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FRONTIER TECHNIQUE OF CREATING PROTECTIVE FORESTS STANDS AROUND NURSERIES ON INEFFICIENT SITES: TECHNOLOGICAL FOUNDATIONS

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Abstract

The technique can be used in forestry when creating and modeling protective forest stands around nursery's objects. The equipment is designed for sites that are difficult to restore or inaccessible to ground-based mechanization and human means. Hard-to-recover sites are defined as: 1) released as a result of deforestation, including fire, ineffective for the operational technology of ground-based sowing or planting; 2) released as a result of fires, ineffective for the operational technology of ground seeding or planting; 3) inaccessible to ground-based mechanization facilities for climatic and geomorphological reasons; 4) inaccessible to people due to the complication of the radiation background and (or) after man-made disasters. The technique provides for accelerating the process of creating forests and improving environmental safety for the environment by reducing the number of operations that violate the forest ecosystem, using environmentally friendly energy sources in unmanned aerial vehicles, equipment and devices used in all groups of operations, improving environmental safety for humans by enabling the implementation of the method without the presence of an operator directly at the site of the groups of operations, reducing the cost of performing energy-intensive and time-consuming operations for preparing sites, transportation of forest reproductive material to the place of preliminary preparation and back.

Keywords: forest nurseries, protective forest stand, seed pelleting, seed grading, UAV-based remote sensing, UAV-based seeding

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ФРОНТИРНЫЙ МЕТОД СОЗДАНИЯ ЗАЩИТНЫХ ЛЕСНЫХ НАСАЖДЕНИЙ ВОКРУГ ПИТОМНИКОВ НА НЕЭФФЕКТИВНЫХ УЧАСТКАХ: ТЕХНОЛОГИЧЕСКИЕ ОСНОВЫ

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Метод может быть использован в лесном хозяйстве при создании и моделировании защитных лесных насаждений вокруг объектов лесного питомника. Предназначен для участков, которые трудно восстановить по причине недоступности для наземных средств механизации и человека. Трудновосстанавливаемые участки определяются как: 1) высвобожденные в результате вырубки лесов, включая пожары, неэффективные для оперативной технологии наземного посева или посадки; 2) высвобожденные в результате пожаров, неэффективные для операционной технологии наземного посева или посадки; 3) недоступные для наземных средств механизации по климатическим и геоморфологическим причинам; 4) недоступные для людей в связи с осложнением радиационного фона и (или) после техногенных катастроф. Метод предусматривает ускорение процесса создания лесов и повышение экологической безопасности для окружающей среды за счет сокращения количества операций, нарушающих лесную экосистему, использования экологически чистых источников энергии в беспилотных летательных аппаратах, оборудовании и устройствах, используемых во всех группах операций, повышение экологической безопасности для людей за счет обеспечения реализации метода без присутствия оператора непосредственно на месте проведения групп операций, снижение затрат на выполнение энергоемких и трудоемких операций по подготовке участков, транспортировке лесного репродуктивного материала к месту предпосевной подготовки и обратно.

Ключевые слова: лесные питомники, защитные лесные насаждения, пеллетирование семян, сортировка семян, дистанционное зондирование молодого леса с БПЛА, посев лесных семян с БПЛА

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Introduction

The results of investments in forestry research can be realized only if tenants or owners of forest areas have access to a wide range of high-quality seed producers adapted to the method and place of creation of forest crops, and also provide timely agrotechnical care for forest crops. Historically, it is Pautov et al. known that "due to the lack of equipment for creating forest crops and caring for them in conditions of cluttered, waterlogged cuttings, the severity of climatic conditions, the lack of systematic care, even in the conditions of the European North, more than half of the crops created are dying [1]".

By improving and adapting the methodology to the conditions of application of the technology, for example in the Russian Federation, we will establish the basic structural elements and elements characteristic of performing operation groups for reforestation of hard-to-reach sites. Well-managed vegetation is associated with the reduction of soil erosion [2] and the protection of juvenile crops of forest nursery from damage by wind, snow and sand [3].

To substantiate the structure, we will consider the most characteristic, traditional technological processes [1], including *n* main groups (n = 2) of *K* operations (Figure 1): preparing the area and planting seedlings (in less common cases – seeding).

Currently, there are no machines in the world for a group of area preparation operations that can be operated on waterlogged soils with low load-bearing capacity without causing certain problems. There are no military vehicles that can repeatedly move along the same track in off-road conditions. Machines with wide tracks and air cushion cannot be used on hard-to-recover areas due to stumps. As a rule, special tractors designed for this purpose should work on the slopes, but it is also allowed to work with flat tractors – universally tilled on slopes with angles up to 8...9 ° and tracked general purpose – up to 12°.

