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Applying chemical control to suppress liverwort (*Marchantia polymorpha* L.) and other mosses when growing containerized seedlings of pine and spruce

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Abstract

The spread of bryophytes (liverworts and green mosses) on the substrate surface in containers and cassettes poses a significant problem when growing containerized coniferous seedlings. It requires a complex control programme to significantly minimize the negative effect which mosses, in particular *Marchantia polymorpha* L., pose to the growth of containerized pine and spruce seedlings. In addition to the preventive and agrotechnical measures, this programme should also involve application of the physiologically active substances. North American and European nurseries have faced this problem for a long time, Russian nurseries have started to experience it only in recent years due to increased output of containerized pine and spruce seedlings grown in greenhouses. In this paper, we assessed the effectiveness of some herbicides for moss control and their selectivity to pine and spruce seedlings of different ages. The following chemicals were applied in the tests: Goal 24% EC (a.i. oxyfluorfen), Stomp 33% EC (a.i. pendimethalin), Velpar 90% SP (a.i. hexazinone), Pledge 25% WP (a.i. flumioxazin), Mogeton 25% WP (a.i. quinoclamine), Granstar 75% WDG (a.i. tribenuron-methyl), Anchor-85 75% WDG (a.i. sulfometuron methyl) as well as cinnamon oil and baking soda. The experiments were conducted in greenhouses and outdoor fields. It was found that the pre-emergent (before the pine and spruce shoots appear) application of Mogeton WP and baking soda in the greenhouse resulted in the effective suppression of green mosses for up to 20 weeks after the treatment, without any signs of injury in seedlings. Under the same conditions, Goal EC, Stomp EC, Pledge WP and their mixtures in different combinations, as well as Velpar SP caused significant damage to pine and spruce seedlings. The post-emergent treatment by Velpar SP, Pledge WP, Mogeton WP, Granstar WDG, Anchor-85 WDG, as well as cinnamon oil and baking soda, provided effective and long-term control of liverwort and green mosses in cassettes without damage to the seedlings.

Keywords: *Marchantia polymorpha* L., pine, spruce, efficacy, selectivity

Introduction

The analysis of growing containerized pine and spruce seedlings in greenhouse complexes in some Russian regions has shown that the moss, mostly *Marchantia polymorpha* L., in peat-based substrate containers and cassettes is widespread, accompanied by its rapid growth, and this causes a serious problem. The spread of mosses produces competitive conditions and has a profound negative effect on the growth and health of seedlings, increasing their mortality rate and wasting fertilizers. As a result, the quality of plants is significantly reduced, whereas the cost of seedling growing is increased.

The existing methods of moss control focus primarily on suppressing moss growth by drying the surface of the substrate. However, it cannot be completely achieved without the use of modern chemical agents. Currently in Russia there are no such studies not only in forestry but also in agriculture, horticulture and floriculture.

Liverworts cause harm by colonizing the substrate surface and preventing water and fertilizers from reaching plant roots, using them to increase their own biomass. In addition, a liverwort thallus often serves as a refuge for various pests and pathogens (Wilen 2005, Landis 2006, Brennan 2008, Mathers 2013).

The American and some European nurseries have been facing the issue of bryophyte control, first of all liverwort, when growing various containerized plants in nurseries for certain time.

For example, in the USA, the liverwort has recently become the most notorious weed in nurseries throughout the country, including the southern states (Newby et al. 2005, Hester et al. 2012b). The main reason is that the liverwort needs the same conditions as those for seedlings, i.e. good lighting, high air humidity and soil moisture, low levels of ultraviolet radiation as well as high nutrition (Wilen 2005, Newby 2006, Newby et al. 2007, Hester et al. 2012a, Chase 2014).

All types of container-grown seedlings are prone to mosses, but slow-growing conifers are especially vulnerable. Outdoor fields are most problematic, as it is almost impossible to completely eradicate developed mosses there only with agrotechnical means (Figure 1).

Figure 1. Spread of liverwort in cassettes with 1-year old spruce seedlings in an outdoor field

For several decades, dozens of chemicals from various categories and with completely different mechanisms of action have been tested in different countries to suppress liverwort and other mosses on the substrate surface. For this purpose, various herbicides, fungicides, essential oils, acetic acid, metal salts and even insecticides have been tested.

