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ECOLOGICAL RESTORATION OF NORWAY SPRUCE STANDS AFFECTED BY DRYING FROM OUTSIDE THE NATURAL RANGE

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Abstract

The forest plantations (Norway spruce, pine) installed outside the habitat are fragile, vulnerable ecosystems, exposed to some risk factors, registering significant damages. In the paper, the analysis of the environmental conditions of some lands with Norway spruce stands outside the habitat, affected by intense drying, and the substantiation of their ecological restoration solutions are presented. The results were obtained based on research carried out in 2023 in the area of the Suceava Plateau (Marginea Forest District). The physicochemical characteristics of the soils were strongly altered, having a low content of nutrients and minerals, with a contrasting texture, being poor in bases and heavy drainage, strong acidity, and affected by pseudo-glazing processes. The ecological restoration of Norway spruce stands affected by drying consists of replacing them with species corresponding to the environmental conditions, but only after carrying out special land and soil preparation works to improve its physical and chemical properties. The results obtained are particularly important considering the need for ecological restoration of large areas with Norway spruce stands outside the habitat, strongly affected by drying.

***Key words**: ecological restoration, environmental conditions, Norway spruce, drying; natural range.*

INTRODUCTION

The resinous forest cultures (pines, Norway spruce) installed on the lands outside the natural range occupy important areas, being fragile and vulnerable ecosystems, exposed to some risky factors (drying, ruptures and windfalls, insect attacks and so on), in many situations registering important damages (Constandache et al., 2017; Vacek et al., 2023; Viljur et al., 2022).

These cultures were created starting from 1972 by substituting poorly productive or derived stands (with species of low economic value), being intended for the production of cellulose wood (Norway spruce) or for the production of rosin (pines). The resinous cultures outside the natural range (pure plantations with Norway spruce or pine) are functionally inferior to the substituted ones. The excessive artificialization of forest regeneration has created a certain discordance between the environmental diversity, on the one hand, and the genetic and ecological uniformity of pure resinous cultures, on the other, which reduces their polyfunctional effectiveness. Pure Norway spruce and pine monocultures were created, endowed with a huge potential for ecological instability, their condition being aggravated by the fact that they were not covered with tending works necessary to strengthen their resistance to adversities (wind, snow, drought and so on) (Constandache et al., 2017).

In the course of their evolution, in the conditions of climate change and of the insufficient scientific substantiation of the afforestation and management works of stands, the risk of them being damaged by the action of disturbing factors appeared and increased before to reach the proposed cycle (Vlad et al., 2019). Some of the stands mentioned were strongly affected, in their youth, by breaks or felling caused by snow and wind. On the other hand, the drought of recent years has greatly worsened the situation of the resinous stands outside their natural range, the drying phenomenon of the Norway spruce being signalled on more and more extensive surfaces, especially after the age of 35-40 years (Constandache et al., 2023). In Central Europe, climate change is making extreme droughts more likely, Norway spruce being particularly

prone to drought-induced mortality through lack of carbon and water, increased susceptibility to pathogens (Rehschuh et al., 2017).
The extent of the damage caused to the resinous stands outside the natural range and the danger that this phenomenon represents in disrupting the ecological balance requires the adoption and application of complex measures aimed at the ecological restoration of the affected stands and the (gradual) return to the natural type of forest (Šēnhofa et al., 2020).
The ecological restoration of natural ecosystems has favourable effects in increasing the biodiversity of forest ecosystems, diversifying ecosystem services (Aronson et al., 2006), restoring the landscape, as well as in regenerating and ensuring the continuity of the forest (Constandache & Dincă, 2019).
The replacement of resinous stands installed outside their natural range, must be scientifically substantiated, with great care to avoid new damages (Barbu et al., 2016).
The purpose of the conducted researches was to evaluate the pedological and environmental conditions of some lands with Norway spruce stands from outside the natural range, affected by intense drying and to substantiate their ecological restoration solutions based on the results of the performed research. The results were obtained on the basis of research on the ecological restoration of resinous stands from outside their natural range carried out in the period 2015-2018 and in 2023.