Algorithmically, the traditional process of reforestation of hard-to-reach areas is described by the main criteria [4] related to geomorphology and climatic conditions of operations. There are the following options for implementing the classical technology of forest landscape restoration [5–7] according to the algorithm shown in the figure:

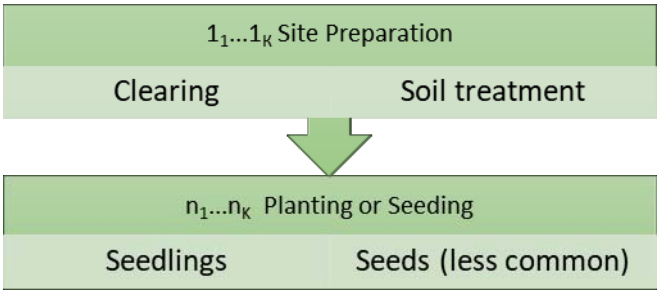

Figure 1. A block diagram of a two-group (n = 2) technological process of forest restoration in areas that are difficult to restore or inaccessible to ground-based mechanization or humans; adapted in [1].

Рис. 1. Структурная схема двухгруппового (n = 2) технологического процесса восстановления лесов на участках, которые трудно восстановить или они недоступны для наземной механизации или людей

Source: Novikov, A.I. Improvement of technology for obtaining high-quality forest seed material : advanced Doctoral Thesis, Voronezh State University of Forestry and Technologies, 2021.

Источник: Новиков, А.И. Совершенствование технологии получения высококачественного лесосеменного материала: дис. ... д-ра техн. наук : 05.21.01. Воронеж, ВГЛТУ, 2021.

The development of an optimization model for the classical mechanized technology of artificial reforestation is not included in the tasks of this scientific work, however, based only on a simplified algorithm (without taking into account: specific machines and aggregates with their performance; variation of soil types; reasons for reforestation – after continuous logging, fires, etc.) we see that such a task is of a multicriteria nature and if a mathematical model is developed based on minimizing downtime of equipment and people, then with a high degree of probability such a task will be NP-complete [4], requiring either a complete search of all possible options, or additional development of a heuristic algorithm to solve it.

It is obvious that a transition is needed from a two-group (see Figure 1) technological process of forest restoration in areas that are difficult to restore or inaccessible to ground-based mechanization or human means to a process that also takes into account the operations of preparing high-quality forest reproductive material.

The purpose is to assess the degree of applicability of technical and technological solutions for the creation of protective forest on inefficient sites.

Materials and Methods

The type of the polygroup process (figure 2) of creating protective forest plantations around gardens in hard-to-reach areas was preliminarily determined. The selection of technical and technological solutions and frontier techniques was based on structural and functional modeling.

