Soils*, **36**, 249-259.

Buchmann N., (2000), Biotic and abiotic factors controlling soil respiration rates in Picea abies stands, *Soil Biology and Biochemistry*, **32**, 1625-1635.

Clinton B., Baker C., (2000), Catastrophic windthrow in the southern Appalachians: characteristics of pits and mounds an initial vegetation response, *Forest Ecology and Management*, **126**, 51-60.

Cools N., De Vos B., (2010), *Manual on Methods and Criteria for Harmonized Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests*, Part X, ICP Forests, Belgium.

Dehghan P., Kharazi M., Rafiei H., Akbari M., Paria G.R., (2014), Enumeration and identification of dust fungal elements from the weather inversion phenomenon in Isfahan, Iran, *Advence Biomedical Research*, **3**, 1-5.

Deyn G.B., Quirk H., Oakley S., Ostle N., Bardgett R.D., (2011), Rapid transfer of photosynthetic carbon through the plant-soil system in differently managed species-rich grasslands, *Biogeosciences*, **8**, 1131-1139.

Dincă L., Sparchez G., Dincă M., (2014), Romanian's forest soil GIS map and database and their ecological implications, *Carpathian Journal of Earth and Environmental Sciences*, **9**, 133-142.

Dincă L., Dincă M., Vasile D., Spârchez G., Holonec L., (2015), Calculating organic carbon stock from forest soils, *Notulae Botanicae Horti Agrobotanici*, **43**, 568-575.

Gafrikova J., Hanajic P., (2016), Soil respiration, microbial abundance, organic matter and C,H,N,S contents among recovering windthrow sites in Tatra National Park, *Phytopedon (Bratislava)*, **14**, 7-14.

Gömöryová E., Strelcová K., Fleischer P., Gömöry D., (2011), Soil microbial characteristics at the monitoring plots on windthrow areas of the Tatra National Park (Slovakia): their assessment as environmental indicators, *Environmental Monitoring and Assessment*, **174**, 31-45.

Gömöryová E., Fleischer P., Pichler V., Homolak M., Gere R., Gömöry D., (2017), Soil microorganisms at the windthrow plots: the effect of post-disturbance management and the time since disturbance, *iForest-Biogeosciences and Forestry*, **10**, 515-521.

Jones D.L., Nguyen C., Finlay R.D., (2009), Carbon flow in the rhizosphere: carbon trading at the soil–root interface, *Plant and Soil*, **321**, 5-33.

Kooch Y., Haghverdi K., (2014), Earthworms-good indicators for forest disturbance, *Journal of Bioscience and Biotechnology*, **1**, 155-162.

Köster K., Püttsepp Ü., Pumpanen J., (2011), Comparison of soil CO_2 flux between uncleared and cleared windthrow areas in Estonia and Latvia, *Forest Ecology and Management*, **262**, 65-70.

Kwit C., Platt W.J., (2003), Disturbance history influences regeneration of non-pioneer understory trees, *Ecology*, **84**, 2575-2581.

Lenart M.T., Falk D.A., Scatena F.N., Osterkamp W.R., (2010), Estimating soil turnover rate from tree uprooting during hurricanes in Puerto Rico, *Forest Ecology and Management*, **259**, 1076-1084.

Manzoni S., Schimel J., Porporato A., (2012), Responses of soil microbial communities to water stress: results from a meta-analysis, *Ecology*, **93**, 930-938.

Mayer M., Matthews B., Schindlbacher A., Katzensteiner K., (2014), Soil CO_2 efflux from mountainous windthrow areas: dynamics over 12 years post-disturbance, *Biogeosciences*, **11**, 6081-6093.

Mayer M., Matthews B., Göransson H., Rewald B., Katzensteiner K., Godbold D., (2015), *Exploring the drivers of post-disturbance soil CO_2 efflux in the Austrian Alps*, Belowground biodiversity in changing environment Proc. of the 2nd Annual Meeting, COST Action FP1305 BioLink Linking belowground biodiversity and ecosystem function in European forests, Krakow.

