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The Effects of Freezing Rain on Forest Stands Administered by Zalău Forestry Department During 2014-2022 Period

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RESEARCH ARTICLE

Abstract

Freezing rain is a rare and extremely dangerous meteorological phenomenon, consisting of the fall of liquid precipitation, while the air temperature at ground level falls below 0°C, favoring the freezing of raindrops and forming an ice sheet on the surfaces on which they are deposited. In Romania, the areas affected by the freezing rain phenomenon undergo significant changes regarding the structure and composition of the forest vegetation. The main purpose of this work is to figure out how to manage the forest stands affected by the freezing rain identifying optimal solutions for ecological reconstruction and prevention of significant damages. For the research of the affected areas, we placed 7 experimental areas, having the size of 500 m^2 each, all the trees that were in this radius were inventoried. In this research work we evaluate the presence of this phenomenon which was reported in the Stejarul Zalău Forest District, in 2014, then in 2017, but with a lower intensity. Out of a total of 1627.6 ha, 500 ha were affected by the freezing rain, most of them being surfaces with beech forest stands with a consistency of 0.9, having a high slenderness index. Following the results obtained, it was observed that the most affected trees were the youngest. These having a reduced diameter, thin branches and a high slenderness coefficient.

Keywords: beech, ecological reconstruction, meteorological phenomenon

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INTRODUCTION

"Freezing rain" is a damaging phenomenon (Fugure 1). The physiological weakness up to the total destruction of the trees caused by this is reflected in the structure of the forest stands. As such, the population of trees decreases, which negatively influences the functional role of the forest. Furthermore, the quality of the remaining trees is also reduced, as growths are smaller, tree crowns are sparser, and health, fruiting capacity and natural regeneration are diminished, these aspects would not have occurred naturally (Murarescu et al., 2016, Constandache at al., 2018). The impact of the execution or, on the contrary, of the non-execution of the appropriate silvicultural works, in the studied forest stands, led to different effects, depending on other important characteristics, such as: composition, crown consistency, slenderness coefficient, diameter, height, age, slope (Murarescu et al., 2016). Regarding the gaps caused in some stands, but also the areas where natural regeneration is affected, as a result of ruptured and fallen trees, or where the trees are missing, reforestation technologies must be applied

(König et al., 2022). The fulfillment of the protection functions depends on the condition/structure of the protective forest crops, so the ecological reconstruction of the affected stands is a necessity. In order to substantiate these works, investigations were carried out regarding the characteristics of the affected stands, especially after the removal of the affected trees. The amount of damage to trees is a reflection of the amount of rainfall, tree temperature and wind speed at the time (Constandache et al., 2017).

After injuries occurred, the evolution of certain physiological processes of natural regeneration (fruiting, germination and seedling development) leads to the natural establishment of seeds of different species (some inappropriate, overwhelming), special works are needed to help and care for or complete the stands, so as to ensure the optimal composition (proportion of species) and the appropriate evolution of valuable species, which can ensure the existence and continuity of the forest over time, creating an appropriate structure for it, exercising protection and production functions, as well as other beneficial effects for the environment (Bond et al., 2001).

In Romania, freezing rain phenomenon was described by Murarescu et al. (2016), on the northern of Persani Mountains, who observed it on 2691.6 hectares of the Măieruș Forest Department, in Brasov County. The main objective is to determine how the forest stands were affected by the freezing rain and identifying the optimal solutions for ecological reconstruction and prevention against significant damages, in the case of repeated occurrence of the phenomenon. The objectives of this paperwork were: the placement of test areas in order to monitor the vegetation status of the stands, investigating the effectiveness of the proposed silvicultural works, respectively the consequences of carrying them out on time, or not, proposing effective solutions for the management of forest stands affected by freezing rain, and for improving natural regeneration.

An extremely important measure was given to natural regeneration, through work to help, favor and support the new generation of seedlings and saplings. The results obtained from the research activity could also be successfully used in the production activity, by implementing them especially in the areas with forest stands affected by harmful abiotic factors or in the stands that were subsequently felled with Incidental cuttings.

Figure 1. The manifestation of the freezing rain phenomenon in 2014 Windbreaks and downfalls

MATERIALS AND METHODS

Seven experimental plots were placed in six compartments. They had an area of 500 m^2 each, in total, an area of 3500 m^2 was inventoried. In order to obtain the most concrete and representative results, the experimental plots were chosen according to the stage of development and composition.

