Chemical control of unwanted vegetation on the forest fund lands using Gorgon herbicide

A Golubev¹* and A Egorov²

¹ All-Russian Institute of Plant Protection, 3 Podbelskogo Highway, Saint-Petersburg, Pushkin 196608, Russian Federation
² Saint-Petersburg Forestry Research Institute, 21 Institutsky Avenue, Saint-Petersburg 194021, Russian Federation

*Corresponding email: golubev100@mail.ru

Abstract. We present the results of two field experiments performed on forest lands in the Leningrad region in 2019–2020. As means to control unwanted vegetation the herbicide Gorgon (water-soluble concentrate, active ingredients: MCPA - 350 g/l and picloram - 150 g/l) was used. We found that at rates of 1.5–4.5 l/ha the herbicide was highly efficient in suppression of a wide range of undesirable dicotyledonous species, but had almost no effect on monocotyledonous species such as grasses, sedges and rushes; as a result, the latter grew rapidly and abundantly. Gorgon is effective towards unwanted deciduous trees (willow, birch, aspen and mountain ash), and at a rate of 4.5 l/ha, also towards conifers (Scots pine and European spruce). At rates of 1.5–4.5 l/ha, the herbicide is promising for use on forest road sides, clearings, forest hayfields, on forest plantations before planting trees, as well as under power transmission lines and along pipelines passing through forest lands.

1. Introduction
In some cases, forest management requires quick and effective removal of unwanted vegetation, both woody and herbaceous. For example, during reconstruction of low-value young stands, vegetative regeneration of aspen, willow, gray alder and some other deciduous species should be removed. When establishing forest plantations, it is advisable to carry out preliminary suppression of not only woody, but also herbaceous vegetation [1]. Forest road sides should be kept free from tree vegetation, as well as other linear objects on the lands of the forest fund including pipelines and power lines.

In addition to the laborious mechanical method of vegetation clearing, which has a number of disadvantages, a chemical method is known and widely used, that is, the use of herbicides (arboricides). In past years, herbicides containing such active substances as ammonium sulfamate, 2,4-D, 2,4,5-T, triclopyr and others were used for these purposes [2, 3]. Over the past 30 years, herbicides based on glyphosate have come out on top in terms of practical use in a number of countries including Russia. Some of them, e.g. Roundup, Glyphos and some other herbicides have been registered for use in forestry and on non-agricultural lands [4]. The properties of herbicides of this chemical group have been studied in detail [5, 6]. At the same time, it is necessary to constantly expand and diversify the range of herbicides in the direction of increased efficiency and environmental safety [7]. One of the promising new herbicides for Russia, which can be used to eliminate unwanted vegetation on forest lands, is Gorgon (water-soluble concentrate, active ingredients: MCPA - 350 g/l and picloram - 150 g/l), developed by JSC Firm "August".
Picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) belongs to the group of auxin herbicides that disrupt cell growth and division. Herbicides belonging to this group were introduced to agriculture in the 1940s and were the first selective organic herbicides used in weed control. They are still widely used in rice, corn, wheat, and sugarcane cultivation and in pastures [8; 9].

In Brazil, two herbicides of this group, 2,4-D (2,4-dichlorophenoxyacetic acid) and picloram are the most common components of commercial herbicides used in agriculture. Most herbicides used on pastures contain these two substances [10; 11].

Picloram-based herbicides have a wide spectrum of applications, including both herbaceous and tree-shrub vegetation. It is important to note that such chemicals are effective against species that are resistant to many herbicides in adulthood. Studies in Australia have shown that herbicides containing picloram can significantly inhibit mature plants of Senecio madagascariensis Poir. Other herbicides effectively suppressed only young plants of this species [12].

An important factor determining a prolonged action of picloram on unwanted vegetation is its ability to persist in soil for a long period of time [13]. The herbicide is so stable in the soil that even after the simulation of precipitation in amount of 240 mm, residues of the herbicide containing 2,4-D mixed with picloram were found in a 30-centimeter-deep soil layer [14]. Residual amounts of picloram can remain in the soil for up to three years, and can even have an adverse effect on successive crops [15-17].