MATERIALS AND METHODS

The research was carried out in research plots, located in representative situations of Norway spruce stands affected by drying. The research plots were located in the area of the Suceava Plateau (Marginea Forest District, Suceava county - Figure 1).
The research consisted of observations, measurements, field data collection, soil analyses, their processing and interpretation. In order to highlight the effect of the limiting factors for forest species, the pedological and environmental conditions were analyzed, starting from the fact that the physical environment of terrestrial ecosystems is the site (ecotope) and the soil represents one of its most important components (Spârchez et al., 2011).

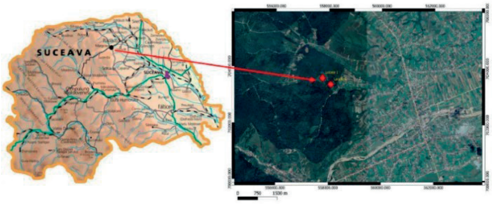

Figure 1. Location of the studied land

For the characterization of the soil in the researched lands, the depth, the groundwater level, the thickness of the horizon with humus (A), the depth at which the horizon C appears, the texture and other characteristics that limit or impose special techniques for the installation and development of new forest cultures were taken into account.
The soil type was determined through field works (soil description on type sheets) and with the help of laboratory analyzes of samples collected on diagnostic horizons from soil profiles.
In order to characterize the soils, main soil profiles and surveys were carried out at distances of approximately 20 to 30 m, in order to determine the change in the soil profile, the plots related to the main profile being delimited. From the main profiles, soil samples were collected on diagnostic horizons. The collected soil samples were analyzed in the "Marin Drăcea" INCDS laboratory, the main chemical and physical properties of the soil being determined: pH, humus, carbonate content, total nitrogen, mobile potassium, degree of saturation in bases (V) and the granulometric fractions which conditionate the trophicity and fertility of the soil. The other characteristics (structure, colour and so on) were determined organoleptically.
The substantiation of the ecological restoration solutions was made based on the analysis of the data related to the relief, lithology, climate, soil and in particular, the limiting factors for the forest vegetation being established in order: the techniques of land and soil preparation, planting of cultures and the species that corresponding with the environmental conditions.

RESULTS AND DISCUSSIONS

The stands/lands studied are located in the north-eastern area of Romania, respectively in the Suceava Plateau. The forest area of both hill and plateau is interspersed with the mountain-premontane storey of beech stands and the hilly one of oak stands with sessile, Greyish and Hungarian oak. From the analysis of climate data, it follows that the "De Martonne" annual aridity index, having a value of 31.87, corresponds to the humid temperate climate domain, with a humid climate and sufficient precipitation for vegetation and a slight surplus of water from precipitation compared to potential evapotranspiration. This highlights the fact that, from a climatic point of view, the studied territory offers favourable conditions for the development of forest vegetation specific to hill highroads.

In terms of forest vegetation, in the studied area, mostly Norway spruce stands were identified at the border or outside their natural range, but also pure beech and mixed stands with hornbeam, sycamore, Silver fir, Norway spruce (at higher altitudes).

The Norway spruce stands were planted in the 1970s, currently being severe affected by drying (Figure 2).

Figure 2. Norway spruce stands affected by drying (Unit Production I, Codrul Voievodesei, management unit 16E%)

From previous analyzes it was established that this phenomenon is due to the combined action of severe droughts (from the periods 2011-2012, 2020-2022) and xylophagous insects *(Ips typographus, Ips amitinus, Ips duplicatus si Pityogenes chalcographus*).

The lands from which the stands affected by the drying were extracted are strongly sodded (*Calamagrostis* sp., *Brachipodium* sp., *Poa* sp. and another gramineae) with height over 1 meter (Figure 3), forming a dense layer of roots in the first 10 to 15 cm of the soil, so that the water from the precipitation below 10 mm is fully retained in the organic substrates on the soil surface. These gramineae species indicate soils poor in bases and rich in acids.

