BALTIC FORESTRY

http://www.balticforestry.mi.lt
ISSN 1392-1355
eISSN 2029-9230

Baltic Forestry 2021 27(2): 225–231
Category: research article
https://doi.org/10.46490/BF317

The influence of synthetic foaming agents on seed germination of coniferous species

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Rantuch, P., Remišová, K. and Rantuch, J. 2021. The influence of synthetic foaming agents on seed germination of coniferous species. *Baltic Forestry* 27(2): 225–231. https://doi.org/10.46490/BF317.

Received 5 November 2018 **Revised** 11 October 2021 **Accepted** 21 October 2021

Abstract

Water is the most frequently used substance for extinguishing of wildfires. Ones of the most commonly used additives enhancing the extinguishing efficiency are foaming agents. This article deals with the influence of foaming agents on germination of coniferous species. Foaming agents Moussol-APS F-15 and Sthamex F-15, foaming solutions of various concentrations were used for the tests. Germination of seeds of Norway spruce *(Picea abies)* and Scots pine *(Pinus sylvestris)* was observed. The percentage of germinating seeds was recorded every 7 days. The results were evaluated in the form of graphs.

When the concentration levels of foaming solutions ranged from 0.1 vol% to 0.25 vol%, their influence on germination of both coniferous species seeds varied from negligible to slightly positive. Subsequently, the negative effect increased considerably and with concentrations exceeding 1 vol%–1.5 vol% the germination of samples reached zero values. While foaming solutions of Sthamex F-15 showed less significant influence on germination of the Scots pine seeds, seeds of the Norway spruce were less influenced by foaming agent Moussol-APS F-15.

Based on obtained results it is possible to recommend minimisation of foaming agents amounts, eventually application of substances with less negative effect on plants germination for extinguishing of wildland fires, in order to gain restoration of affected area as fast as possible.

Keywords: foaming agent, germination, wildfire (wildland fire), foaming solution

Introduction

Ecologists and biogeographers generally assume that plant distribution, abundance and, therefore, community composition, structure and biomass are determined largely by climate and soils (Thomas et al. 2004). On the one hand, the higher densities of wildfires in Europe are mainly concentrated in the southern regions with the Mediterranean countries accounting for most of the fires reported. On the other hand, in some Central and Northern countries fires are also frequent (Catry et al. 2010).

Disturbance by wildland fire plays a prominent role in the ecology of pine ecosystems. Genus *Pinus* is typical by several features that enable them to survive low- to moderate-intensity fires: tissue insulation from lethal temperature provided by thick bark, large and protected buds, relatively thick needles, deep rooting habit, and a crown structure favourable to heat dissipation (Fernandes et al. 2008).

The Scots pine *(Pinus sylvestris)* is a widely distributed pine species (Oleksyninst et al. 2002) and one of the most widely distributed tree species on Earth with population spatially ranging from the Boreal to Mediterranean regions (Barbéro et al. 1998). Growing area of this tree species includes regions and sites of contrasting fertility and nutrient availability, so intraspecific differences in nutrient accumulation and conservation mechanisms may have evolved among diverse populations (Oleksyninst et al. 2002). This tree was classified by Agee (1998) in the moderate-severity fire regime, which is coherent with the wide geographical distribution and environmental variation under which the species can be found. Granström (2001) categorizes *P. sylvestris* trees as moderately fire resistant and able to survive several low-intensity fires. Angelstam and Kuuluvainen (2004) describe *P. sylvestris* forest in boreal Europe dry sites as being park-like and adapted to frequent low-intensity fire that results in multi-aged stands, and state that the species are more tolerant to fire as it ages, due to increased bark thickness and crown base height.

Norway spruce (*Picea abies*) also has a wide area of distribution. It ranges from the northern treeline from Norway and Siberia to the mountainous areas (and neighbouring lowlands) of the Balkans, see Koprowski et Zielski (2006), Thomas et al. (2004).