One of the most comprehensive studies on the chemicals use for liverwort control is the research carried out within the framework of the USA national programme (IR-4 Ornamental Horticulture Program, Liverwort Efficacy Study), being held from 1976 to 2011 (Hester et al. 2012a). A number of other American researchers have also studied a range of chemicals suppressing the growth of liverwort (Newby et al. 2005, 2007, Newby 2006, Altland et al. 2007, Mathers 2013). After many trials, chemicals proven their high efficacy including active ingredients, such as quinoclamine, flumioxazin, some essential oils, and baking soda (sodium bicarbonate), have been identified (Hester et al. 2012a).

Most researchers agree that the use of chemicals for bryophyte control should be part of a wider system that also include sanitary and agrotechnical measures for greenhouses and containers (cassettes) sterilization as well as preventing moss growth (Svenson 2000, Wilen 2005, Landis 2006, Newby et al. 2007, Chase 2014, Navas et al. 2014).

The aim of this research was to identify chemicals that effectively control moss development, first of all, *Marchantia polymorpha* L., in cassettes with peat-based substrate, and that have high selectivity to pine and spruce seedlings at different stages of their development.

Materials and methods

The experiments were carried out in two greenhouse complexes in Leningrad region during 2016–2017. This territory is a part of the Baltic-Belozersky taiga region of the Russian taiga forest zone.

Plantek-121 (121 cell inserts) and Plantek-81 (81 cell inserts) cassettes with the peat substrate cell volume of 50 and 85 cm^3, respectively, were utilised in the trials. Scots pine (*Pinus sylvestris* L.) and European spruce (*Picea abies* (L.) Karst.) seedlings were grown in Plantek-121 and Plantek-81 cassettes, respectively. Peat from the upper layer of the highbog peat profile combined with vermiculite mulch spread on the substrate surface was chosen as a growing medium. Filling cassettes with substrate and the subsequent agrotechnical measures were carried out in accordance with the standard guidelines developed for the management of containerized plants (Zhigunov 2000, 2011).

The trials undertaken in 2016 identified the most promising chemical compositions, whereas their efficacy and selectivity under field conditions were assessed in 2017.

Trial 1. It was conducted in a standard closed greenhouse in the Luzhsky Greenhouse Complex. Pre-emergent chemical treatment was done a day after spruce (April 14, 2016) and pine (April 26, 2016) seeds were sown in moss-free substrate. Goal 24% EC (a.i. oxyfluorfen), Stomp 33% EC (a.i. pendimethalin), Pledge 25% WP (a.i. flumioxazin) and Velpar 90% SP (a.i. hexazinone) were chosen as biologically active ingredients. In this trial, the herbicide selectivity to pine and spruce seedlings was studied.

Trial 2. It was carried out on an outdoor field in Luzhsky Greenhouse Complex. Cassettes with 2-year-old seedlings of pine and spruce were treated with Velpar 90% SP and Pledge 25% WP. The treatment was carried out on July 28, 2016, during the period of active growth of the seedlings. During this trial, the efficacy of liverwort control and herbicide selectivity were studied.

During the observation period, the substrate surface was colonized mostly by *Marchantia polymorpha* L. and, to a lesser extent, by green mosses, common smoothcap (*Atrichum undulatum* (Hedw.) P. Beauv.) and broom forkmoss (*Dicranum congestum* Brid).

Trial 3. It was conducted in a standard closed greenhouse located in Luzhsky Greenhouse Complex. Pre-emergent chemical treatment was done 3–5 days after sowing on moss-free substrate (April 18, 2017). In the capacity of biologically active ingredients, Mogeton 25% WP (a.i. quinoclamine) and baking soda were used. During the vegetative stage, the surface of substrate was colonized by the common smoothcap.

The efficacy of moss control had been monitored for 20 weeks after the treatment. At the end of the observation period, average heights of the seedlings were measured. In this trial, control efficacy on mosses, as well as the selectivity of the chemicals to pine and spruce seedlings were assessed.