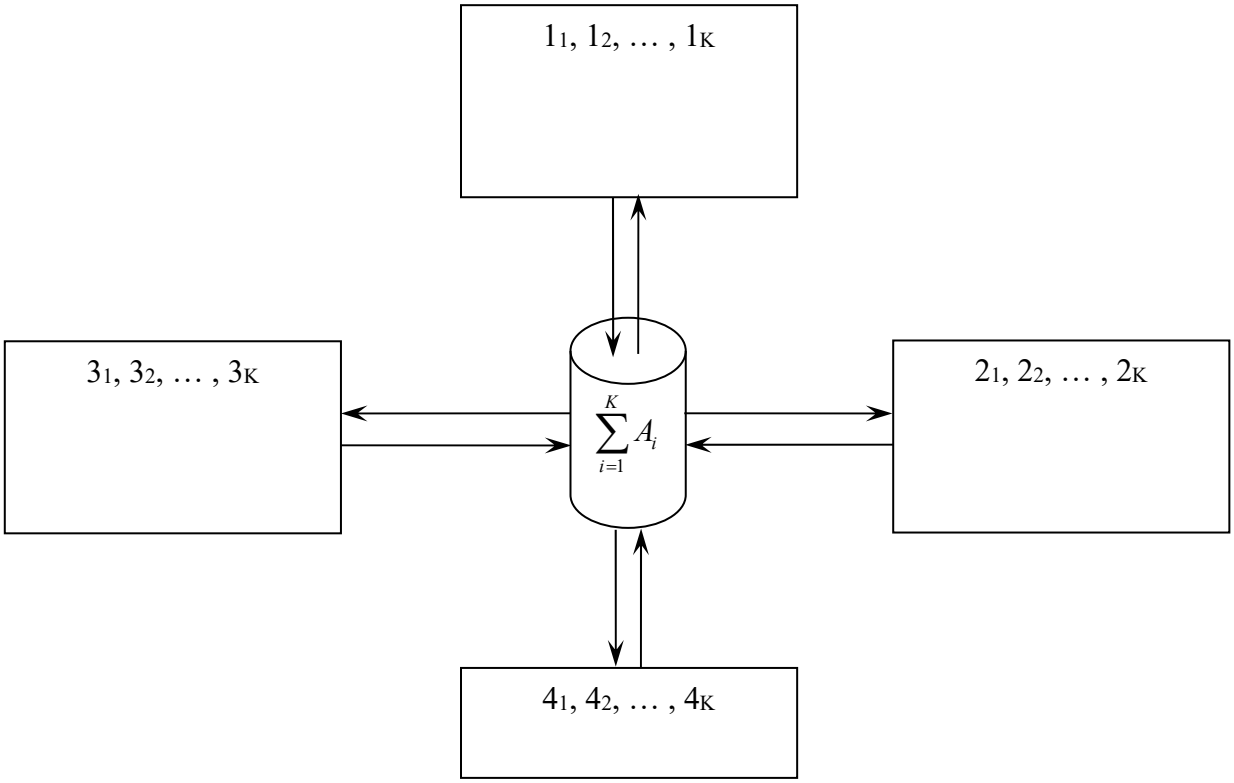

Figure 2. A block diagram of technological solutions of a semi-group (n >2) process of forest restoration technology in areas that are difficult to restore or inaccessible to ground-based mechanization or human means

Рис. 2. Структурная схема технологических решений полугруппового (n >2) процесса технологии восстановления лесов в районах, которые трудно восстановить или недоступны для наземной механизации или человеческих средств

Source: Novikov, A.I. Forest restoration method. RU Patent 2 714 705, 20 May 2019.

Источник: Пат. 2714705 Российская Федерация, МПК A 01 G 23/00. Способ восстановления леса / Новиков А.И.; заявитель и патентообладатель Воронеж. гос. лесотехн. ун-т. – № 2019115418 ; заявл. 20.05.2019 ; опубл. 19.02.2020, Бюл. №5.

The degree of similarity and differences of technical and technological solutions when creating protective forest plantations on inefficient sites was assessed using hierarchy analysis in the IBM SPSS Statistics 25 application software package.

Results and Discussion

Regarding the type of hard-to-reach area vacated as a result of logging or harem, this block diagram is implemented in technological solutions (Pat. SU 1501975; A01G 23/00; 08/23/1989), including strip preparation of the area and planting of forest crops, carrying out simultaneously with gradual logging mineralization of dry sandy soils and thereby ensuring the emergence of undergrowth and renewal of the forest without the cost of creating crops (pat. RU 2138947; A01G 23/00; 10.10.1999). No less interesting is the

technological solution, which includes in the group of operations for preparing the area the incision of the surface of the stumps within the width of the tractor, the application of spores from fruit bodies and mycelium of fungi for the semi-destruction or complete destruction of the stumps within 3-5 years, 1-2-fold passage along the strip marked for planting tools such as knife rollers (pat. RU 2238634; A01G 23/00; 27.10.2004). The process of afforestation and reforestation on a large-scale using aircraft is more technologically advanced from the point of view of accessibility of the area (pat. WO 2007/033446; A01G 23/00, A01C 11/00; 29.03.2007), including the preparation of the area for planting in the form of irrigation with drops with adjustable size (water and herbicides), planting seedlings from a helicopter or glider in disposable cocoons of arrow shape.

The disadvantages of these technological solutions are high energy consumption, material consumption and labor intensity, as well as low survival rate of plants due to damage to the root system during double transplantation, and in the case of a manned aircraft, also a low level of landing accuracy due to the impossibility of approach at an ultra-low altitude.

Regarding the type of inaccessible area caused by geomorphology [8], this block diagram is implemented in technological solutions (pat. RU 2643245; A01G 23/00; 31.01.2018), including the site preparation [9–14], planting, and reforestation is carried out on mountain slopes in stages: at the first stage, mountain areas for reforestation are determined, taking into account the presence of wild seedlings in neighboring areas in the lowlands, near roads, quarries or ravines, at the second stage, two-three-year-old wild seedlings are dug out and transplanted to places on selected sites with subsequent watering, forming curtains to create conditions for the seeds of grown trees, curtains at the age of 20-30 in the autumn and spring periods are transferred by wind currents to the rest of the selected site.

