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Identification and Comparison of Key Parameters of Forest Litter and their Effect on Fire Initiation and Spreading

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Short Report

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Abstract

From the point of view of future prognosing the periods with higher danger of fire initiation and identification of potentially fire dangerous areas, it is important to know the key parameters of fuel which have a significant impact on fire initiation. The main aim of the paper is identification and comparison of parameters of litter of selected tree species which have a significant impact on fire initiation, propagation and further spreading. The most significant key parameter in identification of forest fire danger the fine fuel moisture content. The object of the study represents the biomes of boreal conifer forests and deciduous forests. The result of the study indicates that higher litter moisture content significantly reduces fire initiation potential, intensity and subsequent fire spreading. Pine litter, due to small measures of needles, produces well-rammed and non-aerated litter. This litter can accumulate more than double the volume of water in comparison with deciduous litter. Consequently, in conditions with high humidity, it is very difficult to catch a fire. Deciduous trees produce aerated litter (containing an oxidation element), which can accumulate less water, it dries off better, and for that reason, in conditions with higher humidity the deciduous tree litter catches fires easier. In case of dried fuels, the amounts of initiatory energy required for setting coniferous and deciduous vegetation on fire do not differ significantly. Hard dried oak litter is the highest fire danger, and it is the easiest to catch fire. Pine litter is characterized, due to the high volume of resin and vaporizing substances, with much higher amounts of heat release rate, cumulative heat released, combustion heat and heating power, therefore it poses the highest danger from the point of view of fire intensity and fire spreading.

Keywords: climate change; fire danger; forest fire; fuel moisture; litter; forest fires.

1 Introduction

Climate change, as a change in the state of climate variables, has often been seen as a future threat, but it is currently one of the biggest environmental problems. The society strives not only to adapt to these changes, but especially to mitigate them. (Minďaš et al., 2011) Climate change poses a huge threat, stressful situations, and fear for the lives of people around the world. Many people face the significant impacts of climate change, such as storms, floods, global warming, extreme rain, and dry and extensive forest fires, which have caused considerable damage in recent years. (Hoştut et al., 2020) The number of such extreme weather events is currently growing in Slovakia as well. In our territory, those are mostly the floods, landslides, heat, prolonged droughts, and the growing risk of fires. (MINV, 2021) As climate change intensifies, the need to develop vulnerability assessments and adaptation strategies is becoming more urgent. Reliable and sound prognoses are essential for accurate risk assessment and the development of effective reactions and measures. (Marshal et al., 2019)

Due to global warming and rising average temperatures, the frequency and duration of periods of increased fire risk are expected to increase, and thus the number, extent and severity of fires will also increase. (Marchal et al., 2019) Particularly high temperatures and recurring droughts over the last decade have led to severe periods of fire in forest ecosystems around the world, e.g., in Australia, Sweden, Chile, Greece, the USA and Canada. (Gaboriau et al., 2020) Fuel, weather and topography are the three factors that make up a forest fire environment and determine its behaviour. The initiating source itself is the fourth factor that reacts with others. (Santoni et al., 2020) Predicting the effects of future climate change on fire occurrence requires an understanding of the effects and interactions of temperature and precipitation on fuel moisture content dynamics. As the average temperature increases, fuels will be overdried, which will not only become more prone to ignition, but may also support more intensive fire spreading. (Flannigan et al., 2015) The moisture content of the fuel is thus a key parameter in determining the danger of forest fires.

Surface fires are among the most common fires in the natural environment, due to the availability, moisture content, and volume of fuel. Surface fires burn on the surface and consume fuel as e.g., litter. (Heward, 2019) Litter is a mixture of undecomposed and partially decomposed materials, on ground fallen material such as leaves, needles, and branches. They create forest bed, which strongly influences the ignition and spread of fire. (Burton et al., 2020) Tree species composition of a stand has a significant effect on litter composition. The physical properties, chemical properties, size, and shape of the particles significantly affect the dynamics in moisture content of the litter and its flammability. The properties of deciduous and coniferous forests litter differ from each other. (Cornwell et al., 2015)

From the point of view of the future predictions of periods with an increased danger of fires and the identification of position of possible fires, it is important to know the key fuel parameters that affect the fire behaviour. The main goal of this study was the identification and comparison of the parameters of selected tree species litter, which have a significant impact on the fire behaviour, especially on its initiation, propagation and further spreading.