If we compare fire with other disturbances (e.g. cyclones or floods) they are significantly different. The reason is that fire feeds on complex organic molecules (as do herbivores) and converts them to organic and mineral products. Plants that are inedible for herbivores commonly fuel fires. (Bond et al. 2005). The effect of forest fires on ecosystems is indeed multifarious. In tropical forests, a single fire can reduce woody plant richness by a third to two-thirds depending on fire severity and can have very negative impacts on faunal diversity. (Laurance 2003). By contrast, for ecosystems with a long history of fire, there is concern over the cascading consequences of anthropogenic fire suppression. In tall grass prairies, and comparable grasslands elsewhere, fire suppression has led to the loss of as many as 50 % of the plant species, see Leach et Givnish (1996), Uys et al. (2004). These changes are almost immediately followed by faunal reaction.

The higher densities of wildfires in Europe are mainly concentrated in the southern regions, mainly in the Mediterranean countries, accounting for most of the fires reported. However, in some central and northern countries fires are also frequent (Catry et al. 2010).

Morgan et al. (2015) quantified the effects of burn severity, salvage logging, and post-fire seeding to help define their effects on post-fire vegetation. Seeding with locally sourced native grasses allowed native forbs, shrubs, and conifers to establish and grow but in lower abundance when grass cover was high. Initial differences declined with time so that vegetation richness, diversity, and abundance of shrubs, forbs, and grasses were all similar near the end of the study period (six years after a large wildfire), whether they were salvage logged or not (Morgan et al. 2015).

Influence of surfactants on plants could be appreciable. As is well known, these substances can alter the energy relationship at interfaces and reduce the surface tension of aqueous solutions (Glassman 1948, Colwell and Rixon 1961, Parr and Norman 1965). Among other effects, these substances increase the activity of the urea-sulphuric acid component toward plant seeds, particularly toward seeds that contain and/or are combined with lipophilic substances such as waxes, oils and other hydrophobic substances. Surfactants also increase the wetting ability of the aqueous solutions and thereby improve the distribution of such solutions over the seed surface (Young 1990). They can also remove the resistance to wetting of water repellent soils, thereby improving seedling germination and growth and reducing erosion (Letey et al. 1962a, b, Pelishek et al. 1962).

So far, published studies agree that maximum expression of this property is attained at low surfactant concentrations except in cases in which surfactants are employed in the role of solubilising agents or stabilizers of a 2-phase system. In these cases, higher concentrations may be necessary (Parr and Norman 1964). These characteristics could be used to increase the water movement in soils difficult to wet, particularly those in greenhouse and nurseries (Bayer 1967). On the other hand, there are many cases of negative impact of these solutions to regional and global ecosystems. Finger et al. (1997) deal with study of toxicity of foam suppressant chemicals to plant and animal communities. Surfactants were indicated as major toxic components in the foam. Influence of surfactants is inconsiderable also in cycle of matters in the global ecosystem. For example, Moodie et al. (1986) assumed that the decreased crown density of Norfolk Island pines correlates with the number of surfactants in sea water. They argued by increases of these substances by human activity (discharge from coastal sewage outfalls) in past decades. Due to the above-mentioned reasons, it is very important to identify the consequences of utilisation of foaming agents on germination of commonly grown wood species, their influence on regeneration ability of coniferous forest ecosystem.

Broadcast seeding is one of the most used post-fire rehabilitation treatments to establish ground cover for erosion (Peppin et al. 2011). The rationale for seeding following high-severity wildfires is to enhance plant cover and reduce bare ground, thus decreasing the potential for soil erosion and non-native plant invasion, but post-fire seeding is ineffective in enhancing post-fire plant cover and reducing invasive non-native plants. Seeding has been shown to have negative effects on plant communities, which may have long-term negative effects on plant regeneration. The high financial cost and low potential for effectiveness should call into question the continued practice of seeding areas burned in high-severity wildfires (Stella et al. 2010).

Fire-fighting foams are primarily aggregates of gas-filled bubbles formed from specially formulated liquid foaming agents and have proved to be effective extinguishing agents of both Class A (ordinary combustibles) and class B (flammable liquids) fires (Magrabi et al. 2002). Normally, the gas used is air, but in certain applications may be an inert gas (Scheffey 2008).

