The use of herbicides in cultivation of spruce and pine in the Northwest Russia

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Abstract. This paper presents the results of field experiments that went on in the Leningrad region for seven years with the aim to test the effect of modern herbicides and their mixtures on unwanted vegetation during the first few years after planting European spruce (Picea abies (L.) Karst.) and Scots pine (Pinus sylvestris L.). We provide data on the effect of herbicides on unwanted vegetation in clear-cut areas and former agricultural lands. We report the high efficiency of some applications of herbicides. For example, a mixture of Roundup, WS (360 g/l acid glyphosate), Anchor-85, WDG (750 g/kg potassium salt of sulfometuron-methyl) and Arsenal, WC (250 g/l imazapyr) suppressed the development of herbaceous weeds during two vegetative seasons. We provide data on the growth of the planted seedlings. We propose an efficient and low-cost method of creating forest plantations, which involves preliminary treatment of the area with a mixture of herbicides and the subsequent planting of pine and spruce seedlings.

1. Introduction
In the taiga zone of the European part of Russia, one of the main tasks of forestry is regeneration of highly productive and economically valuable tree stands dominated by conifers, that is, by pine and spruce. This problem is particularly acute after clear-cutting in highly productive forest growing conditions; that is, in cases when a negative impact of weeds on conifer plants is most significant. It is a known fact that in the first few years after planting herbaceous weeds pose the greatest danger to seedlings, and later on so do clonal and other deciduous woody species. Most often an unsatisfactory state of planted seedlings including their death is explained by inadequate care or lack thereof [1-3]. It has been substantiated by multiple studies that mechanical methods to combat weeds are not sufficiently effective and have several disadvantages [4, 5]. At all stages of reforestation and afforestation, chemical methods of weed control allow us to successfully solve the problem of eliminating competition from unwanted vegetation with minimal costs and a high level of environmental safety [4]. Continuous improvement of methods and range of applied herbicides suggests that chemical methods will have the most promising future in the fight against undesirable vegetation [6]. In Russia, herbicides based on only five active ingredients – glyphosate, imazapyr, sulfometuron-methyl, tribenuron-methyl and haloxyfop-P-methyl – are currently permitted for use in forestry, and for chemical treatment of the areas allocated for reforestation, herbicides based on only three of them (glyphosate, imazapyr and sulfometuron-methyl) are permitted [7]. It is well known that control of the ground vegetation, including the use of herbicides, plays and important role in creation of highly productive forest plantations. Based on years of research, a manifold increase in the productivity of plantations of various tree species has been achieved in North America (USA and Canada), South America, South Africa, Australia and New Zealand [8]. As an additional positive
effect of the use of herbicides in pine plantations in Australia, a sharp decrease in the mass of combustible material was recorded and thus, the reduced risk of forest fires [9]. In the foreseeable future, there will be no alternative to the use of herbicides in suppression of the ground vegetation [10]. When comparing various methods of site preparation used in the United States, it turned out that the chemical method provided the highest survival rate of seedlings during the first five years after planting [11].

For reforestation and afforestation in different countries, non-selective herbicides, such as glyphosate (Roundup), imazapyr (Arsenal, Chopper), sulfometuron-methyl (Oust, Anchor-85), metsulfuron-methyl (Ally), hexazinone (Velpar), as well as various mixtures based on the above herbicides are commonly used. In the United States, a variety of herbicides, both recently developed and those that have been in use for a long time, are currently in use in pine plantations: imazapyr, fosamine, glyphosate, aminopyralide, hexazinone, glufosinate-ammonium, triclopyr, sulfometuron-methyl, metsulfuron-methyl, and mixtures of herbicides [12-14]. In Finland, glyphosate, terbutylazine, and their mixtures have been used to care for young plantations of Scots pine, European spruce, hanging birch, and poplar [15, 16].

The aim of our research was to study different methods of site treatment by herbicides to ensure the most effective and long-lasting suppression of a wide range of undesirable herbaceous vegetation (weeds) and thereby creating favorable conditions for the growth of pine and spruce.