The aim of the study was the identification and description of key parameters of pine, oak and beech litter and their impact on the initiation and propagation of a fire. Individual types of forest litter were also mutually compared.

The object of the study was biomes of boreal coniferous forest stands and deciduous broad-leaved forest stands occurring in these biomes and litter of the tree species existing on the composition of those forests. Among those tree species belonged: Masson's pine (*Pinus massoniana*), Scotch pine (Pinus sylvestris) and longleaf pine (*Pinus palustris*) as representatives of coniferous stands, and European oak (*Quercus robur*), sessile oak (*Quercus sessilis*), iron oak (*Quercus stellata*), sawtooth oak (*Quercus acutissima*) and European beech (*Fagus sylvatica*), as representatives of deciduous stands.

2 Material and Methods

To achieve the goal of the study, we used several scientific methods, namely analysis, synthesis, and summarization of knowledge as well as the method of comparing.

After finding the appropriate literature sources, we performed its detailed analysis to determine its contribution to our study. Subsequently, we selected an essential information from the literature and data that were suitable for achieving the goal of our study.

After analysing the scientific literature, we combined selected information from several and summarized it. Using synthesis, we combined information and data of individual authors and their views on the issues addressed.

In the results, we summarized the data and key parameters of the litter of individual trees species, which created the subject of the study.

We compared the key parameters of the litter of individual tree species and derived basic differences between them.

3 Results and Discussion

Fuel moisture content is an important and driving factor that determines the behaviour of a fire. Determining the water content that a fuel can accumulate expresses the moisture holding capacity. This capacity is mainly affected by the weight, dimensions, and composition of the fuel. The values of moisture holding capacities of the litter of individual types of forest stands differ from each other, but there is a significant difference in the values of the capacity between the litter of coniferous and deciduous trees. Fig 1. shows the values of the moisture holding capacity (l / m^2) of European beech, sessile oak, and sawtooth oak litter, as representatives of deciduous stands, and the moisture holding capacity of Masson's pine litter, as a representative of coniferous trees.