The disadvantages of these technological solutions are possible damage to the root system of transplanted two- to three-year-old trees, high costs of transplanting trees, increasing during manual transplanting, as well as a significantly time-stretched reforestation process.

It is obvious that a transition is needed from a two-group (see Figure 1) technological process of forest restoration in areas that are difficult to restore or inaccessible to ground-based mechanization or human means to a process that also takes into account the operations of preparing high-quality forest reproductive material.

Regarding the transition to the poly-group process, there are technological solutions (pat. US 5406898; A01G 23/02; 18.04.1995), including the preparation of the area (cutting down trees and shrubs, transporting whips), preparation of forest reproductive material (crushing on-site felling residues, including cones, and obtaining seeds of various coniferous crops from them), sowing randomly on the area being restored.

The disadvantages of these technological solutions are the absolute seasonality of implementation, since the yield of seeds in cones is provided only in a certain period once every three to four years, high damage and low viability of forest seeds.

Figure 2 shows a block diagram of the implementation of the forest restoration method, including groups of operations: monitoring of area 1_1, 1_2, ..., 1_K; preparation of area 2_1, 2_2, ..., 2_K; preparation of forest reproductive material 3_1, 3_2, ..., 3_K; sowing seeds or planting seedlings on the restored area 4_1, 4_2, ...,4_K.

According to a fundamentally new structure, the implementation of the technology is carried out in the following order.

1. Conduct a group of operations 1_1, 1_2, ..., 1_K monitoring of the forest landscape restoration (FLR) area, including operations of preliminary multi-criteria assessment of the FLR area, implemented on the basis of an unmanned aerial vehicle of helicopter, airplane or hybrid types.

2. Assess the degree of necessity and efficiency of performing energy-consuming and time-consuming operations in groups of operations for site preparing, preparing forest reproductive material [15] (seed spectrometric grading [16], seed pelleting [17,18]), seeding or planting [15] on the site, implemented on the basis of fuzzy logic algorithms [19].

3. Determine the required number of operations (K) in each of the groups and the number of equipment (Q) to perform them.

4. Carry out, if necessary, which is defined in paragraph 2, a group of operations for preparing the area 2_1, 2_2, ..., 2_K.

It should be noted that if it is impossible to completely exclude a group of soil preparation operations, it is necessary to use a tool for cavity tillage, which ensures sufficient patency of the unit in uncorrected cuttings and the required quality of tillage. At the same time, the economic effect will be achieved due to [20]:

– the ability to carry out tillage without prior expensive and energy-intensive operations for uprooting and clearing of cuttings and harems;

– increase productivity by increasing the width of the processing, and therefore reducing the number of passes over the treated area and eliminating stops of the unit for cleaning disk housings, since the design eliminates sticking of the tool with soil and clogging with plant residues;

– reducing the energy consumption of the unit, due to the reduction of the pulling force of the gun, due to the individual adjustment of each disk housing to the optimal technological modes of operation (angle of attack, angle of inclination relative to the vertical, angle of rotation of the blade);

– reduction of material costs for the repair of the gun, since the individual attachment of the disc-cutter housings to the gun frame will reduce the impact loads that occur when encountering obstacles;

– improvement of germination, survival and subsequent development of planting material, due to the exclusion of uprooting of stumps, which leads to the removal of the upper humus soil layer along with the stumps and exposure of underlying structureless horizons, while the strip after clearing acquires a hollow profile, contributing to water stagnation and waterlogging; ensuring full turnover of the soil layer and embedding plant residues in the upper soil layer, which contributes to the accumulation of humus.

The levels of energy costs and environmental safety depending on the method of implementation of seeding and planting operations are illustrated in Fig. 3.