Table 1. Main aspects of the studied stands

Compartment	Total surface (Ha)	Age (years)	Composition	Density	Altitude (m)	Exposition	Slope (G°)
24 A	10.8	78	8FA 1GO 1Ca	0.9	490-700	N-W	18
3 B	13.5	88	8Fa 2GO	0.7	520-670	N-W	20
40 A	15.5	73	9Fa 1Ca	0.8	620	N-E	20
57 A	7	63	6Ca 2 Fa 2Go	0.9	545-720	S-E	20
57 F	2.6	63	6Ca 2 Fa 2Go	0.9	650	S-E	20
63 B	17.8	58	5Fa 4Ca 1PLT	0.9	550-700	S-E	25

As can be seen in (Table 1), the studied stands were aged between 58 years (63B) and 88 years (3B). The

predominant tree species was beech, which was found in all stands in the highest proportion (90%) in compartment 90A, and in the lowest proportion (20%) in compartments 57A and 57F. In the composition, in addition to *Fagus sylvatica* L. (common beech), *Carpinus betulus L.* (common hornbeam), *Quercus petraea* (Matt.) Liebl. (sessile oak) and *Populus tremula* L. (trembling poplar) are also found. But trees of other species were also found in the field, such as *Quercus cerris* L. (turkey oak), *Acer platanoides* L. (norway maple) and *Acer pseudoplatanus* L. (sycamore maple), but their proportion was very small and they were not included in the composition of the stands. Most of the stands have a density of 0.9, only compartments 3B and 40A have a lower density, of 0.7 and 0.8 respectively.

In terms of altitude, the stands are located between 490m and 700m, and an average altitude would be around 600m. Also here we can see that the stands in compartments 57A, 57F and 63B are located on a south-east exposition, and compartment 40A on a north-east exposition, while compartments 24A and 3B on a north-west exposition. The slope of the land was between 18 G°(24A) and 25 G° (63B), and 20 G for the other compartments.

The placement of the experimental plots was done in such a way as to capture the most representative area, without the slope being too high or the base of the forest stand influencing the obtained results, having differences that would cause confusion. Thus, it was chosen that these plots to be located between the intersection of the lowest and the highest altitude. The trips in the field were carried out together with the forestry staff, using the following tools: spray, loggers' tape, tree caliper and hypsometer, for measuring the diameter and height of the inventoried trees.

When inventorying the trees, emphasis was placed on the observations made on the most representative trees affected by this phenomenon. The areas of the compartments where no regenerations were observed were also taken into account.

For each forest compartment, a terrain sheet was made in which it was mentioned: the number of trees from each experimental plots were noted, mentioning: the species, the wood quality, the diameter and the height. The average diameter, average height and series of volumes were also calculated for each plot. The seedlings were not inventoried, considering only its presence or absence.

Data collected from the field were processed and centralized at the office.

For an easier understanding and investigation, several photos of each compartment (plot) were taken, managing to make a comparison of the state of forest stand before and after the occurrence of the phenomenon. Another benefit is that drone and ground photos were taken shortly after the phenomenon occurred. The obtained photos are useful even at this moment, when the phenomenon is no longer visible in the field.

The established control plots were marked in the field with orange spray, the number of the control plots was passed on one tree, to avoid the placement of wood pillars. The placement of the experimental plots was carried out in 2021, more precisely in December. For a clearer vision, photos were also taken in the field in June of 2022. The compartment units where the experimental plots were placed belonged to the Zalău Production Unit I, are: 28 F, 63 B, 3 B, 57 A, 57 F, 24 A, 40 A, Zalău Forestry Department. The area of the production unit is 1627.6 ha. Production unit I Zalău is made up of 76 compartments with 343 sub-compartments.

RESULTS AND DISCUSSIONS

Although the surface area of the plots is the same (0.05 Ha), in (Table 2) it can be seen that the number of inventoried trees is different, varying from only 5 trees (3B) to 73 trees (63B). The most significant characteristic that influences the number of trees inventoried inside the plots is the consistency of the stands, which has a density of only 0.7 in compartment 3B and 0.9 in compartment 63B.

Table 2. Status of the experimental plots located in P. U. I Zalău

Compartment	Total Area (Ha)	Number of inventoried trees	Plot Area (Ha)	Number of experimental plots
63 B	17.8	73	0.05	1
3 B	13.5	5	0.05	1
57 A	7	40	0.05	1
57 F	2.6	30	0.05	1
24 A	10.8	20	0.05	2
		8	0.05	
40 A	15.5	45	0.05	1

The phenomenon occurred on December 1, 2014 and an area of 500 hectares out of a total of 1,627.6 ha was affected. Given that clear cutting solutions of heavily affected areas were proposed, changes were made to the 10-

year management plan.