Trial 4. It was conducted on outdoor fields of Luzhsky Greenhouse Complex, with 2-year-old pine and spruce seedlings being studied; treatment was carried out on April 27, 2017 before the seedlings started growing. Velpar 90% SP, Pledge 25% WP, Mogeton 25% WP, Granstar 75% WDG (a.i. tribenuron-methyl), Anchor-85 75% WDG (a.i. sulphometuron-methyl) as well as cinnamon oil and baking soda were used as active ingredients.

During the vegetative season, *Marchantia polymorpha* L., and, to a lesser extent, green mosses such as *Atrichum undulatum* (Hedw.) Beauv. and *Dicranum congestum* Brid. spread on the surface of substrate.

Moss control efficacy and the selectivity to pine and spruce seedlings were monitored over 16 weeks following the treatment.

Trial 5. It was conducted on outdoor fields of the greenhouse complex belonged to Lisinsky Forestry College in cassettes with pine and spruce seedlings sown in 2017 during their vegetative stage. Spraying was carried out on July 20, 2017, a month after the cassettes were moved from the greenhouse to the outdoor field. Velpar 90% SP, Pledge 25% WP, Mogeton 25% WP, Granstar 75% WDG, Anchor-85 75% WDG as well as cinnamon oil and baking soda were used as biologically active ingredients.

During the observation period, the substrate surface was mostly colonized by *Marchantia polymorpha* L. and, to a lesser extent, by the *Atrichum undulatum* (Hedw.) P. Beauv.

Moss control efficacy and the selectivity of the used chemicals to pine and spruce seedlings were assessed over 6 weeks following the treatment.

In all the trials, the cassettes were treated with a Solo 401 handheld sprayer with a spray volume of 500 L ha^{-1}. During the treatment, an isolated area measuring 1 × 1 m was sprayed, with each trial cassette being positioned there before spraying.

When the cinnamon oil was used, an emulsifier was blended into the spray mixture in quantity of 20 percent of the oil volume.

Chemical efficacy on undesired vegetation was determined by the percentage decrease in substrate surface cover made up by liverwort and green mosses in comparison with the untreated control. A block of 4 cells was chosen as a base unit to determine liverwort and moss cover, each block had an area of about 80 cm^2 (10 base units in each cassette). The total area of each cassette (1 repeat) was about 1,500 cm^2.

At the end of the vegetation season, the height of the seedlings in their first year of cultivation (trials 3 and 5) was measured to assess the effect of the chemicals on the pine and spruce growth. To measure the seedling height, we used at least 50 plants in each repeat, meaning at least 200 seedlings in each trial type.

The trials were replicated three times. As a repeat, we used a single cassette with 81–121 seedlings depending on the cassette type. The chemical treatment of each cassette was undertaken separately.

To calculate chemical efficacy of moss control, a one-way analysis of variance (ANOVA) was applied to determine the factual F-test value, $F_{factual}$. When $F_{factual}$ exceeded the theoretical (tabulated) value, $F_{theoretical}$, we calculated the Least Significant Difference between the trials at a 5 percent level of significance (LSD_{05}).

Assessing the effects of the chemicals on the growth rate of pine and spruce seedlings, we used Student's t-test at a 5 percent level of significance to determine the significant difference between the means.

Results

The results of Trial 1 showed that after the pre-emergent treatment, none of the trial test combinations managed to achieve the acceptable level of herbicide selectivity to pine and spruce seedlings. Some seedlings were damaged; some relatively healthy ones experienced a growth delay, whereas a considerable number of seedlings perished (Table 1).

Applied during the period of seedlings and liverwort active growth, Velpar SP provided effective liverwort control for at least 1.5 months after treatment (Table 2, Figure 2). No significant difference in herbicide efficacy depending on its application rate was noticed. In comparison with Velpar SP, Pledge WP appeared to be less effective and less lasting. No injuries to pine and spruce seedlings were observed in any of the trial test combinations.

Trial 3 showed that several chemicals used as pre-emergents led to slowing down moss growth than that in the control. Thus, after the treatment of pine by Mogeton WP with application rates of 5–15 kg ha^{-1}, green moss cover on the substrate surface was less than 10 percent even after 4.5 months after treatment, while in the control the moss cover reached 90 percent. Baking soda applied at a rate of 200 kg ha^{-1} was not effective for green mosses suppression and the weediness index in the cassettes in this test remained at the control level.