Figure 3. Herbaceous vegetation on the site of the former stands

We identified two representative pedological and environmental situations as follows:

a) flat or lowland sites (bumps, low hollows) which it favours the water stagnation during precipitation periods, being predominant (2/3 from the total surface);

b) sloped lands or with microrelief having positive and elevated shapes.

The results of laboratory chemical analyzes (Table 1) show that the analyzed soils have a low content of nutrients and minerals, are soils poor in bases, strongly acidic and the physical properties are strongly altered (soils with a contrasting texture, with poor drainage, hardly permeable). Since the external and internal drainage are deficient due to the reduced slope of the land and low permeability for water and air of the Bt (argic) horizon, these soils are frequently affected by the periodic excess of stagnant water, causing the accentuation of pseudogleyzation processes. In addition to these unfavorable physical factors, there is also a strong sodding of the soil.

In general, the analyzed soils are both weakly humic in the first horizon (1.46 to 2.02%) and in depth. The same evolution is presented by the nitrogen content (maximum 0.078% being very weakly supplied). Potassium increases steadily on the profile, from 30.03 ppm (weak provision) in the surface horizon (5-25 cm) to 129.10 ppm (medium insurance) at a depth of over 70 cm. The soil reaction is strongly acidic (pH = 4.67-4.78) up to a depth of 45-50 cm, after which it becomes moderately acidic (pH = 5.18-5.27) in depth.

The granulometric analysis (Table 1) shows that the soil texture is Medium (M), Sandy Loam class (S), Dusty subclass (SP) in the first 25-45 cm. Sometimes there is also an intermediate horizon (Ea), where the texture belongs to the Sandy Loam class (S), Sandy-dusty Loam subclass (SS). At a depth greater than 45-50 cm, the texture becomes Fine (F), Clay Loam class (T), Clay and Dusty subclass (TP) (Florea & Munteanu, 2012) where a sudden textural change occurs between horizons (between A/B or Ea and Btw). The clay content increases from 18.2-20% to 25.1%, and in gypses (areas with lower lands) even to 36.7%. At more than 70 cm, the clay content reaches 39.5%, being specific features of the pseudogleyzation process. No micro-biological activity was observed.

The characteristics of the soil analyzed in the two profiles determined the inclusion in the class luvisols (argiluvisols), the types of soil being:

1. *Planosol, stagnant subtype* - representative for approx. 2/3 of the land area under study; the light-textured surface horizon becomes hard at dryness, but is not cemented; the sudden change in clay content from the surface horizon to the underlying one is largely caused by the ferrolysis process, respectively a destruction of clay minerals in conditions of alternating wet periods with dry periods. The clay subsoil has a polyhedral structure developed in blocks and prismatic (Figure 4), or it is even massive (destructured). The low permeability of the subsoil is the cause of water stagnation in the surface horizons, which leads to the worsening of internal drainage and aeration conditions, to the accentuation of pseudogleyzation processes, considered an important limiting factor.

Chemically, planosols are altered soils: the cationic exchange capacity of the clay fraction in the surface layers and in the eluvial horizon is significantly lower than in the underlying horizons.

2. *Luvosol, the albic-stagnant subtype* (albic pseudoglayzed luvisol), for the rest of the plots; they are moderately to strongly texturally differentiated soils, with unfavourable aerohydric properties on the profile. They are weakly fertile soils, with a low humus content, with a pH of 5 to 5.5, sometimes even 4.5 (in the albic subtypes). The degree of saturation in the bases is lower (60%) and in the Ea horizon it can have values of 15 to 20%.