From Table 3 it can be seen that there are much more differences regarding diameters than in the case of tree heights. This fact may derive due to the execution/non-execution of silvicultural operations. Analyzing the diameter of the common beech, in the experimental plot, compared to the one from management plan it shows increases in half of the plots. Regarding the height, again, in most cases, increases in the experimental plots are found Investigating the situation of the common hornbeam, it does not have large increases in diameter, the values are close to those in the management plan

Table 3. Dendrometric elements from the experimental plots

Compartment	Species	Current average age	Diameter (cm)		Height (m)	
			management plan	experimental plots	management plan	experimental plots
28 F	FA	13	-	-	1	-
	CA		-	-	1	-
63 B	FA	58	22	20	18	23
	CA		18	18	16	18
	PLT		24	-	20	-
	GO		-	38	-	22
3 B	FA	88	34	52	25	26
	GO		42	-	26	-
57 A	CA	63	20	11	18	12
	FA		26	24	20	21
	GO		24	27	20	20
	CE		-	22	-	16
57 F	CA	63	20	18	18	18
	FA		26	18	20	19
	GO		24	-	20	-
	PA		-	32	-	23
	PAM		-	34	-	23
24 A	FA	78	28	40	23	25
	GO		28	-	22	-
	CA		24	-	20	-
40 A	FA	73	21	26	21	24
	CA		16	-	18	-

Legend: FA- Common Beech, CA-Common Hornbeam, PLT-Trembling Poplar, GO-Sessile oak, CE- Turkey oak PA- Norway maple PAM- Sycamore maple

After the manifestation of the phenomenon, it was necessary to harvest the affected wood material. In (Table 4), it can be seen that in the studied stands, the following silvicultural works were carried out: filling the gaps with seedlings (0.65 ha), release cuttings (4.8 ha), thinnings (9.5 ha), clear cuttings (6.6 ha), progressive cutting treatments (10 ha), works from where we obtain incidental products (50.95 ha). It should be noted that in some subplots only the affected specimens were extracted in the form of hygiene products.

Table 5 indicates that, regarding the composition, no major changes are present. Only in compartment 3 B there is a change related to the crown density, this being 0.7 before the appearance of the freezing rain, and after the manifestation of the phenomenon, and ending up decreasing to 0.6. The site class remained the same in both cases.

Table 4. Silvicultural practices performed in stands affected by freezing rain

The situation before the phenomenon occurs				The situation after the phenomenon occurs		
Compartment	**Area (ha)**	**Type of silvicultural operation**	**The surface covered with silvicultural operations (ha)**	**Surface (ha)**	**Type of silvicultural operation**	**The surface covered with silvicultural operations (ha)**
28 F	4.8	Clear-Cutting (2013)	3	4.8	Filling the gaps with seedlings (2014)	0.65
					Release cutting (2017)	4.8
63 B	22.2	-	-	17.8	-	-
3 B	13.5	-	-	13.5	Incidental cuttings	6
					Incidental cuttings	13.5
					Progressive cutting 3	10
57 A	9.6	Proposed thinning	No operations were performed	7	Only broken specimens were extracted	-
57 F	-	-	-	2.6	Clear-Cutting (2017)	6.6
24 A	10.8	Thinning (2014)	2.5	10.8	Thinning (2014)	2.5
		Incidental cuttings (2014)	0.5		Incidental cuttings (2014)	0.5
					Incidental cuttings (2015)	10.8
					Incidental cuttings (2017)	5
					Incidental cuttings (2019)	0.15
40 A	20.2	Thinning (2014)	7	15.5	Thinning (2014)	7
					Incidental cuttings (2015)	3
					Incidental cuttings (2015)	12

Tabel 5. The comparative situation of the structural characteristics in the horizontal plane

Compartment	**Old management plan**			**New management plan**		
	Current composition	**Production class Site class**	**Crown density**	**Current composition**	**Production class Site class**	**Crown density**
28 F	3 FA 7 CA	3	0.7	3 FA 7 CA	3	0.7
63 B	5 FA 4 CA 1 PLT	3	0.9	5 FA 4 CA 1 PLT	3	0.9
3 B	8 FA 2 GO	3	0.7	8 FA 2 GO	3	0.6
57 A	6 CA 2 FA 2 GO	3	0.9	6 CA 2 FA 2 GO	3	0.9
57 F	-	-	-	6 CA 2 FA 2 GO	3	0.9
24 A	8 FA 1 GO 1 CA	3	0.9	8 FA 1 GO 1 CA	3	0.9
40 A	9 FA 1 CA	3	0.8	9 FA 1 CA	3	0.8