The application of baking soda at the rate of 400 kg ha^{-1} performed slightly better, but for this test combination the moss control efficacy during the vegetative season was only 41–87 percent in comparison to the con-

Table 1. Herbicide selectivity to pine and spruce seedlings after pre-emergent treatment in a greenhouse (Trial 1, Luzhsky Greenhouse Complex)

Test combination	Seedling distribution by their condition, %							
	pine				spruce			
	healthy		damaged and dead		healthy		damaged and dead	
	weeks after treatment							
	2	6	2	6	4	6	4	6
Goal, 1 l ha^{-1}	12	24	88	76	12	22	88	78
Goal, 2 l ha^{-1}	7	12	93	88	4	11	96	89
Stomp, 3 l ha^{-1}	31	47	69	53	85	31	15	69
Stomp, 6 l ha^{-1}	14	4	86	96	88	16	12	84
Goal, 0,5 l ha^{-1} + Stomp, 2 l ha^{-1}	7	14	93	86	11	13	89	87
Goal, 1 l ha^{-1} + Stomp, 3 l ha^{-1}	-	-	-	-	4	5	96	95
Velpar, 0.5 kg ha^{-1}	-	-	-	-	83	42	17	58
Velpar, 1 kg ha^{-1}	56	70	44	30	84	15	16	85
Pledge, 0.12 kg ha^{-1}	10	11	90	89	-	-	-	-
Pledge, 0.24 kg ha^{-1}	2	3	98	97	-	-	-	-
Goal, 0.5 kg ha^{-1} + Pledge, 0.08 kg ha^{-1}	5	8	95	92	-	-	-	-
Stomp, 2 l ha^{-1} + Pledge, 0.08 kg ha^{-1}	7	6	93	94	-	-	-	-
Control (untreated)	86	81	14	19	89	90	11	10

Table 2. Herbicide efficacy against liverwort in an outdoor field (Trial 2, Luzhsky Greenhouse Complex)

Test combination	Control efficacy, %			
	pine		spruce	
	weeks after treatment			
	3	6	3	6
Velpar, 0.3 kg ha^{-1}	-	-	89 a	93 a
Velpar, 0.5 kg ha^{-1}	93 a	95 a	87 ab	95 a
Velpar, 1.0 kg ha^{-1}	98 a	100 a	-	-
Pledge, 0.08 kg ha^{-1}	55 c	5 b	84 b	19 b
Pledge, 0.12 kg ha^{-1}	75 b	5 b	84 b	23 b

Note: Data which significantly differ at a level of 0.05 of the one-way analysis of variance (ANOVA) are marked with different letters; data which do not differ are marked with the same letters.

Figure 2. Liverwort control efficacy in cassettes with pine seedlings

Left – untreated cassette, right – treated by Velpar SW at the rate of 1.0 kg ha^{-1}.

trol (Table 3). Some discrepancies in the figures for moss control efficacy in the cassettes containing pine and spruce may be explained by the different cell volumes (50 and 85 cm^3), which lead to different speeds at which the substrate dries up.

For different test combinations, the average height of the seedlings (especially for spruce) at the end of the vegetative season exceeded those in the control. Baking soda used at the application rates of 200 and 400 kg ha^{-1} prevented the growth of green mosses, but at its maximum rate it inhibited the pine growth (31-percent difference in comparison with the control). The spruce seedlings were less affected by baking soda (Table 4).

In cassettes containing 2-year-old pine and spruce seedlings, liverwort formed a 2–3 cm thick coverage on the substrate surface, consisting of plants of different ages. Application of some physiologically active substances before the growth of seedlings started to show effective liverwort control. Duration of herbicide effect caused by Velpar SP, Anchor-85 WDG, Granstar WDG, baking soda and cinnamon oil varied greatly, ranging from 2 weeks to 4 months (Table 5). None of the test combinations showed

Table 3. Chemical control efficacy against the common smoothcap in a greenhouse, after pre-emergent treatment (Trial 3, Luzhsky greenhouse complex)