Fire-fighting foam absorbs heat more efficiently than pure water, and the bubble mass provides a barrier to oxygen, necessary to sustain combustion and a protective barrier for unburned, exposed fuels (NWCG 1993) Agents known as Class A foams have become popular in recent years. Water efficiency (less solution used compared to plain water) is the primary advantage of these foams. For wildland/forest fire applications, improved water penetration through surface tension reduction is important (Scheffey et al. 2013).

The ecological impacts of wildland fire-suppression activities (Table 1) can be significant and may surpass the impacts of the fire itself, but fire has a much greater influence on plant species richness than do suppressant foams (Backer et al. 2004).

Immediately after the extinguishing of wildfire the forest regeneration follows and so it is necessary to under-

Table 1. Impact associated with fire-suppression activities (Backer et al. 2004)

Element affected	Impact	Potential sources
Soil	Soil compaction	Fire camps, fire lines, helibases, incident command posts, road construction
	Erosion	Fire lines, road construction
	Non-native species	Fire camps, fire lines, helibases, incident command posts, rehabilitation activities
	Litter and waste	Fire camps, fire lines, extinguished fuses, line explosives, aerial ignition devices, rehabilitation activities
	Reduction of habitat	Contour-felled logs, snag removal
	Soil contamination	Fuel spillage
Air	Air pollution	Fossil fuel emissions – aircraft, vehicles, machinery
	Noise pollution	Aerial support
	Visual pollution	Increase of air traffic
Water	Sedimentation	Contour-felled logs and channelization, fire camps, fire lines, road construction
	Disturbance	Amphibious aircraft, removal of water for suppresion activities
	Fish mortality	Fire retardants
	Eutrophication	Fertilizer use with rehabilitation activities, fire retardants
	Pollution	Fire camps, fire retardants, fuel spillage, rehabilitation activities

stand the consequences of application of foaming agents for germination of plant seeds. Therefore, the aim of this work is to test the effect of widely used foam-forming agents on seed germination of two conifers.

Materials and methods

Seeds of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) were chosen for the experiment considering the presence of these species on the territory of the Slovak Republic and the germination percentage of their seeds. The supplier of reproduction material was Lesy SR state company OZ Semenoles Liptovský Hrádok. Seeds of both species were gathered during the seed gathering season of 2011. The seeds of spruce originated from the Kysuce-Orava seeding region and pine from the Northern-Slovakian seeding region. Both regions are highlighted in Figure 1. Purity of utilised seeds represents 100 % in case of spruce and 99.6 % in case of pine. Germination determined by the supplier was 94 % for spruce and 93 % for pine.

Based on current inventory of Fire and rescue corpses of the Slovak Republic, the following foaming agents were selected to pursue the research: Moussol-APS F-15 and Sthamex F-15. Although both of these foaming agents are mostly used for extinguishing of flammable liquids, their utilization as wetting agents is not excluded, and the producer of Sthamex F-15 directly indicate this way of application. The comparison of properties of mentioned foaming agents is listed in Table 2.

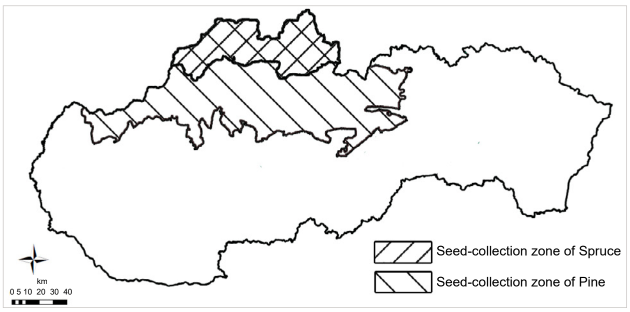

Figure 1. Seed collection areas of seed samples

For the germination testing of seeds of each species, a closed glass vessel, located in conditioned room was used. The temperature during the experiment was 21 °C ± 1 °C. As substrate, the round pieces of filter paper that were sterilised for 60 minutes under temperature of 130 °C in order to avoid infection was used. The pieces of filter paper humidified by foaming agent solution with concentrations ranged from 0,1 vol% to 6 vol% were placed on the bottom of the dishes with diameter of 200 mm. Groups of 25 seeds were chosen using random selection method. For each combination of seed type and foam solution concentration 4 sets were used. To gain the reference values (results), seeds germinated on the pieces of filter paper humidified with pure water were used as a control.