Legend: FA- Common Beech, CA-Common Hornbeam, PLT-Trembling Poplar, GO-Sessile oak,

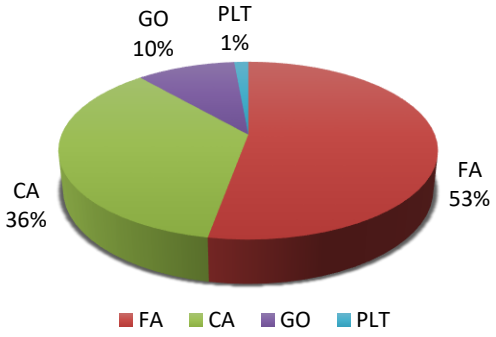

Figure 2. The proportion of species in all the experimental plots
Legend: FA- Common Beech, CA-Common Hornbeam, GO-Sessile oak, PLT-Trembling Poplar

From Figure 2 it can be seen that the dominant species is the common beech, found in most of the compartments where the meteorological phenomenon was manifested, and at the same time being the most severely affected of the species.

Compartment 28 F: Mostly, the trees of pioneer species (poplar, willow) were affected, which tend to overwhelm natural regeneration. Basically, the main species were not affected. Due to the fact that, at the time of the occurrence of the phenomenon, the saplings were in the young development phase, they were very elastic, and after the phenomenon stopped (after 3-4 days) and the ice on them melted, they recovered completely. The silvicultural works were executed on time. The trees did not suffer any damage. Where the pioneer species had a large diameter and a more intense growth, the girdling technique was used, so as not to damage the seedlings of the valuable species. The future proposed silvicultural operation is: cleanings, considering the existing high slenderness coefficient, in 2022, silvicultural corridors from 40 to 40 m will be executed, following that in the next forest management plan (2024) cleaning operations will be carried out, working between those passages.

Compartment 63 B: The fact that no silvicultural cuttings have been carried out until now, correlated with the high density of the stand (0.9), has led to an increase in the trees only in height (Table 3), and in terms of the diameter of the trees, no significant accumulations have been reported. Considering the high slenderness coefficient and the increasingly frequent occurrence of extreme weather phenomena, it is urgently necessary to carry out thinning works, in order to increase the diameter of the trees and stabilize the stand in the face of extreme meteorological phenomena. From the total area of compartment 63B (22.2 ha), it was necessary to intervene on an area of 4.4 ha with clear cuttings, and this portion was organized in a different subcompartment (63F). For the rest of the area (17.8 ha) remaining in compartment 63B, thinnings were proposed. Apart from totally affected the 4.4 ha, no significant damage was recorded, a fact that did not represent an emergency in carrying out thinning operations

Compartment 63 F: In this compartment, no experimental plot was placed, being made up of 63 B, and having an area of 4.4 ha. The proposed works were clear cuttings and afforestation. The slope of the land is 25°, the forest stand being located at an altitude of 550-700 m. wind and snow breakages are very frequent. It was decided that in 2015 clear cuttings would be carried out, thus resulting in a volume of 870m^3 and in 2017 only filling the gaps would be made, around the regeneration of existing common beech and sycamore maple

Compartment 3 B: The silvicultural operation from the current management plan was not carried out, because the regeneration was already triggered (Figure 3 right), and the seeding operation did not make sense. In this compartment, in a first phase, in 2015, only trees that were totally affected (broken, uprooted, etc.) were extracted through Incidental cuttings, obtaining a volume of 453 m^3. It was considered that the remaining trees, which had only a part of the crown affected, would bear fruit and they will ensure the regeneration of the entire plot. In 2018, trees that started to dry, as a result of the phenomenon of 2014 (Figure 3, left), were also extracted. Simultaneously with these cuts, operation was carried out to help natural regeneration, extracting the elder and blackberry specimens that overwhelmed the saplings.