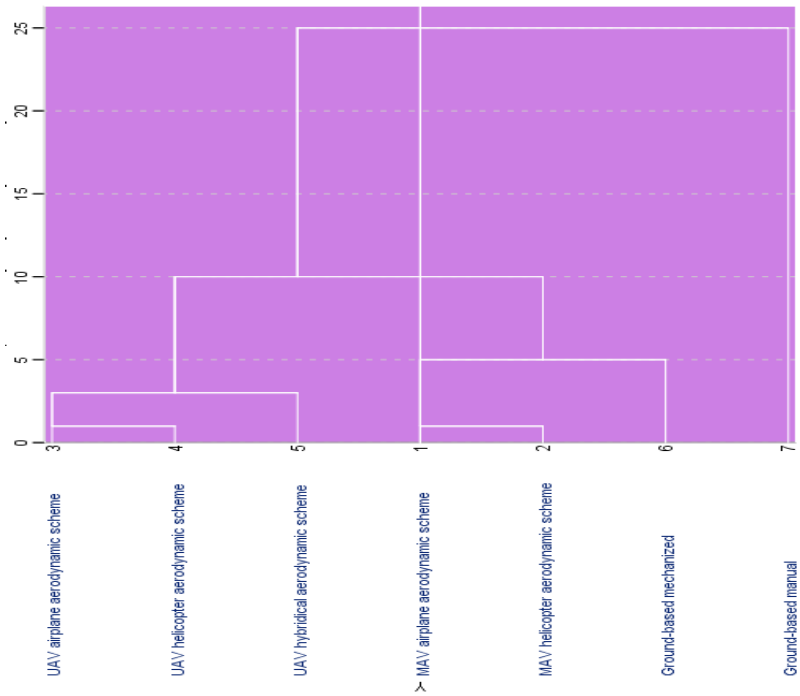

Figure 3. A diagram of the similarity of technical and technological solutions of frontier technique. To visualize the analysis of hierarchies, the median clustering method with a quantitative Euclid Square (Y-axis) measure was used.

Рис. 3. Диаграмма сходства технических и технологических решений фронтирного метода. Для визуализации анализа иерархий использовался метод медианной кластеризации с количественной мерой квадрата Евклидова расстояния (ось Y)

Source: own calculations Источник: собственные вычисления авторов

5. A group of operations for the preparation of forest reproductive material 3_1, 3_2, ..., 3_K is carried out, including: an alternative operation for express analysis of geometric and spectrometric characteristics of seeds, carried out in the field using mobile technical means - separating devices, isolating viable coat colour seed races in the visible and infrared wavelength region [21–24] at the earliest stage of processing, which are the basis for obtaining forest reproductive material with specified qualitative characteristics; an alternative encapsulation operation carried out in the field with the use of mobile technical means forming capsules of a certain aerodynamic shape, weight and strength, with the necessary supply of nutritious, fungicidal and antipredatory substances that ensure optimal performance of seeds during sowing and seedlings during planting, including from the air, and protective functions for early-growing seedlings.

6. A group of seed seeding or seedling planting operations is carried out on an area of 4_1, 4_2, ..., 4_K, including an alternative operation of spot seeding or landing from the air, carried out using unmanned aerial vehicles of helicopter, airplane or hybrid types, equipped with closely integrated (satellite-inertial) navigation equipment [25] for movement under the canopy of the forest at long intervals, equipment for simultaneous storage of sown seeds or planted seedlings, taking into account their take-off weight, control of a given seeding rate or planting seedlings on a quantitative or mass basis and accurate seeding or planting seedlings, depending on a given scheme of placement of forest crops and the speed of an unmanned aerial vehicle, energy storage equipment to create an energy reserve for the purpose of directional movement of seedling capsules or capsules with seedlings to the area being restored, providing a given depth of seeding or planting seedlings, depending on the height of the flight corridor and the agrotechnical condition of the area.

Conclusion

The analysis of hierarchies among technical and technological solutions by the level of time, technological, financial costs and environmental safety identified 4 significantly distinguishable groups that have pronounced features.

Список литературы

1. Novikov, A.I. Improvement of technology for obtaining high-quality forest seed material : advanced Doctoral Thesis, Voronezh State University of Forestry and Technologies, 2021.

2. Rey, F.; Bifulco, C.; Bischetti, G.B.; Bourrier, F.; De Cesare, G.; Florineth, F.; Graf, F.; Marden, M.; Mickovski, S.B.; Phillips, C.; et al. Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. *Sci. Total Environ.* **2019**, *648*, 1210–1218, doi:10.1016/j.scitotenv.2018.08.217.

3. Ivantsova, E.A.; Ovsyankin, R. V.; Matveeva, A.A.; Onistratenko, N. V. Environmental Evaluation of the System of Protective Forest Plantations in Urban Landscapes Volgograd Agglomeration Using Gis-Technologies. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *224*, 012036, doi:10.1088/1755-1315/224/1/012036.

4. Novikova, T.P. The Choice of a Set of Operations for Forest Landscape Restoration Technology. *Inventions* **2022**, *7*, 1, doi:10.3390/inventions7010001.

5. Stanturf, J.A.; Mansourian, S. Forest landscape restoration: state of play. *R. Soc. Open Sci.* **2020**, *7*, 201218, doi:10.1098/rsos.201218.

6. Yu, E.; Zhang, M.; Xu, Y.; Zhang, S.; Meng, Z.; Hou, Y. The development and application of a gis-based tool to assess forest landscape restoration effects on water conservation capacity. *Forests* **2021**, *12*, doi:10.3390/f12091291.