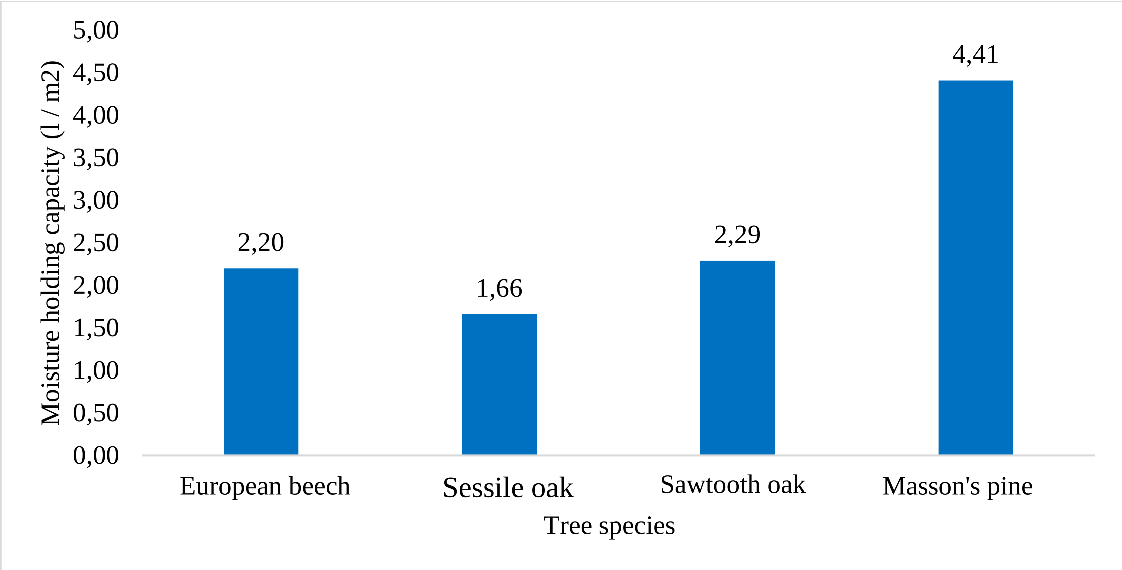

Fig 1. Moisture holding capacity values of different types of forest litter

The lowest value of moisture holding capacity (1.66 l / m^2) showed the litter of sessile oak. This was followed by a litter of European beech with moisture holding capacity of 2.20 l / m^2. The litter of sawtooth oak had a slightly higher value of the moisture holding capacity (2.29 l / m^2). In general, deciduous trees showed very similar values. There was a significant difference in the case of Masson's pine litter, which showed a value of litter moisture holding capacity of 4.41 l / m^2, which is more than twice the value of the deciduous trees.

The volume of water that the litter can accumulate has a significant effect on the initiation and at the same time on the subsequent spread of the fire. The more water the litter contains, the more difficult it is to ignite, because the initiating energy is first consumed to heat and evaporate the water, and then to heat the fuel to the ignition temperature and to form gaseous products. Thus, with a higher moisture content of the fuel, a higher initiation energy is required, and the risk of fire is significantly reduced. In the case of fires that have already occurred, the spread of the fire when a high-moisture content fuel is reached may be stopped if the fire does not have sufficient energy to dry out and subsequently initiate the moist fuel. Moisture content thus significantly dampens the initiation, intensity, and subsequent spread of fire. After rain, the fuel has sufficient moisture, and the risk of fire is almost zero.

Moisture holding capacity depends on weight. Due to the small particle size (the needle has significantly smaller dimensions compared to the leaves), the coniferous litter creates a well-compacted (higher weight per unit area) and a non-aerated litter, which retains moisture well. The litter of conifers, since it can accumulate more than twice the amount of water compared to deciduous litter, has a longer period after rain, when the fuel still has a high moisture content, which prevents fuel initiation and does not support the intensity of fire. Due to the moisture content, it requires a longer drying time under normal natural conditions, is difficult to ignite and does not support the spread of fire. Deciduous litter can in turn accumulate less water and creates a well-aerated litter that dries faster due to air access. Thus, after rain, the deciduous litter, due to the lower moisture content, dries under normal natural conditions, in a significantly shorter time, and thus the risk of fire increases faster, and the litter increases the intensity of the fire. Pine litter (representative of coniferous stands) therefore has a significantly lower risk of fire initiation and development in periods of higher air humidity. Oak and beech litter (representatives of deciduous stands) have a higher risk of fire initiation and development in periods with higher air humidity.

The values of the heat flux required for the ignition of the litter did not differ significantly when comparing the individual stands. Fig. 2 shows the ignition times (s) as a function of the magnitude of the thermal radiation (kW / m^2). A value of ignition time of 0 s in the Fig 2. means that the sample did not ignite.