Mayer M., Sanden H., Rewald B., Godbold L.D., Katzensteiner K., (2016), Increase in heterotrophic soil respiration by temperature drives decline in soil organic carbon stocks after forest windthrow in a mountainous ecosystem, *Functional Ecology*, **31**, 1163-1172.

Mitchell P., (1988), *The influence of Vegetation, Animals and Micro-Organisms on Soil Processes*, In: *Biogeomorphology*, Viles H. (Ed.), Basil Blackwell Ltd Press, Oxford, UK, 43-82.

Moore G.M., (2014), *Wind-Thrown Trees: Storms or Management?*, *Arboriculture & Urban Forestry*, **40**, 53-69.

Moyano F., Manzoni S., Chenu C., (2013), Responses of soil heterotrophic respiration to moisture availability: an exploration of processes and models, *Soil Biology and Biochemistry*, **59**, 72-85.

Oneț A., Dincă L.C., Grenni P., Laslo V., Teusdea A.C., Vasile D.L., Enescu R.E., Crisan V.E., (2019a), Biological indicators for evaluating soil quality improvement in a soil degraded by erosion processes, *Journal of Soils and Sediments*, **19**, 2393-2404.

Oneț A., Dincă L., Teusdea A., Crisan V., Braga C., Enescu R., Oneț C., (2019b), The influence of fires on the biological activityof forest soils in Vrancea, Romania, *Environmental Engineering and Management Journal*, **18**, 2643-2654.

Orchard V.A., Cook F.J., (1983), Relationship between soil respiration and soil moisture, *Soil Biology and Biochemistry*, **15**, 447-453.

Pumpanen J., Longdoz B., Kutsch W.L., (2010), Field measurements of soil respiration: principles and constraints, potentials and limitations of different methods, *Soil Carbon Dynamics: An Integrated Methodology*, 16-33, https://doi.org/10.1017/CBO9780511711794.003.

Samonil P., Kral K., Hort L., (2010), The role of tree uprooting in soil formation. A critical literature review, *Geoderma*, **157**, 65-79.

Schimel J., Balser T., Wallenstein M., (2007), Microbial stress-response physiology and its implications for ecosystem function, *Ecology*, **88**, 1386-1394.

Schjønning P., Thomsen I., Moldrup P., Christensen B., (2003), Linking soil microbial activity to water-and air-phase contents and diffusivities, *Soil Science Society of America Journal*, **67**, 156-165.

Simon A., Gratzer G., Sieghardt M., (2011), The influence of windthrow microsites on tree regeneration and establishment in an old growth mountain forest, *Forest Ecology and Management*, **262**, 1289-1297.

Spârchez G., Târziu D.R., Dincă L., (2013), *Pedology with Elements of Geology and Geomorphology* (in Romanian), Transylvania University of Brasov Publishing House, Brasov, Romania.

Spârchez G., Dincă L., Marin G., Dincă M., Enescu R.E., (2017), Variation of eutric cambisols' chemical properties based on altitudinal and geomorphological zoning, *Environmental Engineering and Management Journal*, **16**, 2911-2918.

Stark J., Firestone M.K., (1995), Mechanisms for soil moisture effects on activity of nitrifying bacteria, *Applied and Environmental Microbiology*, **61**, 218-221.

Târziu D.R., Spârchez G., Dincă L., (2004), *Pedology with Elements of Geology* (in Romanian), Silvodel Publishing House, Brasov, Romania.

Ulanova N.G., (2000), The effects of windthrow on forests at different spatial scales: a review, *Forest Ecology and Management*, **135**, 155-167.

Vorovencii I., (2014), Detection of environmental changes due to windthrows using Landsat 7 ETM+ satellite images, *Environmental Engineering and Management Journal*, **13**, 565-576.

Wardle D.A., Ghani A., (1995), Why is the strength of relationships between pairs of methods for estimating soil microbial biomass often so variable, *Soil Biology and Biochemistry*, **27**, 821-828.

Yuste J.C., Janssens I. A., Ceulemans R., (2005), Calibration and validation of an empirical approach to model soil CO_2 efflux in a deciduous forest, *Biogeochemistry*, **73**, 209-230.

Zarnesti, (2020), About the city, On line at: www.zarnesti.net.