7. Bollenbacher, B.L.; Graham, R.T.; Reynolds, K.M. Regional forest landscape restoration priorities: Integrating historical conditions and an uncertain future in the Northern Rocky Mountains. *J. For.* **2014**, *112*, 474–483, doi:10.5849/jof.13-086.

8. Shalizi, M.N.; Goldfarb, B.; Burney, O.T.; Shear, T.H. Effects of five growing media and two fertilizer levels on polybag-Raised camden whitegum (Eucalyptus benthamii maiden & cambage) seedling morphology and drought hardiness. *Forests* **2019**, *10*, doi:10.3390/f10070543.

9. Thiffault, N.; Hébert, F. Mechanical site preparation and nurse plant facilitation for the restoration of subarctic forest ecosystems. *Can. J. For. Res.* **2017**, *47*, 926–934, doi:10.1139/cjfr-2016-0448.

10. Chaves Cardoso, J.; Burton, P.J.; Elkin, C.M. A Disturbance Ecology Perspective on Silvicultural Site Preparation. *Forests* **2020**, *11*, 1278, doi:10.3390/f11121278.

11. Sikström, U.; Hjelm, K.; Holt Hanssen, K.; Saksa, T.; Wallertz, K. Influence of mechanical site preparation on regeneration success of planted conifers in clearcuts in Fennoscandia – a review. *Silva Fenn.* **2020**, *54*, doi:10.14214/sf.10172.

12. Aleksandrowicz-Trzcińska, M.; Drozdowski, S.; Studnicki, M.; Żybura, H. Effects of Site Preparation Methods on the Establishment and Natural-Regeneration Traits of Scots Pines (Pinus sylvestris L.) in Northeastern Poland. *Forests* **2018**, *9*, 717, doi:10.3390/f9110717.

13. Manner, J.; Ersson, B.T. Mechanized tree planting in Nordic forestry: Simulating a machine concept for continuously advancing site preparation and planting. *J. For. Sci.* **2021**, *67*, 242–246, doi:10.17221/203/2020-JFS.

14. Thiffault, N.; Elferjani, R.; Hébert, F.; Paré, D.; Gagné, P. Intensive Mechanical Site Preparation to Establish Short Rotation Hybrid Poplar Plantations—A Case-Study in Québec, Canada. *Forests* **2020**, *11*, 785, doi:10.3390/f11070785.

15. Novikov, A.I.; Sokolov, S.V.; Drapalyuk, M.V.; Zelikov, V.A.; Ivetić, V. Performance of Scots Pine Seedlings from Seeds Graded by Colour. *Forests* **2019**, *10*, 1064, doi:10.3390/f10121064.

16. Novikov, A.I.; Ivetić, V. The effect of seed coat color grading on height of one-year-old container-grown Scots pine seedlings planted on post-fire site. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *226*, 012043, doi:10.1088/1755-1315/226/1/012043.

17. Ostroshenko, V.Y.; Akimov, R.Y.; Gamaeva, S. V.; Inshakov, S. V.; Ostroshenko, V.Y.V.Y.; Ostroshenko, L.Y.; Zamyshlyaev, S. V. Formation of the seed layer from the organomineral mixture during the seed pelleting of coniferous tree species. *EurAsian J. Biosci.* **2018**, *12*, 77–82.

18. Afzal, I.; Javed, T.; Amirkhani, M.; Taylor, A.G. Modern Seed Technology: Seed Coating Delivery Systems for Enhancing Seed and Crop Performance. *Agriculture* **2020**, *10*, 526, doi:10.3390/agriculture10110526.

19. Novikov, A.I.; Vovchenko, N.G.; Sokolov, S. V; Novikova, T.P.; Demidov, D.N.; Tylek, P. Improving the quality of automated VIS–grading of Scots pine seeds using fuzzy logic algorithm. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *875*, 012032, doi:10.1088/1755-1315/875/1/012032.

20. Zimarin, S.; Novikov, A.I.; Meshcheryakova, A.; Borodin, N. Forestry innovation in new disk cutter for soil preparation on non-uprooting site. *Proc. 33rd Int. Bus. Inf. Manag. Assoc. Conf.* **2019**, 3120–3129.

21. França-Silva, F.; Rego, C.H.Q.; Gomes-Junior, F.G.; Moraes, M.H.D. de; Medeiros, A.D. de; Silva, C.B. da Detection of Drechslera avenae (Eidam) Sharif [Helminthosporium avenae (Eidam)] in Black Oat Seeds (Avena strigosa Schreb) Using Multispectral Imaging. *Sensors* **2020**, *20*, 3343, doi:10.3390/s20123343.