Test combination	Control efficacy, %					
	pine			spruce		
	weeks after treatment					
	14	16	20	14	16	20
Mogeton, 5 kg ha^{-1}	100 a	90 b	86 a	71	68 a	54 a
Mogeton, 10 kg ha^{-1}	100 a	100 a	82 a	70	58 b	49 a
Mogeton, 15 kg ha^{-1}	100 a	85 b	87 a	75	55 b	55 a
Baking soda, 200 kg ha^{-1}	0 c	0 d	0 c	74	47 c	39 b
Baking soda, 400 kg ha^{-1}	87 b	50 c	50 b	71	57 b	41 b

Note: data which significantly differ at a level of 0.05 of the one-way analysis of variance (ANOVA) are marked with different letters; data which do not differ are marked with the same letters.

any damage to pine and spruce seedlings during the entire observation period.

Spraying of the cassettes containing pine and spruce seedlings on their first rotation (a month after they were moved to the outdoor field) showed rather effective liverwort control for 6 weeks after the treatment. In this trial, Mogeton WP, Velpar SP, Anchor-85 WDG, Pledge WP, cinnamon oil and baking soda were the most effective (with different duration of action) for the moss control (Table 6).

In almost all the trial test combinations, both species did not show visible damage and injury after chemical treatment (Figure 3). The exceptions were only the test combinations with Anchor-85 WDG, where noticeable damage to the spruce seedlings, depending on its application rate at different times, occurred in 33 to 53 percent of the plants.

Table 4. Effects of chemicals on the height of pine and spruce seedlings in a greenhouse, 20 weeks after pre-emergent treatment (Trial 3, Luzhsky Greenhouse Complex)

Test combination	Average height of seedlings, cm	
	pine	spruce
Mogeton, 5 kg ha^{-1}	6.3 a	8.0 a
Mogeton, 10 kg ha^{-1}	6.1 ab	6.8 b
Mogeton, 15 kg ha^{-1}	6.1 ab	7.4 ab
Baking soda, 200 kg ha^{-1}	6.2 a	5.9 c
Baking soda, 400 kg ha^{-1}	4.0 c	5.4 c
Control (untreated)	5.8 b	5.3 c

Note: data which significantly differ at a level of 0.05 of the Student t-test are marked with different letters; data which do not differ are marked with the same letters.

Figure 3. Liverwort control efficacy in cassettes with 1-year-old spruce seedlings
Left – untreated cassette, right – treated by Pledge WP at a rate of 0.12 kg ha^{-1}.

Table 5. Chemical control efficacy against liverwort in pine and spruce seedlings in an outdoor field (Trial 4, Luzhsky Greenhouse Complex)

Test combination	Control efficacy, %						
	weeks after treatment						
	2	4	6	8	10	12	16
Velpar, 0.5 kg ha^{-1}	0 f	0 f	0 e	40 e	100 a	70 c	41 c
Velpar, 1.0 kg ha^{-1}	0 f	11 f	22 d	77 bc	100 a	89 b	52 b
Pledge, 0.12 kg ha^{-1}	5 f	38 e	40 c	60 d	55 b	0 e	0 e
Mogeton, 5 kg ha^{-1}	0 f	0 f	0 e	0 j	0 c	0 e	0 e
Mogeton, 10 kg ha^{-1}	0 f	53 d	43 c	24 f	0 c	0 e	0 e
Mogeton, 15 kg ha^{-1}	25 d	50 d	70 b	70 c	52 b	50 d	0 e
Granstar, 0.025 kg ha^{-1}	52 c	100 a	100 a	100 a	100 a	85 b	50 b
Anchor-85, 0.025 kg ha^{-1}	15 e	72 c	74 b	81 b	95 a	62 c	19 d
Anchor-85, 0.050 kg ha^{-1}	17 e	91 a	100 a	100 a	100 a	100 a	46 bc
Cinnamon oil, 1 ml m^{-2}	50 c	80 b	75 b	70 c	55 b	0 e	0 e
Cinnamon oil, 2 ml m^{-2}	73 b	75 bc	96 a	95 a	95 a	95 a	82 a
Baking soda, 200 kg ha^{-1}	76 ab	77 bc	79 b	66 cd	54 b	55 d	53 b
Baking soda, 400 kg ha^{-1}	81 a	95 a	100 a	100 a	95 a	73 c	55 b

Note: data which significantly differ at a level of 0.05 of the one-way analysis of variance (ANOVA) are marked with different letters; data which do not differ are marked with the same letters.