2. Methods and materials

Field experiments were carried out in the Gatchina district of the Leningrad region in 2010–2017; the district belongs to the Baltic-Belozersky region of the taiga zone. Three long-term field experiments were carried out (two of them, in small plots, and one, on the industrial scale). We used herbicides registered in Russia for the use in forestry. The focus of our field experiments was on tank mixtures of herbicides. Herbicide application options, dates of seedling treatment and planting are presented in Tables 1–6.

Experiment 1 was carried out in a two-year old clear-cut area in a bilberry type of vegetation conditions; the soil was sod-podzolic, light loamy with humus content in the A1 horizon of 2.8%. Experiments 2 and 3 were carried out in drained areas taken out of agricultural use, heavily overgrown with grass; humus content in the upper 20-cm soil layer was 5.7 and 3.8%, respectively. In Experiments 1 and 2, the area of the experimental plot was 100 m² (10 m × 10 m); the treatments were repeated three times, spraying was performed with a "Solo" manual backpack sprayer, the spray volume was 200 l/ha. In Experiment 3, the area of the plot was 500 m², the treatments were repeated twice, the spraying was carried out using a “Shihl” backpack motor sprayer, spray volume was 200 l/ha.

In Experiment 1, standard one-year old seedlings of European spruce (Picea abies (L.) Karst.) were planted. The seedlings had a closed root system (CRS) and were grown on a peat substrate in Plantek-81 cassettes (the volume of the root-closing clump was 85 cm³), in a green house (the first rotation). In Experiment 2, two-year old seedlings of spruce with CRS (the volume of the root-closing clump was 250 cm³) were planted, and in the fall, three-year old seedlings of spruce with the bare root system (BRS). In Experiment 3, two-year old standard seedlings of Scots pine (Pinus sylvestris L., the second rotation) and two-year old seedlings of spruce (Picea abies, the first rotation) with CRS (the volume of the root-closing clump was 85 cm³) were planted. In each experiment, 100 seedlings of each species were planted. The seedlings were planted manually using the Kolesov’s sword.

The biological effect of herbicides on herbaceous vegetation was determined by measuring the reduction (in percent) of the projective soil cover of the herbaceous layer in relation to the control (without treatment), for which 30 temporary reference areas 1x1 m in size each for each type of experiment were established. The survival rate of seedlings was defined as the ratio of the number of healthy and weakened seedlings to the number of planted ones. At the end of the growing season, the biometric characteristics of the seedlings were determined including the diameter at the root neck (mm), height (cm) and increase in height per year (cm). The significance of the differences was determined by Student’s t-test at a probability level of 95%.
In Experiment 1, the following species were dominant: *Calamagrostis arundinacea* (L.) Roth., *Avenella flexuosa* (L.) Drejer, *Deschampsia caespitosa* (L.) Beauv., *Agrostis capillaries* L., *Veronica officinalis* L., *Chamaenerion angustifolium* (L.) Scop., *Cirsium heterophyllum* (L.) Hill, *Aegopodium podagraria* L., *Anthriscus sylvestris* (L.) Hoffm., *Fragaria vesca* L., *Rubus idaeus* L., *Rubus saxatilis* L., *Potentilla erecta* (L.) Raeusch., and *Geranium sylvaticum* L.

In Experiment 2, the following species were dominant: *Calamagrostis epigeios* (L.) Roth., *Calamagrostis purpurea* (Trin.) Trin. s. l., *Deschampsia caespitosa* (L.) Beauv., *Dactylis glomerata* L., *Lysimachia vulgaris* L., *Alchemilla acutiloba* Opiz, *Anthriscus sylvestris*, *Lathyrus pratensis* L., *Taraxacum officinale* Wigg., *Veronica chamaedrys* L. s.l., *Cirsium arvense* (L.) Scop., *Tussilago farfara* L., *Trifolium pratense* L., *Rubus fruticosus* Willd., *Lupinus polyphyllus* Lindl., and *Chamaenerion angustifolium* (L.) Scop.

In Experiment 3, the following species were dominant: *Calamagrostis arundinacea* (L.) Roth., *C. epigeios* (L.) Roth., *Avenella flexuosa* (L.) Drejer, *Deschampsia caespitosa* (L.) Beauv., *Agrostis capillaries* L., *Veronica chamaedrys* L., *Heracleum sibiricum* L., *Chamaenerion angustifolium* (L.) Scop., *Cirsium heterophyllum* (L.) Hill, *Aegopodium podagraria* L., *Anthriscus sylvestris* (L.) Hoffm., *Fragaria vesca* L., *Rubus idaeus* L., *Potentilla erecta* (L.) Raeusch., *Trifolium pratense* L., *Geranium sylvaticum* L., *Alchemilla acutiloba* Opiz, and *Vicia cracca* L.