Figure 4. The structure of soil profiles

The physical and chemical characteristics of the soils have been strongly altered under the effect of Norway spruce stands and as a result of improper silvotechnique. The analyzed soils have a low content of nutrients and minerals, are poor in bases, strongly acidic, have a contrasting texture, poor drainage and are hardly permeable. Since external and internal drainage are deficient due to the reduced slope of the land and low permeability for water and air of the Bt (argic) horizon, these soils are frequently affected by the periodic excess of stagnant water, causing the accentuation of pseudogleyzation processes (Btw horizon). Acidity (strongly acidic pH) represents another limiting factor for forest vegetation, in the case of the two soil types determined. On acidic soils, there is a solubilization of aluminium and manganese from the soil in toxic amounts for plants. Another limiting factor is added to these: the strong sodded of the soil following the drying or thinning of the Norway spruce stands. These characteristics determine the need for special works of:

- land preparation (clearing the land of herbaceous vegetation, removing stumps);
- preparation of the soil (scarification at great depths, plowing, discing) for the stimulation of ascending water processes, the limitation of the stagnant one and the improvement of the physical properties of the soil;
- pedo-ameliorative works (application of calcium amendments and complex fertilizers).

The land and soil preparation works have the role of improving the physical properties of the soil, preventing water stagnation and limiting the stagnant water process, ensuring the minimum conditions for the installation of forest cultures and the pedo-ameliorative ones, have the purpose of improving the pH, the structure of the soil, the microbiological activity in the soil, to accelerate the decomposition of the organic matter in the soil and so on.

The ecological restoration of the researched Norway spruce stands, strongly affected by drying, consists in replacing them with species corresponding to environmental conditions, but only after a minimum of one year after carrying out the special land preparation, soil and pedo-ameliorative works.

The degree of correspondence (suitability) of the edificative composition of trees species for certain environmental conditions is expressed by the Ellenberg Coefficient (EQ), calculated according to the formula:

$$EQ = Tw/P * 1000,$$

where:
- Tw is the temperature of the hottest month of the year;
- P is the annual precipitations.

The data presented in the specialized literature show that various EQ values indicate specific climatic conditions for the growth and development of a certain type of forest. The value of this coefficient for the researched area is 33.27 (EQ between 30 and 40), being characteristic of mesophyll oak forests or other species of oaks (Nedealcov et al., 2019). Therefore, mesophilic species from the *Quercus* Genus, with high amplitude and adaptability to climatic conditions, will be associated in the forest composition (Şofletea & Curtu, 2007).

Therefore, the afforestation composition recommended for the ecological restoration of Norway spruce stands affected by drying is with deciduous species corresponding to the phytoclimatic storey and whose ecological requirements can be satisfied by improved pedological and environmental conditions, respectively: 70% Sessile Oak and 30% Wild Pear, Field Maple, Pennsylvanian Ash, shrubs (Pennsylvanian Ash will be introduced into hollow, in biogroups) (MMAP, 2022).

In the hilly sites, characterized by the presence of slight unevenness and small depressions, on slightly inclined slopes, sensible different vegetation conditions are achieved for resinous species, in the sense that the negative microrelief, due to the temporary stagnation of water and pseudoglayzation phenomena, becomes inappropriate for the introduction of them. This mosaic of environmental conditions leads to a non-uniformity of resinous stands.

The sites where some ecological factors occur in excess (heavy texture, temporary excess of humidity, windy sites) are contraindicated for the installation of intensive resinous cultures, especially with species sensitive to these factors, such as Norway spruce, Douglas fir (Radu et al., 1975). Medium-porosity, well-ventilated, weakly skeletal soils with sufficient moisture are favorable to Norway spruce. Actively draining, stony, sandy soils are much more favorable to it than heavy, slow-draining ones. Even if in the presented situations it supports podzols, it transforms them by accumulating raw humus that is mostly hard to decompose, raising the acidity of the upper horizons of solicides. In fact, due to its litter deposited in thick and felty layers, which decomposes with difficulty and imperfectly, the artificially installed Norway spruce cultures contributed decisively to the acidification of the soils on which it was installed. In these conditions, a large part of the mineral elements remained blocked in the partially decomposed organic substance (Şofletea & Curtu, 2007). The inadequate current state of the Norway spruce stands outside the area was also due to the lack of adaptation to a symbiotic nutrition with mycotrophic fungi for which the environment created by luvisoils is unsuitable for their development. The efficiency of the fungus-plant association is determined by the adaptability of the fungal partner to a certain soil pH level. The pH affects both spore germination and their development. The low pH and the low amounts of assimilable phosphorus in the soil resulted in insufficient development of mycorrhizae (Stoian, 2015). Poor soil fertility is one of the limiting factors for the normal development of forest vegetation and the ecological restoration of stands is necessary (Constandache et al., 2022).