All these qualities of picloram contributed to its wide use not only in agriculture, but also in forestry. Since the second half of the 20th century, it has been used as such in the United States to control hard-to-eradicate weeds, usually in combination with 2,4-D [18; 19]. The use of such a combination is less expensive than pure picloram. Despite lower efficiency of the mixture against individual objects, it is still of interest due to reduced damage to the environment [20].

From the end of the last century to the present, in the United States picloram has been used to control hardwoods and cedar by injection into tree trunks. The herbicide is applied at a rate of 1 ml per cut (notch); there should be no more than 2-3 inches between cuts, and the entire cut surface should be wet [21, 22].

Picloram is currently in demand in many countries of the world. In New Zealand, studies were conducted to investigate the possibility of using picloram in combination with triclopyr, clopyralid and terbuthylazine for protection of Pinus radiata D. Don. The tank mixture of picloram with triclopyr and terbuthylazine was the only one of all combinations that ensured elimination of Buddleja davidii Franchet. [23].

At the same time, the use of high doses of picloram and triclopyr can be toxic for Pinus radiata, therefore, their combinations are used at low rates in mixture with clopyralid [24].

In China, picloram is used to control Eupatorium adenophorum Spreng, an invasive weed that, due to its rapid spread, causes significant damage to the environment, economy and human health [25].

In the UK, picloram is used to control Gaultheria shouldon L., a vigorous evergreen woody plant that is becoming an increasingly serious problem in many forests, where it completely shades young trees and prevents natural regeneration [26]. In this country, picloram (along with triclopyr) is considered as a potential replacement for glyphosate [27].

The purpose of our work was to study the effectiveness of spraying with a new herbicide Gorgon forest areas overgrown with unwanted herbaceous plants, trees, and shrubs.

2. Methods and Materials

Field experiments were carried out in the Gatchinsky district of the Leningrad region, which belongs to the Baltic-Belozersky taiga region of the taiga zone, in 2019–2020. Two field experiments were performed. The variants of application of Gorgon, dates of treatments and inventory results are provided in tables 1 and 2.

Experiment 1 was carried out under a power transmission line passing through a forest area; and experiment 2, on the side of a forest road. Both experiments were performed in the blueberry type of forest growing conditions; the soil was sod-podzolic, light loamy. The area of the experimental plot
was 150 m² (12.25 m × 12.25 m), with three replications. Spraying was carried out with a motor knapsack sprayer "Shtil" with a working fluid flow rate of 100 l/ha. During the treatment, the meteorological conditions were favorable: the air temperature was + 21–22°C, and there was no precipitation for at least 24 hours.

The biological effect of herbicides on herbaceous vegetation was determined by measuring the reduction (in percent) of the projective soil cover of herbaceous species in relation to the control (without treatment), for which 30 temporary 1x1 m reference plots for each type of experiment were established. In the first year after treatment, the effectiveness of the action on unwanted tree species was assessed by the number of dead leaves (needles), and in the second year, by the number of dead stems (as a percentage of the total).

In experiment 1, the following herbaceous plants dominated: *Cirsium heterophyllum* (L.) Hill, *Angelica sylvestris* L., *Aegopodium podagrigaria* L., *Anthriscus sylvestris* (L.) Hoffm., *Chamaenerion angustifolium* (L.) Scop., *Potentilla erecta* (L.) Rauesch., *Rubus idaeus* L., *Rubus saxatilis* L., *Vaccinium myrtillus* L., *Rhodococcum vitis-idaea* (L.) Avror., *Filipendula ulmaria* (L.) Maxim., *Carduus crispus* L., *Lathyrus pratensis* L., *Geranium sylvaticum* L., *Maianthemum bifolium* (F.W. Schmidt, *Veronica officinalis* L., *Melilotus albus* (L.) Medik., *Gallium aparine* L., *Calamagrostis arundinacea* (L.) Roth, *Avenella flexuosa* (L.) Drejer, *Deschampsia cespitosa* (L.) Beauv., *Carex spp.*, and *Juncus spp.*