Sufficient humidity of filter paper was assured using suction underlay placed underneath it. Relative humidity of air inside of the dish was kept at 80 % using water spray. Potable water was utilised for preparation of foaming solutions as well as for maintenance of humidity. The seeds prepared in this way were exposed to indirect daily light without application of additional artificial lightning. The incubation period took 21 days, and the number of ger-

Table 2. Properties of utilised foaming agents (EuroFire SK 2005a, b)

Foaming agent	Moussol-APS F-15	Sthamex F-15
Recommended induction rate [%]	3–6	0.5–1.0 (wetting agent) 2.0–3.0 (foam)
Density at 20 °C [kg m^{-3}]	1050 ± 20	1040 ± 20
Frost resistance [°C]	–15	–15
pH value	6.5–8.5	6.5–8.5
Viscosity [mm^2 s^{-1}]	Thixotrope liquid	≤ 10 (20 °C) ≤ 20 (0 °C) ≤ 35 (–15 °C)

minating seeds was recorded on the 7th, 14th and 21st day. Results from the 21st day of the incubation period were statistically evaluated by the Mann-Whitney U test.

Results

The reference germination of samples of the Scots pine seeds and Norway spruce seeds is shown in Figure 2. In both cases, the duration of test was prolonged to 28 days to determinate the curves more accurately. As is evident from Figure 2, the most seeds (80 % and 83 %) germinated within 7 days from the beginning of the test.

The influence of concentration of foaming agents on germination of samples is depicted in Figure 3–6. In case of Moussol-APS F-15 application on the Norway spruce seeds, with concentrations being 0.1 % and 0.25 %, (Figure 3) the increase in number of germinated seeds in comparison with the reference sample is visible. On the 7th day from the beginning of the experiment the germination was 88 % in case of concentration 0.25 % and 96 % of seeds in case of 0.1 % concentration. After 14 days the germination slightly increased to 98 % (0.1 % foaming solution) and to 96 % (0.25 % foaming solution) and on the 21st day its values in both cases represented 98 %. During the experiment, germination was higher in these cases than in the control set.

The influence of foaming agent on germination changed negatively at higher concentrations of foaming agent. A decrease in the number of germinated seeds to 40 % when the concentration of the foaming agent was 0.5 % during the first 7 days was observed. After 14 days the number of germinating seeds increased to 92 % but it did not rise additionally until the end of the test. Therefore, the final result showed very small decrease in germination due to the foaming solution.

In case of 1 % solution of the foaming agent, the germination was significantly lower. After 7 days the germination decreased to 12 %. On the 14th day the germination reached 15 % and remained at this level until the 21st day. When 3 % and 6 % solutions of the foaming agent were applied, the germination was at zero level.