3. Results

In Experiment 1, during the first two months after the application of herbicides, the maximum suppression of herbaceous vegetation was observed in the Roundup treatment, 6 l/ha, and the minimum, in the AtronPro treatment, 1.5 kg/ha (table 1). The effect of herbicides on herbaceous monocotyledons and dicotyledons was similar in all treatments. In treatments with mixtures of herbicides, a high efficiency of suppression of vegetative cover was observed, 95-96%. In treatments 1 – 4, that is when herbicides persistent in soil were used, at the end of the first growing season this indicator reached the maximum values of 96 – 99%. The greatest decrease in the projective soil cover of the herbaceous layer (99%) was observed when three-component mixtures of herbicides (options 2 and 3) were used. At the same time, all monocotyledons died off completely, and among dicotyledons, *Calamagrostis arundinacea* (L.) Roth., *Rubus saxatilis* L., *Convallaria majalis* L. and *Maianthemum bifolium* (L.) F.W. Schmidt remained. In the Roundup treatment, 6 l/ha, a gradual recovery of the herbaceous vegetation was observed. In July of the following year, in treatments 1–3, a slow recovery of the herbaceous vegetation was observed, primarily due to perennial dicotyledons, such as *Rubus saxatilis* L., *R. idaeus* L. and *Cirsium heterophyllum* (L.) Hill. In these treatments, the projective soil cover of the herbaceous layer reached 7 – 8%, and the recovery of monocotyledonous species did not exceed 1%. As a result the overall effectiveness of herbicide mixtures decreased from 98 – 99% to 92 – 93%. In the AtronPro treatment, there was a more intensive recovery of monocotyledonous species, mainly of *Calamagrostis arundinacea* (L.) Roth.; the suppression effectiveness of the treatment did not exceed 90%. As expected, the most active growth of the herbaceous vegetation was observed after the Roundup treatment (6 l/ha); the efficiency decreased from 96 to 71%. In this treatment, *Chamaenerion angustifolium* (L.) Scop., *Rubus saxatilis* L., *R. idaeus* L., *Cirsium heterophyllum* (L.) Hill., *Calamagrostis arundinacea* (L.) Roth. were dominant.
Table 1. The effect of herbicides on undesirable herbaceous vegetation in the experiment in chemical treatment of a clear-cut area designated for reforestation (Experiment 1, treatment on 05/22/2015).