22. Bianchini, V.; Mascarin, G.; Silva, L.C.; Arthur, V.; Carstensen, J.; Boelt, B.; Silva, C.B. da Multispectral and X-ray Images for Characterization of Jatropha Curcas L. Seed Quality. *Plant Methods* **2020**, 1–14, doi:10.21203/rs.3.rs-28449/v1.

23. Galletti, P.A.; Carvalho, M.E.A.; Hirai, W.Y.; Brancaglioni, V.A.; Arthur, V.; Barboza da Silva, C. Integrating Optical Imaging Tools for Rapid and Non-invasive Characterization of Seed Quality: Tomato (Solanum lycopersicum L.) and Carrot (Daucus carota L.) as Study Cases. *Front. Plant Sci.* **2020**, *11*, 577851, doi:10.3389/fpls.2020.577851.

24. Barboza da Silva, C.; Bianchini, V. de J.M.; Medeiros, A.D. de; Moraes, M.H.D. de; Marassi, A.G.; Tannús, A. A novel approach for Jatropha curcas seed health analysis based on multispectral and resonance imaging techniques. *Ind. Crops Prod.* **2021**, *161*, 113186, doi:10.1016/j.indcrop.2020.113186.

25. Sokolov, S. V.; Polyakova, M. V.; Kucherenko, P.A. Analytic Synthesis of a Kalman Adaptive Filter on the Basis of Irregular Precise Measurements. *Meas. Tech.* **2018**, *61*, 232–237, doi:10.1007/s11018-018-1414-5.

References

1. Novikov, A.I. Improvement of technology for obtaining high-quality forest seed material : advanced Doctoral Thesis, Voronezh State University of Forestry and Technologies, 2021.

2. Rey, F.; Bifulco, C.; Bischetti, G.B.; Bourrier, F.; De Cesare, G.; Florineth, F.; Graf, F.; Marden, M.; Mickovski, S.B.; Phillips, C.; et al. Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. *Sci. Total Environ.* **2019**, *648*, 1210–1218, doi:10.1016/j.scitotenv.2018.08.217.

3. Ivantsova, E.A.; Ovsyankin, R. V.; Matveeva, A.A.; Onistratenko, N. V. Environmental Evaluation of the System of Protective Forest Plantations in Urban Landscapes Volgograd Agglomeration Using Gis-Technologies. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *224*, 012036, doi:10.1088/1755-1315/224/1/012036.

4. Novikova, T.P. The Choice of a Set of Operations for Forest Landscape Restoration Technology. *Inventions* **2022**, *7*, 1, doi:10.3390/inventions7010001.

5. Stanturf, J.A.; Mansourian, S. Forest landscape restoration: state of play. *R. Soc. Open Sci.* **2020**, *7*, 201218, doi:10.1098/rsos.201218.

6. Yu, E.; Zhang, M.; Xu, Y.; Zhang, S.; Meng, Z.; Hou, Y. The development and application of a gis-based tool to assess forest landscape restoration effects on water conservation capacity. *Forests* **2021**, *12*, doi:10.3390/f12091291.

7. Bollenbacher, B.L.; Graham, R.T.; Reynolds, K.M. Regional forest landscape restoration priorities: Integrating historical conditions and an uncertain future in the Northern Rocky Mountains. *J. For.* **2014**, *112*, 474–483, doi:10.5849/jof.13-086.

8. Shalizi, M.N.; Goldfarb, B.; Burney, O.T.; Shear, T.H. Effects of five growing media and two fertilizer levels on polybag-Raised camden whitegum (Eucalyptus benthamii maiden & cambage) seedling morphology and drought hardiness. *Forests* **2019**, *10*, doi:10.3390/f10070543.

9. Thiffault, N.; Hébert, F. Mechanical site preparation and nurse plant facilitation for the restoration of subarctic forest ecosystems. *Can. J. For. Res.* **2017**, *47*, 926–934, doi:10.1139/cjfr-2016-0448.

10. Chaves Cardoso, J.; Burton, P.J.; Elkin, C.M. A Disturbance Ecology Perspective on Silvicultural Site Preparation. *Forests* **2020**, *11*, 1278, doi:10.3390/f11121278.

11. Sikström, U.; Hjelm, K.; Holt Hanssen, K.; Saksa, T.; Wallertz, K. Influence of mechanical site preparation on regeneration success of planted conifers in clearcuts in Fennoscandia – a review. *Silva Fenn.* **2020**, *54*, doi:10.14214/sf.10172.