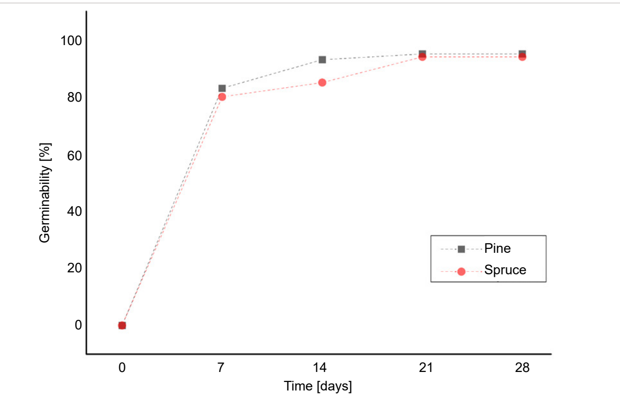

Figure 2. Rate of germination of the control samples

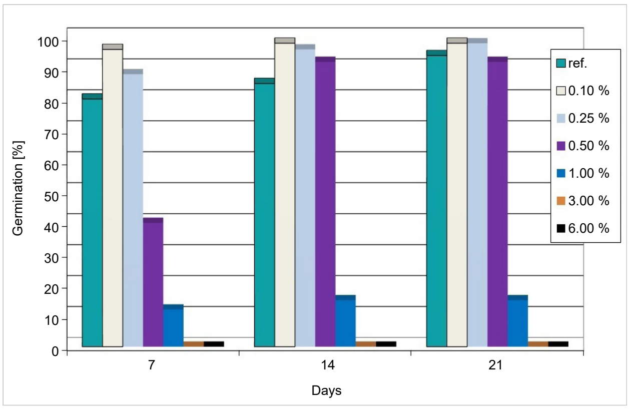

Figure 3. The germination of the Norway spruce seeds when the solutions of Moussol-APS F-15 were applied

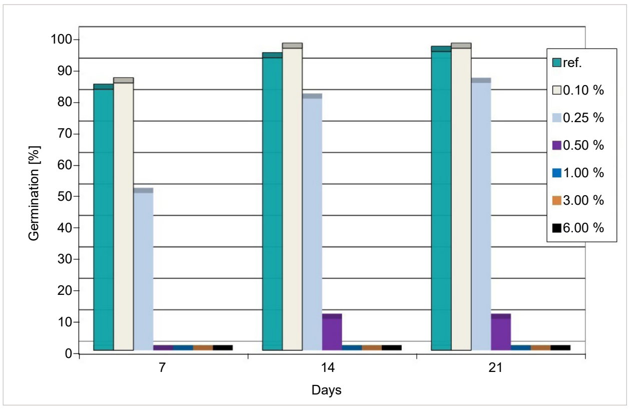

Figure 4. The germination of the Scots pine seeds when the solutions of Moussol-APS F-15 were applied

The influence of foaming agent Moussol-APS F-15 on germination of the Scots pine seeds is shown in Figure 4. Its effect on them was significantly more negative than on the seeds of Norway spruce as it is obvious from the graph. Similarly, as in the previous case, very low concentrations of foaming agent caused very mild increase in germination. It was 85 % at the 0.1 % solution of the foaming agent after 7 days, and 96 % after 14 days and after 21 days. However, the 0.25 % solution of the foaming agent caused decrease in germinated seeds to 50 % after 7 days. After 14 days it increased to 80 % and after 21 days it reached the level of 85 %. The 0.5 % solution of the foaming agent resulted in rapid decease in germination of seeds. After 7 days the germination equalled to zero level. Within 14 days only 10 % of the seeds germinated and this value did not change until the end of the test. Applied concentrations of foaming agent of 1 % and higher led to zero germination throughout whole duration of the test.

In the same way, as in the case of foaming agent Moussol-APS F-15, the samples of seeds were exposed to foaming agent Sthamex F-15. Graphic representation of germination of the Norway spruce seeds is shown in Figure 5. Like in the case of Moussol-APS F-15, the solution of low concentration of the foaming agent caused an increase in germination of seeds. When the concentration was 0.1 %, germina-

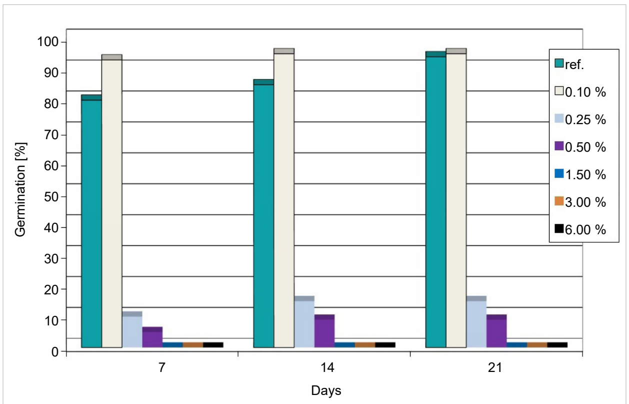

Figure 5. The germination of the Norway spruce seeds when the solutions of Sthamex F-15 were applied