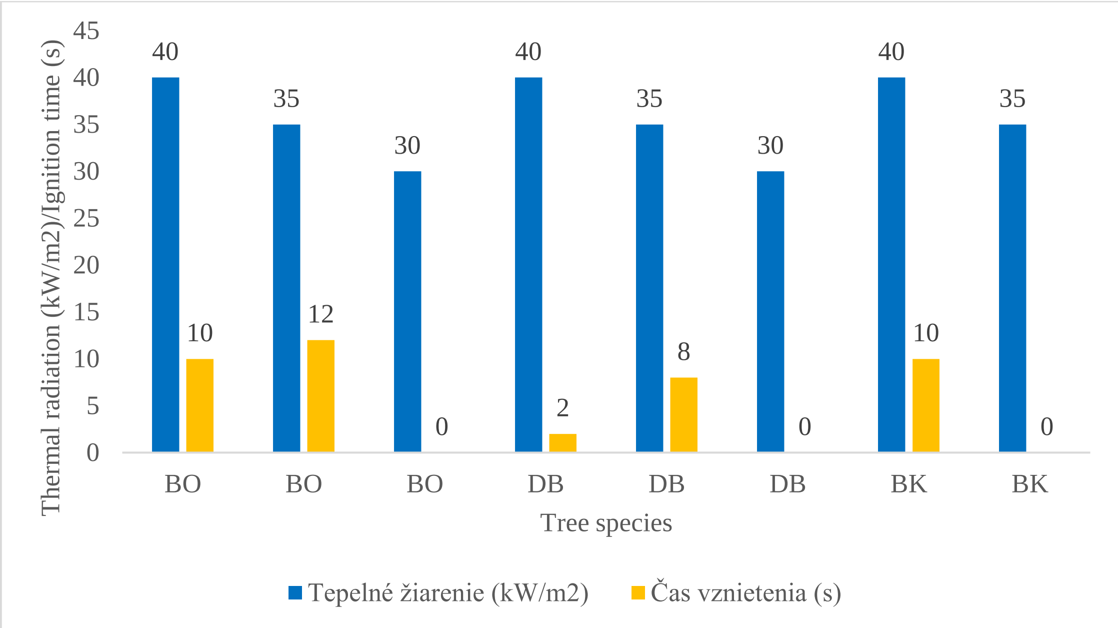

Fig 2. Ignition times of individual stands litter depending on the thermal radiation magnitude

The limit value of thermal radiation required for ignition of pine and oak litter is 35 kW / m^2. At a thermal radiation value of 30 kW / m^2, the litter of oak and pine did not ignite. The limit value of thermal radiation required for ignition of beech litter is slightly higher, namely 40 kW / m^2. At a thermal radiation value of 35 kW / m^2, the beech litter did not ignite. At a thermal radiation value of 40 kW / m^2, in the case of pine and beech litter, ignition occurred after 10 s, while in the case of oak litter, ignition occurred in a relatively very short time (2 s). Beech litter, therefore, required greater thermal radiation to ignite. The oak litter ignited in the shortest time again.

Thermal radiation is the energy needed to ignite a fuel. The ignition time depends on the magnitude of the thermal radiation. The greater the thermal radiation, the faster the ignition will occur. In the case of dry fuels (low moisture content - below the moisture limit value), the energy of the initiation source is used to heat the fuel to the ignition temperature and to form gaseous products. The thermal radiation limit value is the minimum value of the energy of the initiation source that is required to ignite the dried fuel. The fuel is moved to a moisture content below the moisture limit value in periods when the air temperature is elevated for a long time (heat, dry in spring and summer). In the case of overdried fuel, approximately the same ignition energy was required, regardless of the type of vegetation. The difference is in the times when the flame burned. Oak litter is composed of leaves that are large. This litter is well aerated with a high content of air (oxidizing agent) and forms a flammable group (oxidizing agent + flammable substance). This affects the initiation and development of the fire. The oak litter ignited after only 2 s, which means that it has a high risk of fire and can be very easily ignited. On the contrary, in the case of beech and pine litter, ignition occurred after 10 s. Beech litter is formed by small leaves (significantly smaller dimensions compared to oak leaves), which create, compared to oak leaves, better compacted and non-aerated litter with lower air content. Pine litter has the smallest particles and creates a well-compacted and non-aerated litter. The litter of pine and beech was therefore more difficult to ignite. The ignition time therefore depends on the particle size.

Fig 3. shows the maximum and average values of the heat release rate, the values of the total heat released, and the ignition time of pine, oak and beech litter when ignited due to thermal radiation of 40 kW / m^2.