| Treatment | Date       | Projective soil cover of herbaceous layer, % | Effectiveness of suppression of undesirable vegetation, % |
|-----------|------------|---------------------------------------------|--------------------------------------------------------|
|           |            | Total | Monocots | Dicots | Total | Monocots | Dicots |
| 1. Roundup, 4 l/ha + Anchor-85, 100 g/ha | 28.06.15   | 16    | 7        | 9      | 82    | 83        | 82    |
|          | 24.07.15   | 5     | 0        | 5      | 95    | 100       | 89    |
|          | 04.09.15   | 2     | 0        | 2      | 98    | 100       | 95    |
|          | 19.07.16   | 8     | 1        | 7      | 92    | 98        | 84    |
|          | 03.09.16   | 16    | 4        | 12     | 83    | 92        | 72    |
|          | 19.08.17   | 49    | 17       | 32     | 50    | 72        | 16    |
| 2. Roundup, 3 l/ha + Anchor-85, 100 g/ha + Arsenal, 0.5 l/ha | 28.06.15   | 16    | 7        | 9      | 82    | 83        | 82    |
|          | 24.07.15   | 4     | 0        | 4      | 96    | 100       | 91    |
|          | 04.09.15   | 1     | 0        | 1      | 99    | 100       | 98    |
|          | 19.07.16   | 8     | 1        | 7      | 92    | 98        | 84    |
|          | 03.09.16   | 9     | 2        | 7      | 85    | 96        | 84    |
|          | 19.08.17   | 38    | 13       | 7      | 61    | 78        | 34    |
| 3. Roundup, 3 l/ha + Anchor-85, 50 g/ha + Arsenal, 0.5 l/ha | 28.06.15   | 17    | 10       | 7      | 81    | 76        | 86    |
|          | 24.07.15   | 5     | 1        | 4      | 95    | 98        | 91    |
|          | 04.09.15   | 1     | 0        | 1      | 99    | 100       | 98    |
|          | 19.07.16   | 7     | 1        | 6      | 93    | 98        | 86    |
|          | 03.09.16   | 13    | 5        | 8      | 86    | 90        | 81    |
|          | 19.08.17   | 45    | 23       | 22     | 54    | 62        | 42    |
| 4. AtronPro, 1.5 kg/ha | 28.06.15   | 42    | 22       | 20     | 53    | 46        | 59    |
|          | 24.07.15   | 29    | 20       | 9      | 69    | 60        | 80    |
|          | 04.09.15   | 4     | 2        | 2      | 96    | 96        | 95    |
|          | 19.07.16   | 10    | 8        | 2      | 90    | 85        | 95    |
|          | 03.09.16   | 13    | 11       | 2      | 86    | 78        | 95    |
|          | 19.08.17   | 40    | 27       | 13     | 59    | 55        | 66    |
| 5. Roundup, 6 l/ha | 28.06.15   | 8     | 1        | 7      | 91    | 98        | 86    |
|          | 24.07.15   | 2     | 0        | 2      | 98    | 100       | 96    |
|          | 04.09.15   | 4     | 1        | 3      | 96    | 98        | 93    |
|          | 19.07.16   | 28    | 4        | 24     | 71    | 92        | 45    |
|          | 03.09.16   | 45    | 10       | 35     | 52    | 80        | 19    |
|          | 19.08.17   | 78    | 30       | 48     | 20    | 50        | 26    |
| 6. Control | 28.06.15   | 90    | 41       | 49     | -     | -         | -     |
|          | 24.07.15   | 95    | 50       | 45     | -     | -         | -     |
|          | 04.09.15   | 91    | 48       | 43     | -     | -         | -     |
|          | 19.07.16   | 96    | 52       | 44     | -     | -         | -     |
|          | 03.09.16   | 94    | 51       | 43     | -     | -         | -     |
|          | 19.08.17   | 98    | 60       | 38     | -     | -         | -     |

*This symbol means that the effectiveness of suppressing undesirable vegetation in the control variant was not determined.

At the end of the second growing season, a further recovery of the grass cover was observed; this process was most active when only a treatment with Roundup was applied. At the same time, in
treatments 1–4, the effectiveness of herbicides remained quite high; the total projective cover of the herbaceous species did not exceed 16%.

In August 2017, after the application of mixtures of herbicides and AtronPro (treatments 1–4), their effect on a wide range of herbaceous species persisted; the projective soil cover was 38 – 49% (98% in the control), and the effectiveness of grass suppression exceeded 50%. The highest effectiveness was observed in the AtronPro treatment and in the treatment with a mixture of herbicides with a high Anchor-85 consumption of 100 g/ha (treatments 2 and 4, respectively). The lowest effectiveness of herbicides was observed in the Roundap treatment where the projective soil cover of the herbaceous layer increased up to 78%; the abundance of dicotyledonous species exceeded that in the control.

In Experiment 2, the quickest action of herbicides on herbaceous vegetation was observed in treatments with mixtures of herbicides which also included Roundup. The effect of a treatment with Arsenal was much slower (Table 2). By the end of the first season, a very high degree of suppression of herbaceous vegetation (97 – 100%) was observed in all treatments. Virtually all types of herbs present were effectively suppressed, including *Calamagrostis purpurea* (Trin. Trin. s. l.). The only exception was a treatment in which Roundup was applied in its pure form; three months after the chemical treatment of the soil, weeds partially recovered. In treatments when herbicides were most effective, active recovery of unwanted vegetation began only by the end of the second vegetation season (Table 2). In all treatments, in the fall of the second year chemical treatments were carried out as part of agrotechnical care for plantations. This measure eliminated competition from undesirable herbaceous vegetation for the duration of the following growing season.