Table 6. Moss control efficacy after treatment of pine and spruce seedlings sown in 2017 in an outdoor field during the period of their active growth (Trial 5, the Greenhouse Complex of Lisinsky Forestry College)

Test combination	Control efficacy, %			
	2 weeks after treatment		5 weeks after treatment	
	liverwort	green mosses	liverwort	green mosses
Velpar, 0.15 kg ha^{-1}	38 d	92 b	72 d	80 b
Velpar, 0.3 kg ha^{-1}	51c	50 d	71 d	100 a
Velpar, 0.5 kg ha^{-1}	60 c	52 d	73 d	84 b
Pledge, 0.12 kg ha^{-1}	25 e	50 d	93 b	81 b
Mogeton, 15 kg ha^{-1}	26 e	83 c	100 a	100 a
Granstar, 0.025 kg ha^{-1}	25 e	17 e	64 d	83 b
Anchor-85, 0.03 kg ha^{-1}	27 e	18 e	85 c	81 b
Anchor-85, 0.05 kg ha^{-1}	0 f	51 d	93 b	80 b
Cinnamon oil, 1 ml m^{-2}	100 a	100 a	29 e	0 e
Cinnamon oil, 2 ml m^{-2}	100 a	100 a	87 bc	64 c
Baking soda, 50 kg ha^{-1}	0 f	0 f	83 cd	47 d
Baking soda, 100 kg ha^{-1}	37 d	0 f	82 cd	53 d
Baking soda, 200 kg ha^{-1}	75 b	0 f	85 c	79 b
Baking soda, 400 kg ha^{-1}	100 a	100 a	100 a	100 a

Note: data which significantly differ at a level of 0.05 of the one-way analysis of variance (ANOVA) are marked with different letters; data which do not differ are marked with the same letters.

Analysis of the seedling height showed that after the application of Velpar SP, Pledge WP, Mogeton WP and Granstar WDG, the seedlings were either equal to or significantly higher than those in the control (Table 7).

Table 7. Effects of post-emergent chemical treatment on the height of pine and spruce seedlings in an outdoor field, 42 days after treatment (Trial 5, the Greenhouse Complex of Lisinsky Forestry College)

Test combination	Average height of seedlings, cm	
	pine	spruce
Velpar, 0.15 kg ha^{-1}	10.4 a	7.2 b
Velpar,0.3 kg ha^{-1}	8.9 bc	7.7 ab
Velpar,0.5 kg ha^{-1}	9.3 b	7.7 ab
Pledge, 0.12 kg ha^{-1}	8.8 bc	7.3 b
Mogeton, 15 kg ha^{-1}	9.2 b	8.9 a
Granstar, 0.025 kg ha^{-1}	8.0 c	8.2 a
Anchor-85, 0.03 kg ha^{-1}	7.8 cd	7.2 b
Anchor-85, 0.05 kg ha^{-1}	7.0 d	4.9 c
Cinnamon oil, 1 ml m^{-2}	8.1 c	6.6 bc
Cinnamon oil, 2 ml m^{-2}	8.7 bc	7.3 b
Baking soda, 50 kg ha^{-1}	8.1 c	6.3 bc
Baking soda, 100 kg ha^{-1}	9.0 b	6.0 bc
Baking soda, 200 kg ha^{-1}	9.8 a	6.5 bc
Baking soda, 400 kg ha^{-1}	8.3 bc	6.6 bc
Control (untreated)	8.9 b	7.2 b

Note: data which significantly differ at a level of 0.05 of the Student t-test are marked with different letters; data which do not differ are marked with the same letters.

Discussion and conclusions

The negative side of the herbicide usage is their toxicity and persistence in the ecosystems for the certain period. Although the investigated chemicals are only little toxic, their application in the greenhouses can lead to the unwanted consequences for the cultivated plants and people working in the greenhouses. In the controlled conditions of the greenhouses, it is possible to prevent the moss growth with the preventive and agrotechnical measures, such as sterilization of the nutritious substrate and cassette, minimizing the irrigation and fertilization, maintenance of the recommended light and ventilation regimes (Landis 2006, Newby 2006, Hester et al. 2012b). In the outdoor fields, after cassettes with seedlings being removed from the greenhouses, during the unfavourable weather conditions in the raining seasons, it is impossible to regulate the moisture regime and to dry out the substrate surface to prevent moss development. Under those conditions, this might be necessary to apply the chemical agents (including herbicides).