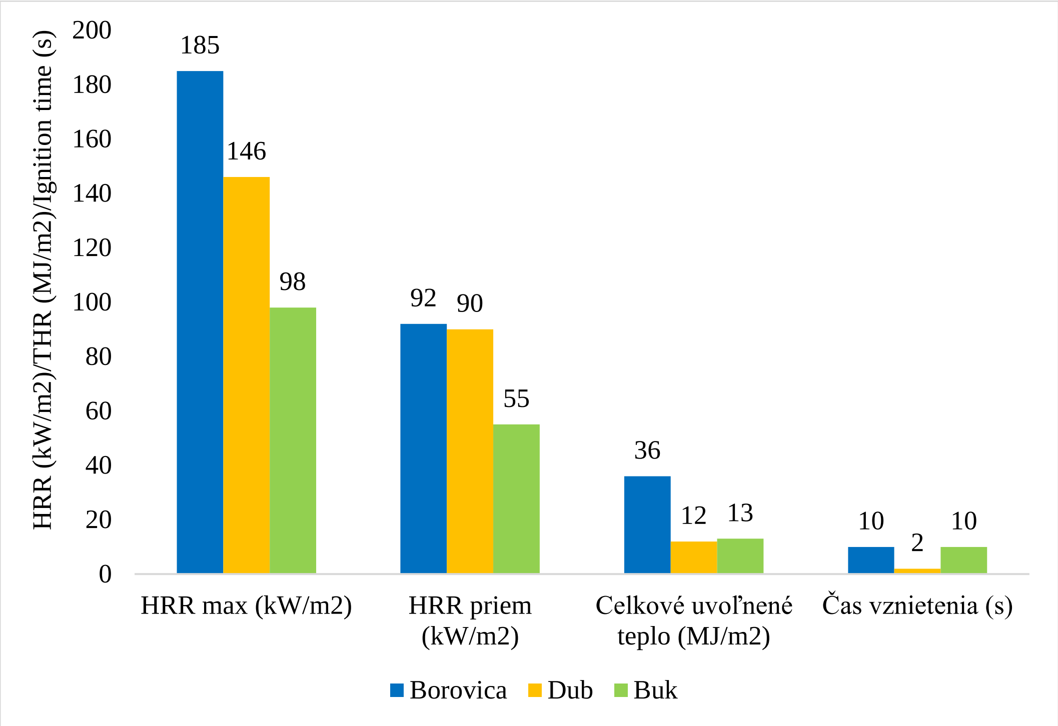

Fig 3. Maximum and average values of the heat release rate (HRR), total heat released (THR) and the ignition time of the litter, when ignition occurred due to thermal radiation of 40 kW / m^2

Pine litter showed significantly higher values of maximum heat release rate (HRR_{max}) and total heat released (*THR*). The HRR_{max} of pine litter reached 185 kW / m^2. This is followed by the HRR_{max} of oak litter (146 kW / m^2). The lowest value of HRR_{max} showed beech litter (98 kW / m^2). The average *HRR* values do not differ significantly by pine (92 kW / m^2) and oak (90 kW / m^2) litter. Lower average *HRR* values showed beech litter (55 kW / m^2). Significantly higher values of THR showed pine litter, up to 36 MJ / m^2, that is three times more than THR of oak litter (12 MJ / m^2) and almost three times more than the THR of beech litter. By pine and beech litter, ignition occurred after 10 s, while in the case of oak litter, ignition occurred in a relatively very short time (2 s).

Fig 4. shows the values of gross calorific value and net calorific value of oak and pine litter.

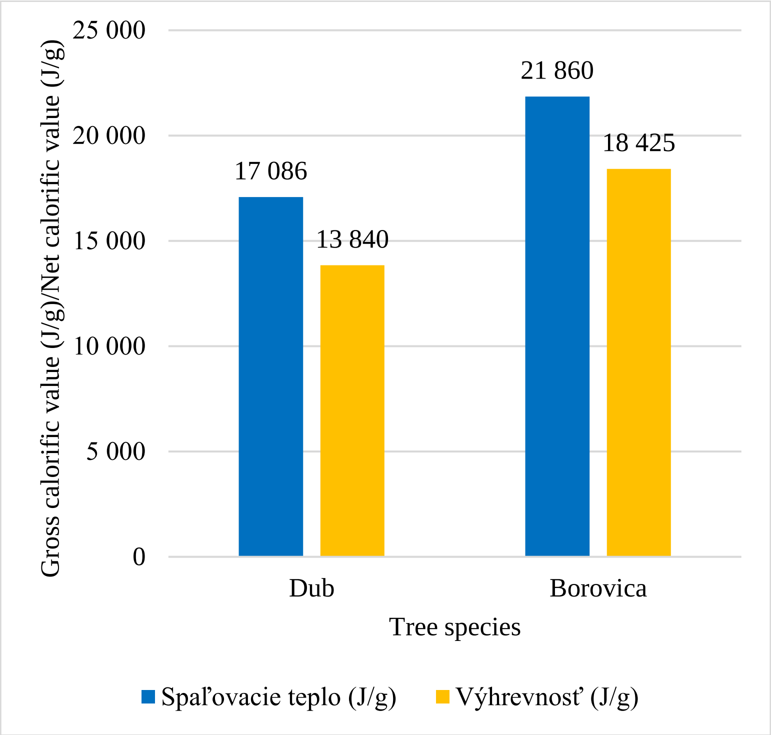

Fig 4. Oak and pine litter gross and net calorific values

The litter of pine had significantly higher values of gross and net calorific value.