In experiment 2, the following species dominated: *Cirsium heterophyllum* (L.) Hill, *Aegopodium podagrigaria* L., *Angelica sylvestris* L., *Lysimachia vulgaris* L., *Achillea millefolium* L., *Alchemilla vulgaris* L., *Chamaenerion angustifolium* (L.) Scop., *Rubus saxatilis* L., *Rhodococcum vitis-idaea* (L.) Avror., *Convallaria majalis* L., *Maianthemum bifolium* (F.W. Schmidt, *Potentilla erecta* (L.) Rauesch., *Tussilago farfara* L., *Rubus idaeus* L., *Filipendula ulmaria* (L.) Maxim., *Comarum palustris* L., *Geum rivale* L., *Melilotus albus* (L.) Medik., *Gallium aparine* L., *Calamagrostis purpurea* (Trin.) Trin. s.l., *Calamagrostis arundinacea* (L.) Roth, *Deschampsia caespitosa* (L.) Beauv., *Avenella flexuosa* (L.) Drejer, *Agrostis capillaries* L., *Alopecurus pratensis* L., *Carex spp.*

The following deciduous trees and shrubs were present: willow (*Salix spp.*), birch (*Betula spp.*), aspen (*Populus tremula* L.), mountain ash (*Sorbus aucuparia* L.) and in experiment 1, also conifers: Scots pine (*Pinus sylvestris* L.) and European spruce (*Picea abies* (L.) H. Karst.). Deciduous trees were 0.9–1.6 m tall, and conifers, 0.8–1.2 m tall.

3. Results and Discussion

A month after treatment, in both experiments Gorgon effectively suppressed dicotyledonous species, reducing their projective cover by 77% and 67% when applied at a rate of 1.5 l/ha, and by 91% when applied at a rate of 4.5 l/ha (table 1). In variants with the rate of 1.5 l/ha, most of the species of this group received only moderate or severe damage, and only *Carduus crispus* L. and *Chamaenerion angustifolium* (L.) Scop. were completely dead. In variants with the rate of 4.5 l/ha, 90–100% of the following species were completely dead: *Carduus crispus* L., *Chamaenerion angustifolium* (L.) Scop., *Filipendula ulmaria* (L.) Maxim., *Cirsium heterophyllum* (L.) Hill, *Angelica sylvestris* L., *Anthriscus sylvestris* (L.) Hoffm., *Rubus idaeus* L., *Vaccinium myrtillus* L., *Geranium sylvaticum* L., *Melilotus albus* Medik., *Gallium aparine* L. The following surviving species were severely damaged: *Rubus saxatilis* L., *Convallaria majalis* L., *Geum rivale* L. The following species had no signs of damage: *Rhodococcum vitis-idaea* (L.) Avror., *Comarum palustris* L. and *Maianthemum bifolium* (L.) F.W. Schmidt. In experiment 1, with Gorgon applied at the rate of 1.5 l/ha, the growth and increase in the abundance of monocotyledonous species were observed. In experiment 2, at the same rate of application, the that abundance of those species remained at the control level. In both experiments in variants with the rate of 4.5 l/ha we observed some growth inhibition without substantial external damage. As a result, the effectiveness of the herbicide action on all herbaceous species turned out to be low, 20–63% (table 1).

At the end of the first growing season, the influence of the herbicide applied at the rate of 1.5 l/ha on dicotyledonous species increased significantly, to 80–88%, and at the rate of 4.5 l/ha, it remained at
the same high level, 90–95%. In both experiments, at the rate of 4.5 l/ha we observed no inhibition of growth of monocotyledonous species.

The following year after the treatment, the effect of the herbicide on dicotyledonous species persisted: at the rate of 1.5 l/ha, the effectiveness was 83–89%, and at the rate of 4.5 l/ha, 88–98% (table 1). No recovery was observed. The most resistant species, *Rubus saxatilis* L., *Rhodococcum vitis-idaea* (L.) Avr., *Comarum palustris* L. and *Maianthemum bifolium* (L.) FW Schmidt, partly survived. In all variants, active growth of monocotyledonous species was observed; their abundance exceeded that in the control by 1.4–1.9 times.