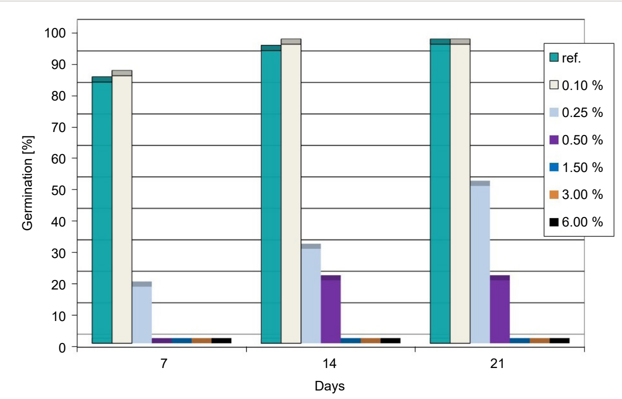

Figure 6. The germination of the Scots pine seeds when the solutions of Sthamex F-15 were applied

tion of 93 % of seeds occurred within 7 days what means an increase by 13 % in comparison with the reference sample. After 14 days the germination raised to 95 % and no further increase was recorder until the end of the test. Increase in concentration of the solution to 0.25 % caused a decrease in germination to 10 % only on the 7th day. This number represents only one eighth compared to the reference sample. During following 7 days, additional 5 % of seeds germinated, but this number did not change until the end of the measurement. There were 79 % of less germinated seeds than in the case of moistening the piece of substrate by pure water without addition of the foaming agent after 21 days.

In case of 0.5 % solution of the foaming agent, only 5 % of seeds germinated within first 7 days and within 14 days the number raised to 9 %. Similarly, as at the concentration of 0.25 %, no increase in germination was observed in the last third of the experiment. No germination was observed at concentrations exceeding 1.5 %.

The last observed combination consisted of the Scots pine seeds and the foaming solutions of Sthamex F-15 (Figure 6). When the concentration of the applied solution was 0.1 %, a very slight increase in germinated seeds occurred again in comparison to the reference sample, but only during the two thirds of the test. After the 7th and 14th days, the germination represented 85 % and 90 %. With the concentration level at 0.25 % a striking decrease in germination occurred. The germination recorded after 7 days was 18 %. On the 14th day 30 % and in the end of the test 50 % of seeds were germinated. At a concentration of 0.5 % of foaming agent, the seeds germinated only within the period from the 7th to the 14th day. At that time germination was 20 %. The rest of seeds did not germinate until the end of the test on the 21st day. When the concentration levels were 1.5 %, 3 % and 6 % the germination throughout the whole test was at zero level.

Discussion

It is evident in all cases that the concentration of the foaming agent in water used for moistening of the substrate piece has significant impact on the germination of the tested seeds.

The germination of the control seeds series (94 % for Norway spruce and 95 % for Scots pine) under identical conditions with the rest of measurements was in good correlation with germination declared by the seed supplier. The time course of germination of the seeds of both tree species is almost identical to that reported by Kamra (1972) for germination of pine originated from the regions of Switzerland, Italy and Spain and for the germination of some samples of spruce reproductive material from Germany and Sweden. Similar course is presented also for different samples of spruce seeds although their germination is considerably lower.

From the measured results it seems that very low concentrations of the tested foaming agents have rather positive influence on germination of spruce and pine seeds. The concentration of 0.1 % solution led to acceleration in seeds germination in all cases. When foaming agent Moussol-APS F-15 and the Norway spruce seeds were combined, mild acceleration in germination still occurred with increasing solution concentration to 0,25 %. However, based on the Mann-Whitney U test, no significant statistical difference was found between the tested samples and the control set. With rising concentration of the foaming agents, the negative effect on germination increases, while it is statistically significant for pine seed samples from 0.25 % and for spruce seed samples from 0.25 % (Sthamex) to 1 % (Moussol). Concentration higher than 1 %–1.5 % inhibited the seed germination practically to zero level.