Table 1. The chemical and physical characteristics of the soil in Norway spruce stands outside the natural range (Marginea Forest District)

Identification		pH	Ht %	Nt %	Km ppm	SH me/ 100 g	SB me/ 100 g	T me/ 100 g	V %	Granulometry		
Hori-zon	Depth (cm)									Sand (% gr*)	Silt (% gr*)	Clay (% gr*)
Ao	5-25	4.78	2.02	0.078	30.03	4.5	3.7	8.2	45.1	31.6	53.1	15.3
A/B	26-45	4.67	1.28	0.065	36.70	6.5	5.6	12.1	46.3	27.2	54.6	18.2
Btw1	46-70	5.18	0.55	0.021	94.17	5.5	11.4	16.9	67.5	20.0	43.3	36.7
Btw2	> 70	5.27	0.91	0.035	129.1	5.6	14.8	20.4	72.5	18.2	42.3	39.5
Ao	0-25	4.68	1.46	0.056	26.46	6.9	3.4	10.3	33.2	21.8	53.8	24.4
Ea	26-50	4.70	0.94	0.036	23.69	5.7	3.2	8.9	36.2	30.7	49.3	20.0
Btw1	51-80	5.06	0.41	0.016	37.49	5.6	6.8	12.4	55.1	31.6	43.3	25.1
Btw2	> 80	5.12	0.22	0.008	36.57	5.7	9.0	14.7	61.4	32.8	39.4	27.8

Note: *colloidal clay<0.002 mm; coarse sand = 2.0-2 mm; fine sand = 0.2-0.063 mm; silt = 0.063-0.002 mm; Ht - total humus; Nt - total nitrogen; Km - mobile potassium; SH - the sum of hydrogen cations; SB - the sum of basic cations; T - troficity; V - the degree of saturation in bases.

CONCLUSIONS

The researches carried out highlights the fact that the Norway spruce stands from the outside of the natural range, created during the 70's, are currently strongly affected by drying. The stability of the Norway spruce stands from outside the natural range is threatened by different abiotic (climatic changes, pedological and environmental conditions) and biotic (insects, fungi and invasive plants) factors with great power to destabilize the stands. The magnitude of the damage caused to the resinous stands from outside the natural range and the danger that this phenomenon represents in disrupting the ecological balance, requires the adoption and application of complex measures aimed at the ecology of the affected stands and the (gradual) return to the natural type of forest. The results of the research consisted in the analysis of the pedological and environmental conditions of the lands with Norway spruce stands affected by drying and the scientific substantiation of the afforestation compositions for their ecological restoration. In order to highlight the limiting factors for the forest species that will be introduced, the pedological and environmental conditions were analyzed, starting from the fact that the physical environment of terrestrial ecosystems is the site (ecotope) and the soil is one of its most important components. As limiting factors for the culture of forest species, the following were identified:
- the strong acidity of the soil;
- reduced content of nutrients and minerals;
- the presence of an argic horizon with low permeability for water and air, which hinders internal drainage and causes the accentuation of pseudoglayzation processes;
- strong weeding of the soil.

The presence of these limiting factors determines the need to apply special works of: land preparation (clearing the land of herbaceous vegetation, removing stumps); soil preparation (scarification at great depths, plowing, discing) for stimulating water processes, limiting the stagnant water process and improving the physical properties of the soil; the application of calcium amendments and complex fertilizers, with the aim of reducing acidity and improving the chemical properties of the soil.

The species recommended for the ecological restoration of Norway spruce stands affected by drying are indigenous deciduous species, predominantly from the *Quercus* Genus, with high amplitude and adaptability to climatic conditions and whose ecological requirements can be satisfied by improved pedological and environmental conditions.

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