In this research, we established the high herbicide effectiveness of Anchor-85 WDG, Granstar WDG and Velpar SP against *Marchantia* for the first time. We did not find similar information in the previous papers. The high resistances of the coniferous trees, in particular, spruce and pine, to those chemicals was established earlier (Egorov 1997, Egorov and Bubnov 2013).

The obtained results showed that it is recommended to apply the chemicals studied to suppress *Marchantia* and the green mosses only in the outdoor fields after removing cassettes from the greenhouses. The chemical treatment inside the greenhouses leaded to the unacceptable pine and spruce seedlings damage.

Therefore, the results of our study are as follows:

1. Pre-emergent application of Goal EC, Stomp EC, Pledge WP and Velpar SP in greenhouses led to the significant thinning of pine and spruce seedlings and suppressed growth of the survived seedlings.
2. Application of Velpar SP (0.3–1.0 kg ha^{-1}) and Pledge WP (0.08–0.12 kg ha^{-1}) during the period of active growth of 2-year-old pine and spruce seedlings resulted in the effective liverwort control for 1.5 months after treatment. No damage to the seedlings of both species was noticed.
3. Pre-emergent application of Mogeton WP in greenhouses at rates of 5–15 kg ha^{-1} reduced the spread of green mosses on the substrate surface in the cassettes by 49–100 percent, depending on the application rate. Baking soda used at rates of 200 and 400 kg ha^{-1} decreased moss spreading by 39–87 percent for 14– 20 weeks after the treatment. The only exception was the trial, when baking soda was applied at the rate of 400 kg ha^{-1}, when the growth of pine and spruce seedlings was observed to be not inhibited.
4. When spraying well-developed liverwort into cassettes with 2-year-old pine and spruce seedlings before their growth started, the most effective herbicides were Anchor-85 WDG (0.025–0.050 kg ha^{-1}), Granstar WDG (0.025 kg ha^{-1}), Velpar SP (0.5–1.0 kg ha^{-1}), Mogeton WP at its maximum application rate (15 kg ha^{-1}) as well as cinnamon oil (1–2 ml m^{-2}) and baking soda (200–400 kg ha^{-1}).
5. When spraying young liverwort in the cassettes with actively growing seedlings of pine and spruce, Velpar SP (0.15–0.5 kg ha^{-1}), Pledge WP (0.12 kg ha^{-1}), Mogeton WP (15 kg ha^{-1}), Granstar WDG (0.025 kg ha^{-1}) as well as cinnamon oil (1–2 ml m^{-2}) and baking soda (200–400 kg ha^{-1}) were effective for the liverwort and green mosses control and safe for the seedlings. In the test combination when Anchor-85 WDG (0.03– 0.05 kg ha^{-1}) was used, the growth of pine and spruce seedlings was significantly inhibited.
6. Pledge WP (0.12 kg ha^{-1}), Mogeton WP (15 kg ha^{-1}), Granstar WDG (0.025 kg ha^{-1}), cinnamon oil (1–2 ml m^{-2}) and baking soda (200–400 kg ha^{-1}) can be recommended for treatment of 1- and 2-year old pine and spruce seedlings, both in the resting period of seedlings and during the active growth. Application of Anchor-85 WDG is possible only before the seedlings start to grow with safe application rates of up to 0.03 kg ha^{-1} for spruce seedlings and up to 0.05 kg ha^{-1} for pine. At application rates of up to 0.5 kg ha^{-1}, Velpar SP is safe for seedlings of both species in their

first year of cultivation, and at rates of 0.3–0.5 kg ha^{-1} and 0.5–1.0 kg ha^{-1}, respectively, for spruce and pine seedlings in their second year of cultivation.

Thus, for effective control of liverwort and green mosses in the peat-based substrate cassettes, several chemicals belonging to different compound groups and having different action mechanisms may be applied. These chemicals proved to be the most effective when young, actively growing mosses were treated.

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