**Table 1.** The effect of Gorgon herbicide on undesirable herbaceous vegetation on forest lands (experiment 1: treatment performed on 24.06.2019; experiment 2: treatment performed on 25.06.2019).

| Experiment | Treatment | Date of inventory | Projective cover of herbaceous plants, % | Effectiveness of suppression of undesirable vegetation, % |
|------------|-----------|-------------------|----------------------------------------|-----------------------------------------------------|
|            |           |                   | total | dicotyledons | monocotyledons | all species | dicotyledons | monocotyledons |
| 1          | 1. Gorgon, 1.5 l/ha | 26.07.19 | 68 | 10 | 58 | 20 | 77 | -38 |
|            |           | 28.08.19 | 60 | 8 | 52 | 26 | 80 | -27 |
|            |           | 14.06.20 | 65 | 7 | 58 | 22 | 83 | -41 |
| 2          | 2. Gorgon, 4.5 l/ha | 26.07.19 | 39 | 4 | 35 | 54 | 91 | 17 |
|            |           | 28.08.19 | 44 | 4 | 40 | 46 | 90 | 2 |
|            |           | 14.06.20 | 66 | 5 | 61 | 20 | 88 | -49 |
| 3          | Nontreated check | 26.07.19 | 85 | 43 | 42 | - | - | - |
|            |           | 28.08.19 | 81 | 40 | 41 | - | - | - |
|            |           | 14.06.20 | 83 | 42 | 41 | - | - | - |
| 2          | 1. Gorgon, 1.5 l/ha | 26.07.19 | 40 | 15 | 25 | 43 | 67 | 0 |
|            |           | 28.08.19 | 38 | 5 | 33 | 42 | 88 | -50 |
|            |           | 14.06.20 | 50 | 5 | 45 | 26 | 89 | -88 |
| 2          | 2. Gorgon, 4.5 l/ha | 26.07.19 | 26 | 4 | 22 | 63 | 91 | 12 |
|            |           | 28.08.19 | 29 | 2 | 27 | 55 | 95 | -23 |
|            |           | 14.06.20 | 41 | 1 | 40 | 40 | 98 | -67 |
| 3          | Nontreated check | 26.07.19 | 70 | 45 | 25 | - | - | - |
|            |           | 28.08.19 | 65 | 43 | 22 | - | - | - |
|            |           | 14.06.20 | 68 | 44 | 24 | - | - | - |

A high efficiency of the herbicide action on dicotyledonous herbaceous weeds demonstrated by our experiments is in good agreement with the results of experiments performed in Australia and China where Thordon, Grazon Extra and other herbicides containing picloram were used [9, 12]. The absence of an apparent herbicidal effect of picloram on monocotyledonous species has been confirmed by research results from New Zealand [23, 24].

A month after the treatment, Gorgon applied at both rates effectively suppressed all deciduous trees and shrubs present (table 2). At the rate of 1.5 l/ha, the herbicide caused fatal damage to 83–98% of leaves, and at the rate of 4.5 l/ha, to 92–100% of leaves, depending on the tree species. The highest
sensitivity was shown by aspen, and a relatively high resistance, by mountain ash. In the variant with the rate of 1.5 l/ha Scots pine received no damage, and with the rate of 4.5 l/ha, slight damage. At the rate of 1.5 l/ha, all European spruce plants were weakly damaged (deformation of shoots, desiccation of 5–10% of needles), and at the rate of 4.5 l/ha were severely damaged (desiccation of 50–60% of all needles).