**Table 2.** Biological effectiveness of herbicides in the experiment in chemical treatment of an area that came out of agricultural use, % (Experiment 2, treatment 10.07.2010; care for seedlings 15.10.2011 – Roundap, 3 l/ha + Anchor-85, 50 g/ha).

| Treatment | 2010 | 2011 | 2012 |
|-----------|------|------|------|
|           | August | September | October | May | June | July | August | September | October | May | June | July | August | September | October |
| 1. Arsenal, 2 l/ha | 46 | 95 | 97 | 100 | 94 | 81 | 44 | 18 | 10 | 100 | 94 | 85 | 70 | 45 | 30 |
| 2. Arsenal, 2 l/ha + Anchor-85, 100 g/ha | 79 | 97 | 99 | 100 | 100 | 95 | 88 | 65 | 47 | 100 | 94 | 86 | 71 | 47 | 33 |
| 3. Roundup, 4 l/ha + Anchor-85, 150 g/ha | 95 | 98 | 100 | 100 | 98 | 95 | 90 | 76 | 70 | 100 | 97 | 89 | 77 | 53 | 38 |
| 4. Roundup, 4 l/ha + Anchor-85, 50 g/ha + Arsenal, 0.5 l/ha | 95 | 99 | 100 | 100 | 100 | 93 | 80 | 47 | 31 | 100 | 97 | 87 | 75 | 50 | 31 |
| 5. Roundup, 3 l/ha + Anchor-85, 100 g/ha + Arsenal, 0.5 l/ha | 94 | 97 | 100 | 100 | 94 | 87 | 67 | 50 | 35 | 100 | 91 | 81 | 61 | 31 | 23 |
| 6. Roundup, 6 l/ha | 93 | 90 | 85 | 60 | 54 | 32 | 16 | 7 | 5 | 68 | 54 | 32 | 6 | 3 | 3 |
Table 3. The effect of herbicides on undesirable herbaceous vegetation in the industrial-scale experiment in chemical treatment of an area that came out of agricultural use (Experiment 3, treatment 06/25/2015).

| Treatment                      | Date      | Projective soil cover of herbaceous layer, % | Effectiveness of suppression of undesirable vegetation, % |
|--------------------------------|-----------|----------------------------------------------|----------------------------------------------------------|
|                                |           | Total | Monocots | Dicots | Total | Monocots | Dicots |
| 1. Roundup, 8 l/ha + Anchor-85, 100 g/ha | 29.07.15  | 12    | 2        | 10     | 86    | 95       | 80     |
|                                | 27.08.15  | 3     | 0        | 3      | 96    | 100      | 94     |
|                                | 31.07.16  | 7     | 1        | 6      | 92    | 97       | 88     |
|                                | 06.09.16  | 35    | 5        | 30     | 61    | 88       | 40     |
|                                | 19.07.17  | 61    | 0        | 61     | 34    | 100      | -20    |
| 2. Roundup, 5 l/ha + Anchor -85, 100 g/ha + Arsenal, 0.5 l/ha | 29.07.15  | 9     | 2        | 7      | 90    | 95       | 86     |
|                                | 27.08.15  | 2     | 0        | 2      | 98    | 100      | 96     |
|                                | 31.07.16  | 8     | 1        | 7      | 91    | 97       | 86     |
|                                | 06.09.16  | 40    | 10       | 30     | 56    | 75       | 40     |
|                                | 19.07.17  | 53    | 0        | 53     | 42    | 100      | -4     |
| 3. Roundup, 8 l/ha             | 29.07.15  | 16    | 4        | 12     | 82    | 89       | 76     |
|                                | 27.08.15  | 8     | 0        | 8      | 91    | 100      | 83     |
|                                | 31.07.16  | 46    | 18       | 28     | 48    | 54       | 44     |
|                                | 06.09.16  | 80    | 20       | 60     | 11    | 50       | -20    |
|                                | 19.07.17  | 78    | 15       | 63     | 15    | 63       | -24    |
| 4. Control                     | 29.07.15  | 87    | 38       | 49     | -a   | -a       | -a     |
|                                | 27.08.15  | 85    | 37       | 48     | -a   | -a       | -a     |
|                                | 31.07.16  | 89    | 39       | 50     | -a   | -a       | -a     |
|                                | 06.09.16  | 90    | 40       | 50     | -a   | -a       | -a     |
|                                | 19.07.17  | 92    | 41       | 51     | -a   | -a       | -a     |

*a This symbol means that the effectiveness of suppressing undesirable vegetation in the control variant was not determined.