Na Fig 5. shows the maximum flame heights and the litter flame burning time of beech, oak, and pine litter.

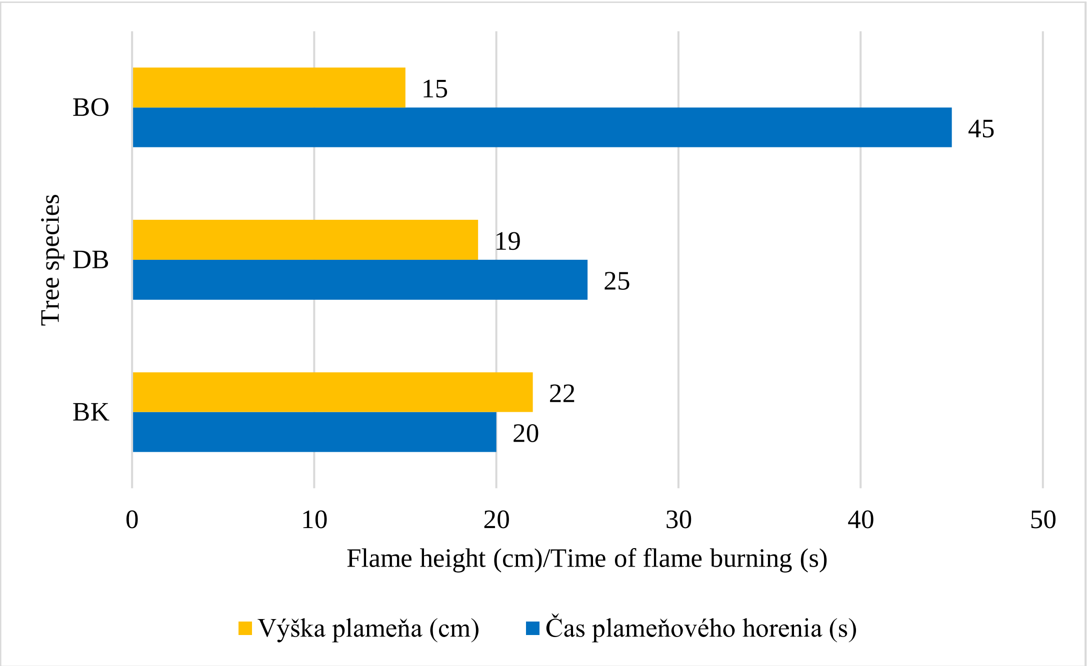

Fig 5. Maximum flame heights and the litter flame burning time

Beech litter showed the shortest time of flame burning (20 s). The oak litter showed the time of flame burning time of 25 s, about 5 s longer compared to the beech litter. Significantly, the longest time of flame burning was recorded by the litter of pine (45 s), the value of which is almost twice if the deciduous stands litter. The beech litter had the highest flame height (22 cm), but this height began to decline rapidly. The litter of the pine showed the lowest flame (15 cm). The litter of the oak had a flame height of 19 cm, but it was able to maintain this height for up to 5 s. The litter of the pine stand produced a consistent flame over time.

The heat release rate (HRR), total heat released (THR), gross and net calorific value have a significant effect on the intensity of fire spread. Pine litter (representative of a coniferous stand) contains many resins and volatile substances (terpenes), which release a large amount of heat during combustion, which further affects the intensity and spread of the fire. The HRR and the THR are expressed in kW / m^2, i.e., energy per unit area. Pine litter forms a well-compacted litter and has a high weight per unit area. Higher values of HRR and THR are caused by chemical composition (resins, volatiles) and higher weight, i.e., the volume of fuel. Gross and net calorific value are expressed in J / g, i.e., energy per unit of weight. By pine litter, higher values of gross and net calorific values are caused by the chemical composition (volatile resin). Pine litter also showed the longest time of flame burning (more than twice as much as deciduous litter), which is also due to the chemical composition. Pine litter therefore poses the greatest risk in terms of fire development and intensity. It creates a consistent flame for a long time with a large amount of heat released. This means that the fire increases in intensity very quickly, dries the surrounding fuels with higher moisture content due to radiant heat and spreads into surroundings.