At the end of the first growing season, Gorgon herbicide applied at the rate of 1.5 l/ha caused fatal damage to 87–98% of leaves, and at the rate of 4.5 l/ha, to all (100%) leaves in all four deciduous species. Mountain ash was the most resilient. Vegetative regeneration of deciduous species was not observed. In the variant with the application rate of 1.5 l/ha Scots pine was slightly damaged, and with the rate of 4.5 l/ha, desiccation of needles was 30–40%. European spruce received severe damage: at the rate of 1.5 l/ha desiccation was observed in 40–50% of needles, and at the rate of 4.5 l/ha, in 95% of needles. Scots pine showed higher herbicide resistance compared to European spruce.

The following year, after Gorgon application at the rate of 1.5 l/ha, 93–96% of willow trees, 93–95% of birch trees, and 98–100% of aspen and 93–96% of mountain ash trees died. At the rate of 4.5 l/ha, the death of all (100%) tree species was observed. However, at the rate of 1.5 l/ha, all deciduous species began to recover due to resprouting, and in variants with the rate of 4.5 l/ha, no resprouting was observed. In the variant with the rate of 1.5 l/ha, only 25% of Scots pine trees and 85% of European spruce trees died; and in the variant with the rate of 4.5 l/ha, 65% and 100%, respectively.

Table 2. The effect of Gorgon herbicide on undesirable trees and shrubs growing on forest lands (experiment 1: treatment performed on 24.06.2019; experiment 2: treatment performed on 25.06.2019).

| Experiment | Treatment | Date of inventory | Share of dead leaves (trees), % |
|------------|-----------|-------------------|---------------------------------|
| 1          | 1. Gorgon, 1.5 l/ha | 26.07.19          | Willow: 88, Birch: 90, Aspen: 98, Mountain ash: 85 |
|            |           | 28.08.19          |                                 |
|            |           | 14.06.20          |                                 |
| 2          | 2. Gorgon, 4.5 l/ha | 26.07.19          | Willow: 98, Birch: 97, Aspen: 100, Mountain ash: 95 |
|            |           | 28.08.19          |                                 |
|            |           | 14.06.20          |                                 |
| 1          | 1. Gorgon, 1.5 l/ha | 26.07.19          | Willow: 91, Birch: 83, Aspen: 91, Mountain ash: 78 |
|            |           | 28.08.19          |                                 |
|            |           | 14.06.20          |                                 |
| 2          | 2. Gorgon, 4.5 l/ha | 26.07.19          | Willow: 96, Birch: 95, Aspen: 96, Mountain ash: 92 |
|            |           | 28.08.19          |                                 |
|            |           | 14.06.20          |                                 |

The arboricidal properties of picloram in respect to deciduous species have been studied by Neary et al. [18, 19]. However, the data on its effect on conifers are limited. In the available literature, we could not find experimental data on the effectiveness of Gorgon towards Scots pine and European spruce.

4. Conclusion

Based on the results of our experiments we came to the following conclusions:

- Gorgon herbicide (water-soluble concentrate, active ingredients: MCPA, 350 g/l and picloram, 150 g/l) at the rates of 1.5–4.5 l/ha showed high (83–98%) suppression efficiency towards herbaceous dicotyledonous species typical for taiga forest zone.
- The herbicide does not have a significant effect on monocotyledonous grasses, including cereals, sedges and rushes. As a result, there was a significant and rapid increase in their
abundance (1.4–1.9 times compared to the control), as a result of reduced competition with dicotyledonous species.

- Gorgon is effective towards unwanted deciduous trees: willow, birch, aspen and mountain ash. When Gorgon was applied at the rate of 1.5 l/ha, 93–100% of all trees died, depending on the species, and at the rate of 4.5 l/ha, 100% of all trees died. Aspen was the species most sensitive to the herbicide, while mountain ash, the most resistant. At the rate of 1.5 l/ha, the regrowth of deciduous species from root systems was observed.

- At the rate of 4.5 l/ha, Gorgon was quite effective towards conifers: 65% of Scots pine trees and all European spruce trees died. The rate of 1.5 l/ha was not high enough to effectively suppress conifers.

At the rates of 1.5–4.5 l/ha, the herbicide is promising for use on forest road sides, clearings, forest hayfields, on forest plantations before planting trees, as well as under power transmission lines and pipelines passing through forest lands.

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