In the industrial-scale Experiment 3, one month after the treatment the herbicides produced a noticeable effect on a wide range of herbaceous species in all three experimental treatments (Table 3). The treatment with a three-component mixture of herbicides (option 2) was the most effective; the effect of Roundup (8 l/ha, option 3) was slightly weaker. Two months after the treatment, the reduction in the projective soil cover of the herbaceous species reached 91–98% in comparison with the control. Monocotyledonous species were completely suppressed. Of the dicotyledonous species, Aegopodium podagraria L., Alchemilla vulgaris L., Potentilla erecta (L.) Raeusch., Trifolium pratense L. remained, but suffered severe damage. Of the three experimental options, a three-component mixture (option 2) was the most effective (98%), and the Roundup treatment (option 3) was the least effective (91%). In the year of treatment, no recovery of herbaceous species after the use of herbicides was observed. In the following year, there was only a slight recovery of perennial herbaceous species in treatments 1 and 2; the effectiveness of their suppression decreased slightly and was 91–92% at the end of July. There were such species as Cirsium heterophyllum (L.) Hill, C. arvense (L.) Scop., Aegopodium podagraria L., Anthriscus sylvestris (L.) Hoffm., Angelica sylvestris L., Veronica chamaedrys L., Calamagrostis arundinacea (L.) Roth. When Roundup was applied (8 l/ha, option 3), active growth of grasses, both monocotyledonous and dicotyledonous, was observed. At the end of the growing season of 2016, further growth of weeds was observed, primarily of dicotyledonous perennial species. At the same time, in the treatments with herbicide mixtures, the total projective cover of the herbaceous layer did not exceed 40%, which is quite acceptable in afforestation and reforestation. After the use of Roundup, dicotyledonous species grew very fast, their abundance exceeded that in the control. In July 2017, in the treatments with the use of mixtures of herbicides, the recovery of herbaceous species continued; at the same time the reduction of the projective cover remained at a...
rather high level compared with the control, 34 – 42%. It should be noted that monocotyledonous plants were completely suppressed in these treatments. Roundup had almost no protective effect.

In Experiment 1 carried out in a clear-cut area, after three years the survival of spruce seedlings was significantly different depending on the time of planting (Table 4). A general pattern has been observed: when the planting of spruce was delayed, the survival and growth rate of plants were higher than when planting was carried out 10 days after the treatment (Table 4).

**Table 4.** Indicators of growth and survival of spruce seedlings in the experiment in chemical treatment of a clear-cut area (Experiment 1, treatment 05/22/2015, planting 06/01/2015 and 06/24/2015, survey 29.08.2017).

| Treatment                                      | Date of planting | Survival, % | Diameter, mm | Height increment, cm | Height, cm |
|------------------------------------------------|------------------|-------------|--------------|----------------------|------------|
| 1. Roundup, 4 l/ha + Anchor-85, 100 g/ha       | 01.06.2015       | 56.7        | 8.2 ± 0.38   | 12.4 ± 0.67          | 38.1 ± 1.85|
|                                                 | 24.06.2015       | 78.8        | 9.1 ± 0.42   | 16.2 ± 0.74          | 41.3 ± 2.01|
| 2. Roundup, 3 l/ha + Anchor -85, 100 g/ha + Arsenal, 0.5 l/ha | 01.06.2015       | 60.0        | 9.4 ± 0.42   | 15.3 ± 0.76          | 38.9 ± 1.94|
|                                                 | 24.06.2015       | 76.8        | 8.2 ± 0.39   | 15.9 ± 0.68          | 40.6 ± 1.94|
| 3. Roundup, 3 l/ha + Anchor -85, 50 g/ha + Arsenal, 0.5 l/ha | 01.06.2015       | 48.5        | 7.6 ± 0.39   | 16.1 ± 0.79          | 36.9 ± 1.72|
|                                                 | 24.06.2015       | 83.9        | 9.9 ± 0.44   | 16.2 ± 0.71          | 43.2 ± 2.07|
| 4. AtronPro, 1.5 kg/ha                         | 01.06.2015       | 47.0        | 7.2 ± 0.41   | 14.9 ± 0.62          | 36.4 ± 1.83|
|                                                 | 24.06.2015       | 85.6        | 8.3 ± 0.40   | 15.4 ± 0.74          | 42.2 ± 1.94|
| 5. Roundup, 6 l/ha                            | 01.06.2015       | 24.4        | 8.1 ± 0.41   | 14.7 ± 0.69          | 35.2 ± 1.70|
|                                                 | 24.06.2015       | 78.1        | 8.5 ± 0.42   | 15.1 ± 0.74          | 41.1 ± 1.97|