12. Aleksandrowicz-Trzcińska, M.; Drozdowski, S.; Studnicki, M.; Żybura, H. Effects of Site Preparation Methods on the Establishment and Natural-Regeneration Traits of Scots Pines (Pinus sylvestris L.) in Northeastern Poland. *Forests* **2018**, *9*, 717, doi:10.3390/f9110717.

13. Manner, J.; Ersson, B.T. Mechanized tree planting in Nordic forestry: Simulating a machine concept for continuously advancing site preparation and planting. *J. For. Sci.* **2021**, *67*, 242–246, doi:10.17221/203/2020-JFS.

14. Thiffault, N.; Elferjani, R.; Hébert, F.; Paré, D.; Gagné, P. Intensive Mechanical Site Preparation to Establish Short Rotation Hybrid Poplar Plantations—A Case-Study in Québec, Canada. *Forests* **2020**, *11*, 785, doi:10.3390/f11070785.

15. Novikov, A.I.; Sokolov, S.V.; Drapalyuk, M.V.; Zelikov, V.A.; Ivetić, V. Performance of Scots Pine Seedlings from Seeds Graded by Colour. *Forests* **2019**, *10*, 1064, doi:10.3390/f10121064.

16. Novikov, A.I.; Ivetić, V. The effect of seed coat color grading on height of one-year-old container-grown Scots pine seedlings planted on post-fire site. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *226*, 012043, doi:10.1088/1755-1315/226/1/012043.

17. Ostroshenko, V.Y.; Akimov, R.Y.; Gamaeva, S. V.; Inshakov, S. V.; Ostroshenko, V.Y.V.Y.; Ostroshenko, L.Y.; Zamyshlyaev, S. V. Formation of the seed layer from the organomineral mixture during the seed pelleting of coniferous tree species. *EurAsian J. Biosci.* **2018**, *12*, 77–82.

18. Afzal, I.; Javed, T.; Amirkhani, M.; Taylor, A.G. Modern Seed Technology: Seed Coating Delivery Systems for Enhancing Seed and Crop Performance. *Agriculture* **2020**, *10*, 526, doi:10.3390/agriculture10110526.

19. Novikov, A.I.; Vovchenko, N.G.; Sokolov, S. V; Novikova, T.P.; Demidov, D.N.; Tylek, P. Improving the quality of automated VIS–grading of Scots pine seeds using fuzzy logic algorithm. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *875*, 012032, doi:10.1088/1755-1315/875/1/012032.

20. Zimarin, S.; Novikov, A.I.; Meshcheryakova, A.; Borodin, N. Forestry innovation in new disk cutter for soil preparation on non-uprooting site. *Proc. 33rd Int. Bus. Inf. Manag. Assoc. Conf.* **2019**, 3120–3129.

21. França-Silva, F.; Rego, C.H.Q.; Gomes-Junior, F.G.; Moraes, M.H.D. de; Medeiros, A.D. de; Silva, C.B. da Detection of Drechslera avenae (Eidam) Sharif [Helminthosporium avenae (Eidam)] in Black Oat Seeds (Avena strigosa Schreb) Using Multispectral Imaging. *Sensors* **2020**, *20*, 3343, doi:10.3390/s20123343.

22. Bianchini, V.; Mascarin, G.; Silva, L.C.; Arthur, V.; Carstensen, J.; Boelt, B.; Silva, C.B. da Multispectral and X-ray Images for Characterization of Jatropha Curcas L. Seed Quality. *Plant Methods* **2020**, 1–14, doi:10.21203/rs.3.rs-28449/v1.

23. Galletti, P.A.; Carvalho, M.E.A.; Hirai, W.Y.; Brancaglioni, V.A.; Arthur, V.; Barboza da Silva, C. Integrating Optical Imaging Tools for Rapid and Non-invasive Characterization of Seed Quality: Tomato (Solanum lycopersicum L.) and Carrot (Daucus carota L.) as Study Cases. *Front. Plant Sci.* **2020**, *11*, 577851, doi:10.3389/fpls.2020.577851.

24. Barboza da Silva, C.; Bianchini, V. de J.M.; Medeiros, A.D. de; Moraes, M.H.D. de; Marassi, A.G.; Tannús, A. A novel approach for Jatropha curcas seed health analysis based on multispectral and resonance imaging techniques. *Ind. Crops Prod.* **2021**, *161*, 113186, doi:10.1016/j.indcrop.2020.113186.

25. Sokolov, S. V.; Polyakova, M. V.; Kucherenko, P.A. Analytic Synthesis of a Kalman Adaptive Filter on the Basis of Irregular Precise Measurements. *Meas. Tech.* **2018**, *61*, 232–237, doi:10.1007/s11018-018-1414-5.

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