During fire extinguishing under field conditions, foaming agents seep into lower ground layers which leads to decrease in their concentration in the soil. However, contamination of subsurface water sources may occur. The part of foaming solutions in the soil is diluted and drained by rainfalls into adjacent water flows. Here, their more or less negative influence on aquatic organisms can be shown as mentioned by several researchers (Lewis and Suprenant 1983, Gaikowski et al. 1996, Buhl and Hamilton 2000, Oakes et al. 2010).

Høisæter, Pfaff and Breedveld (2019) monitored soil contamination with foam-forming components. They state that foam is kept on soil surface after its application. Over time, it disintegrates, and its solution enters the soil. Foam bubbles were still visible in the top layer of soil for 24 hours after application. The highest concentrations of foaming agents were measured at a horizon on the depth of 22 cm–32 cm for both low and high infiltration experiments. The foaming agent applied the experiments can thus affect the germination of the plants, especially during the first days after the application of the extinguishing foam.

Although the consequences of wild fire are significantly more striking than consequences on application of the foaming agents utilised for fire extinguishing, the results of this study suggest that proper selection of extinguishing agent can help hasten recovery of forest crops on affected area. Similar conclusion is presented also by Adams and Simmons (1999) who stated that there is a great potential for the application of foams for wildfire suppression, but widespread treatment by them should be minimised until their potential ecological impacts can be assessed.

Substances that have less negative influence over germination of plants, as well as water originating from natural sources, can be used for extinguishing of wildfires. To cool down the structures in the immediate vicinity of fires, barricade fire gel retardants can be utilised. Walkinshaw and Ault (2009) write that barricade gel application on wildland fuels adjacent to a structure inhibited combustion immediately adjacent to the structure.

Song, Mun and Waldman (2014) report a significant reduction in soaked seed germination in a 1 % solution of a foaming agent, with germination declining sharply with increasing exposure time. However, in the field experiment neither the standard application rate of fire-suppressant foams nor even doubling this rate appeared to affect the seeds. For this reason, it is important to continue research in this area so that their results can be confirmed or refuted. The influence of foaming agents on the further growth of germinated seeds is also important. Although this investigation was not the aim of this paper, visual observation revealed a negative effect of the foaming agent on plant growth.

Conclusion

Since extinguishing foam agents can be applied for extinguishing wildfires, it is necessary to know the impact of foam-forming ingredients on the restoration of fire-affected areas. On the basis of testing germination progress of spruce and pine seeds exposed to the solutions of two different foaming agents, the following conclusions can be drawn:

At low concentrations of foaming agents (0.1 %), the positive effect on seed germination of the coniferous trees associated with better wettability exceeds negative impacts and germination increases slightly. However, the statistical significance of this assumption has not been demonstrated and further measurements with a higher number of samples would be appropriate to assess it.

At a higher concentration of foaming agent (above 0.25 %), the impact on germination depends on the type of foaming agent as well as on the type of tree species. In the case of Sthamex, a significant decrease in germination was observed for both pine and spruce seed samples. This also occurred when pine seeds were exposed to Mousol, but there was no decrease in germination of spruce seeds.

Foam concentrations ranging from 0.5 % to 1 % results in a considerable reduction in germination of both tested tree species.

At concentrations above 3 %, germination was reduced to zero level in all cases.

The effect of foaming agents on germination of both plant species was different. Sthamex less affected the pine seed germination, while spruce seeds were more resistant to the negative effect of Mousol.

In general, it can be stated that with the treatment by fire extinguishers, it is necessary, among other negative factors, to consider the effect on the germination of plants. A suitable measure in this respect seems to be an additional dilution of the foam medium in the soil to lower concentrations.

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