In Experiment 2, high growth rates of spruce were observed in all treatments seven years after planting (Table 5).

In Experiment 3, the survival rate of pine and spruce was 100% in all three experimental treatments during the following three growing seasons. In the second year after planting, high growth rates of pine and spruce were observed (Table 6). The annual increase in height was 13.3 – 15.1 cm in pine, and 8.3 – 9.5 cm in spruce. The height of pine seedlings exceeded 35 cm, and that of spruce seedlings, 31 cm. In the third year, high growth rates of seedlings persisted: the annual increase in height was 23.3 –31.5 cm in pine, and 20.1 – 22.9 cm, in spruce. The height of pine seedlings was 56.6 – 68.5 cm, and that of spruce seedlings, 51.4 – 56.5 cm. Considering that in the experimental plots the average height of the recovered grass cover did not exceed 50 cm by the third growing season, it can be argued that competition from undesirable vegetation did not threaten further growth of the planted species.
Table 5. Growth indicators of spruce seedlings planted with CRS (planting 07/24/2010) and BRS (planting 09/23/2010) in the experiment in chemical treatment of an area that came out of agricultural use (Experiment 2, chemical treatment 07/10/2010; care for seedlings 10/15/2011; survey 10/05/2017).

| Treatment                                      | Seedlings with CRS | Seedlings with ORS |
|------------------------------------------------|--------------------|--------------------|
|                                                | Diameter, mm       | Height, cm         | Diameter, mm       | Height, cm         |
| 1. Arsenal, 2 l/ha                            | 45±2.2             | 205±9.7            | 47±2.6             | 196±11.3           |
| 2. Arsenal, 2 l/ha + Anchor-85, 100 g/ha      | 51±3.7             | 228±11.4           | 46±2.4             | 221±12.1           |
| 3. Roundup, 4 l/ha + Anchor-85, 150 g/ha      | 37±1.8             | 172±9.1            | 43±2.5             | 176±9.4            |
| 4. Roundup, 3 l/ha + Anchor-85, 100 g/ha + Arsenal, 0.5 l/ha | 49±3.4             | 208±12.2           | 44±2.4             | 196±12.4           |
| 5. Roundup, 6 l/ha                            | 44±2.6             | 205±11.6           | 42±3.8             | 202±15.1           |

Table 6. Indicators of growth of pine and spruce seedlings in the industrial-scale experiment in chemical treatment of an area that came out of agricultural use (Experiment 3, chemical treatment 06/25/2015, planting seedlings 07/31/2015).