In view of the ongoing climate change and the growing number of fires in the wildland, it is essential that the system for prognosing, detecting, monitoring, locating, and eliminating wildfires is constantly improved. In the following section, we present measures which application in practice could significantly contribute to improving the situation in the field of prevention of wildfires, as well as minimizing their impact, and thus to reduce the fire consequences.

Early fire detection is key pre-requisite to perform a quick and effective response. The first step should be to cover the areas with a high risk of fire with warning systems that can assess the fire danger and early detect the forming fire. These systems should be equipped with CCTV cameras installed in fire most susceptible areas in locations with good visibility. The recordings from the cameras should real time transmit the videorecords to the control centre, where the operator is sitting, and who is ready to evaluate the recordings optically. Early detection (GPS coordinates) will allow to immediately inform the Fire and Rescue Service operation centre, which will then send forces and resources to fight the wildfire. At the same time, relevant bodies, e.g., forest owners/users/managers are informed. This allows the firefighters to start the fire extinguishing activities in time, prevent its uncontrollable spread and reduce its negative consequences.

The next step should be the effort to prevent mostly the ground fires, which are most common due to the availability of fuel on the ground. The forest owners/users/managers should remove the residues after logging and regularly check the condition and thickness of deforestation at critical locations. When there is a large volume of the litter, they should ensure its removal, accumulation in a designated place, or its controlled burning. They should also remove dead wood and combustible debris.

4 Conclusions

Climate change is current environmental problems. The society is not only finding ways to adapt to these changes, but especially to mitigate them. Due to global warming and rising average annual temperatures, the frequency and duration of periods with higher fire risk are expected to increase, and thus the number, extent and severity of fires will also increase. As the average annual temperature increases, forest fuels will be overdried, which will not only become more prone to ignition, but may also support the fire when spreading. Ground fires belong among the most common fires in the wildland, due to availability, moisture content and volume of fuel.

From the point of view of the future prediction of periods with high risk of fires and the detection of fires, it is important to know the key fuel parameters that affect the fire behaviour. The aim of this study was to identify and compare the parameters of litter of selected tree species, which have a major impact on the forest fire behaviour, especially on its initiation, propagation and further spreading.

The results of the study point to the following important facts.

The more water the litter contains, the more difficult it is to ignite, because the initiating energy is first consumed to heat and evaporate the water, and only then to heat the fuel to the ignition temperature and to form gaseous products. Thus, with a higher moisture content of the fuel, a higher initiation energy is required, and the risk of fire is significantly reduced. In fires that have already occurred, the spread of the fire, in areas with a high-moisture content of fuel, is stopped if the fire does not have sufficient energy to dry out and subsequently initiate the moist fuel. Thus, fuel moisture content significantly dampens the initiation, intensity, and subsequent spread of fire.

Moisture holding capacity depends on weight. Coniferous litter is very difficult to ignite in high humidity conditions and it does not support the spread of fire. Deciduous trees litter is more easily ignited.

When studying overdried fuels, we found that the values of initiation energy required for ignition of coniferous and deciduous stands do not differ significantly. Dried oak litter showed that it should be very easily ignited and therefore was assigned to be of the highest fire danger. The litter of pine and beech was more difficult to ignite, due to the litter structure. Beech litter is formed by small leaves (significantly smaller dimensions compared to oak leaves), which create well-compacted and non-aerated litter, with lower air content. Pine litter is formed by the smallest particles and creates a well-compacted and non-aerated litter.

Pine litter showed also significantly higher values of heat release rate (HRR_{max} of 185 kW / m^2), total heat release (36 kW / m^2), gross (21,860 J / g) and net (18,425 J) calorific value, due to the high content of resins and volatile substances. Pine litter also showed the longest time flame burning (more than twice as much as deciduous litter). Pine litter therefore poses the greatest danger in terms of development and fire intensity.

We also proposed recommendations that could positively affect the future development of safety practices in terms of wildfire prevention and extinguishing.

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