Compartment 57 A: In 57A, no works has been carried out. Therefore, there are no substantial changes in the diameter and height of the trees, which proves that the failure to carry out thinning operations leads to slower growth and an unthrifty development of the stand. Due to the fact that the forest areas is near the Municipality of Zalău and a great emphasis is placed on the social function of the forest, not only on the production one, the decision was made to extract only the broken and bent specimens, so that after the completion of the silvicultural operations,

they intervene with other solutions during the 10 years of management plan. It was decided that in compartment 57A, having 7 ha, thinnings should be proposed for 60% of the area, due to the fact that the respective area was not affected by the phenomenon, it was decided to establish the compartment 57 F of 2.6 ha where clear cuttings and afforestation were proposed as a solution (Table 4)

Figure 3. The area affected by the freezing rain (2014) left,
Natural regeneration in the affected areas within the stand (2022) right

Compartment 57 F: The current affected area is 2.6 ha (Table 1). The works proposed in the new management plan are clear cutting and afforestation.The proposed solution was to extract only the totally affected trees, so as not to create a negative visual impact. This decision was also made due to the fact that the wood mass that was to be extracted was not particularly valuable, the composition being 6CA-Hornbeam 2FA-Beech, 2 GO-Sessile oak, (same as in 57A). In this way, half of the volume of this compartment was extracted, especially the hornbeam, which had the highest slenderness coefficient, leaving only the unaffected trees of the species: Sessile oak, common beech and hornbeam standing. No major differences are identified regarding tree heights. But the analyzed diameters show significant changes.

Compartment 24A: Two experimental plots were placed in this subcompartment, because the effects of the phenomenon and the injuries were much more intense. The solutions proposed in both management plans were thinning operations (Table 3). In 2017, we intervened, punctually on 5 ha, extracting a volume of 464 m3, and all the trees which they showed die-back symptoms, who were less affected by the phenomenon, were extracted. In the areas where the phenomenon manifested itself with greater intensity, natural regeneration was triggered, the voids produced by the extraction of fallen trees, also affected at the crown level, currently being covered with beech seedlings. The phenomenon was not spread uniformly over the entire studied area, it mainly manifested itself only in certain sections. And in the points where it had a greater intensity, the gaps produced in the forest stand were occupied by common beech seedlings.

Compartment 40A: Only the trees affected by the freezing rain were extracted. Currently, the health status of the forest is good, being a closed stand, without gaps, with almost full crown density. Here the forest stand has an area of 15.5ha. The composition is close to a pure common beech one: 9 FA -common beech 1 CA-common hornbeam. Crown density of the stand is 0.8. The altitude where the affected stand is located is 620 m, with the northeast exposure, the slope has 20^{o}. After the occurrence of the phenomenon, was created another compartment 40F from 40A of 4.7 ha, totally affected, where the solution adopted was clear cutting and afforestation. Thinning works were carried out in 2014 on half of the surface. Carrying out the appropriate works and applying them at the right time has led to a good state of forest health, having a closed stand without gaps, with almost full crown density. The thinning operations was carried out in 2014, and the other two Incidental cuttings cutting works were performed in 2015.

Compartment 40F: In this forest stand, the solution of clear cuts was chosen, because on the entire area, all the trees were actually affected. Due to the existing roads in the compartment, the logging was done without damaging the existing seedlings (1277 m^3 was removed from 4.7 ha). In the following year (2016), works was done to help natural regeneration, cutting down the specimens of elder, willow and poplar. In 2018, we intervened again, extracting specimens from the pioneer species that tended to overwhelm the common beech, as well, the elder specimens were eliminated. In the areas with sycamore maple, release cuttings were made to help this species. Currently, the stand is closed, the surface being completely regenerated.

CONCLUSIONS

The species that was most seriously affected by the freezing rain phenomenon was the common beech.The seedlings that were very elastic recovered completely. Where the pioneer species had a large diameter and a more intense

growth, the girdling technique was used, so as not to damage the seedlings of the valuable species. In the stands with almost full crown consistency, in which no silvicultural works has been carried out, until the present, only an increase in height is identified, regarding the diameter there are no substantial accumulations. No thinning was done in the compartment's units around the city, but the specimens that were broken or affected by the freezing rain phenomenon were extracted. In this way, the forest is not visually altered, emphasizing its social and recreational functions. Trees of smaller age classes, with reduced diameters, and with thin branches, having a high slenderness ratio, were in the greatest danger, being the most seriously injured. As recommendations, it is proposed to help the natural regeneration and the care of the advance growth seedlings, where the number of saplings from the main species is sufficient, thus giving the possibility of the growth and development of valuable species. On the rest of the surfaces that are not regenerated, but are under the shelter of the mother forest stand, to intervene also with silvicultural operations, which have the purpose of helping and stimulating the germination of seeds but also protecting the seedlings

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Conflicts of Interest
The authors declare that they do not have any conflict of interest.

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