| Treatment                                      | Date     | Tree species | Diameter, mm | Height increment, cm | Height, cm |
|------------------------------------------------|----------|--------------|--------------|----------------------|------------|
| 1. Roundup, 8 l/ha + Anchor-85, 100 g/ha      | 09.09.15 | pine         | 4.9 ± 0.25   | 15.1 ± 1.34          | 23.4 ± 1.66 |
|                                                | 15.09.16 |              | 7.9 ± 0.40   | 15.1 ± 1.41          | 37.2 ± 2.91 |
|                                                | 29.08.17 |              | 12.0 ± 0.58  | 23.3 ± 1.83          | 56.6 ± 3.59 |
|                                                | 09.09.15 | spruce       | 4.3 ± 0.19   | 7.7 ± 0.62           | 25.1 ± 1.30 |
|                                                | 15.09.16 |              | 6.6 ± 0.33   | 8.9 ± 0.81           | 31.1 ± 2.10 |
|                                                | 29.08.17 |              | 10.2 ± 0.49  | 20.8 ± 1.98          | 52.8 ± 3.41 |
| 2. Roundup, 8 l/ha + Anchor-85, 100 g/ha + Arsenal, 0.5 l/ha | 09.09.15 |              | 4.7 ± 0.23   | 14.9 ± 1.26          | 22.9 ± 1.40 |
|                                                | 15.09.16 | pine         | 7.9 ± 0.47   | 14.2 ± 1.39          | 36.1 ± 2.67 |
|                                                | 29.08.17 |              | 13.2 ± 0.63  | 31.5 ± 2.41          | 68.5 ± 4.22 |
|                                                | 09.09.15 | spruce       | 4.1 ± 0.16   | 9.6 ± 0.91           | 25.9 ± 1.41 |
|                                                | 15.09.16 |              | 6.8 ± 0.34   | 9.5 ± 0.87           | 32.6 ± 2.16 |
|                                                | 29.08.17 |              | 10.4 ± 0.55  | 22.9 ± 1.91          | 56.5 ± 3.56 |
| 3. Roundup, 8 l/ha                            | 09.09.15 |              | 4.9 ± 0.22   | 14.3 ± 1.28          | 23.5 ± 1.51 |
|                                                | 15.09.16 | pine         | 7.7 ± 0.42   | 13.1 ± 1.21          | 35.4 ± 2.72 |
|                                                | 29.08.17 |              | 12.2 ± 0.80  | 28.6 ± 2.31          | 67.4 ± 4.15 |
|                                                | 09.09.15 |              | 4.3 ± 0.18   | 8.9 ± 0.74           | 24.9 ± 0.95 |
|                                                | 15.09.16 | spruce       | 5.7 ± 0.29   | 8.3 ± 0.75           | 31.2 ± 2.14 |
|                                                | 29.08.17 |              | 10.2 ± 0.49  | 20.1 ± 1.96          | 51.4 ± 3.38 |

4. Discussion and conclusions
The positive results of the use of herbicides before planting spruce and pine seedlings demonstrated by our experiments are also confirmed by data obtained in the USA, Canada, Australia and other
countries [8, 11–14]. A relatively short-term herbicidal action of Roundup (Experiments 1 – 3) is explained by the lack of persistence, that is, the lack of a systemic effect on plants through the soil [4, 5]. Planting of spruce with CRS in the period of active growth of shoots of the current year (June 1) led to a decrease in survival and growth rates of seedlings compared with planting at a later date (June 24). In most cases, a significant difference in the growth rates of spruce and pine in experimental treatments with persistent herbicides and mixtures was not observed.

It should be noted that herbicides based on glyphosate and imazapyr are also effective arboricides acting on many deciduous tree species [4, 5]. It is worth mentioning that the elimination of all unwanted vegetation including herbaceous species is achieved simultaneously.

We found that:
- Preliminary chemical treatment of the area before planting is an effective measure to combat unwanted herbaceous vegetation. In the experimental treatments, pine and spruce seedlings were in quite favorable conditions for growth and development for the following 2–3 years after the treatment with herbicides due to the suppression of the development of undesirable vegetation.
- In both clear-cut areas and in areas that came out of agricultural use the most rapid and powerful effect was achieved when two- and three-component tank mixtures based on glyphosate, sulfometuron-methyl and imazapyr (Roundup, 4–8 l/ha + Anchor-85, 100–150 g/ha; Roundup, 3–5 l/ha + Anchor-85, 50–100 g/ha + Arsenal, 0.5 l/ha) were used. Slightly slower, but also effective and long-lasting suppression of undesirable herbaceous vegetation was achieved when a mixture of persistent herbicides, Arsenal, 2 l/ha + Anchor-85, 100 g/ha, and AtronPro, 1.5 kg/ha, was used.
- The use of Roundup in its pure form, even at a high rate (6–8 l/ha), turned out to be less effective; by the end of the first growing season there was a significant recovery of weeds.
- Spruce and pine seedlings had high survival and growth rates when they were planted during favorable agrotechnical periods and when a long-term protection from competing vegetation was provided through the use of herbicides. No external signs of damage from the soil residuals of persistent herbicides were recorded.

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