

UTILIZATION OF BY-PRODUCTS GENERATED BY A WOOD GASIFICATION PLANT THROUGH ITS USE FOR THE RECLAMATION OF DISTURBED TERRAINS

Petar G. Petrov¹

Abstract: One of the biggest disturbances and pollutants of the environment occur due to the mining industry. For this reason, when talking about the restoration and recultivation of damaged lands and soils a recovery of the disturbed areas affected by mining activities should be first understood. Current waste management trends make us look for opportunities to recultivate disturbed mining areas by using waste or products that have the necessary properties and are a by-product (or waste) of industry. In this study, we have investigated, through laboratory methods, the possibility of using a by-product from a biomass gasification plant (FP) that potentially possesses the properties to improve soils quality during the reclamation process.

The paper analyzes the possibilities of using the FP by defining its effect on the soil forming process on disturbed sites, including: acidity, content of nutrients and mobility of heavy metals.

In order to determine the possibility of using the FP to enhance soils quality, in the experiment, we used soils that are going to be used for the reclamation of the Eastern embankment of the Ellatzite copper mine and by-product (FP), generated from a Biomass gasification plant located near the mine.

The territory that is possible to be reclaimed with FP is an embankment covered with rocks from the Ellatzite mine which has acidic reaction, high content of heavy metals and very low organic content. In general, conditions for land reclamation are severe and specific measures need to be implemented to achieve sustainable results.

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Introduction

The biggest disturbances and pollutants of the environment occur due to the mining industry, the enrichment of raw materials, the energy industry and the chemical industry (Kundu et. al.; 1997; Leia et al., 2016). For this reason, when talking about the restoration of damaged lands and soils, a recovery from the impact of these anthropogenic activities should be first understood (Zheleva, 2010; Sheoran 2010).

The extraction of minerals in an open way inevitably leads to the generation of large amounts of mining waste for storage and disposal. Although the present priority continues to be the prevention of already generated waste, it is important to try to cease pollution by achieving the requirement of getting to the process of "end of waste" (Kostadinova et al., 2014, 2015).

Current waste management trends make us look for opportunities to recultivate disturbed mining areas by using waste or products that have the necessary properties and are a by-product (or waste) of an industry. In this study, we have investigated, through laboratory methods, the possibility of using a by-product from a biomass gasification plant (FP) that potentially possesses the properties to improve soil quality during reclamation processes.

The paper analyzes the possibilities of using the FP by defining its effect on the soil forming process on disturbed sites, including: acidity, content of nutrients and mobility of heavy metals. The scientific set-up involves mixing the FP with soils, used for reclamation of disturbed areas (East embankment of Ellatzite mine), in different ratios.

In order to determine the possibility of using the fermentation product (FP), generated by the biomass gasification process, to enhance soils quality, in the experiment, we used soils that are going to be used for the reclamation of the Eastern embankment of the Ellatzite copper mine and by-product (FP), generated from a Biomass gasification plant located near the mine.

The territory that is possible to be reclaimed with FP is an embankment covered with rocks from the Ellatzite mine which has acidic reaction, high content of heavy metals and very low organic content. In general, conditions for land reclamation are severe and specific measures need to be implemented to achieve sustainable results.

The main characteristics of the soils to be used for reclamation of the East embankment of Ellatzite mine are presented in Table 1.

¹ University of Forestry, Sofia, Bulgaria, petargpetrov@abv.bg

Table 1: Main characteristics of the soils to be used for reclamation of East embankment of Ellatzite mine

Soil	Total N	Organic C	pH	Ca	K	Mg	Na	P	P
	%	%		%	%	%	%	mg/kg	(pH 4,8)
Sample 1	0.087	1.12	5.67	0.11	0.1	0.89	0.1	530	12.5
Sample 2	0.026	0.88	5.16	0.12	0.11	0.92	0.11	528	10.1

Source: Zheleva et al., 2015

The content of heavy metals in the soils to be used for reclamation of the East embankment of Ellatzite mine are presented in Table 2.

Table 2: content of heavy metals in the soils to be used for reclamation of East embankment of Ellatzite mine

Soil	As	Cr	Cu	Fe	Mn	Ni	Pb	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Sample 1	22.5	129.6	80.3	5.33	567	46.6	24.3	73.6
Sample 2	23.2	44.7	80.7	5.54	538	31.5	29.8	67

Source: Zheleva et al., 2015

To achieve the goals of the study we set-up following tasks:

- Determination of the density and moisture content of the fermentation product and the soils.
- Determination of the influence of the product on the pH in mixture at different ratios of fermentation product / soil materials.
- Determination of the carbon content and essential nutrients in the soils and the fermentation product and in the mixtures of soils and the fermentation product.
- Determination of the content of the major heavy metals contained in the bulk rock from the designed site.

Methodology and methods

The main method of work to characterize the quality of the FP as an element of the soil-forming process is an ex-sito experiment. During the work, four mixtures with different ratio soils/fermentation product are formed. The following mixture ratios were examined:

- I variant of mixture FP:S = 1:1
- II variant of mixture FP:S = 1:2
- III variant of mixture FP:S = 1:3
- IV variant of mixture FP:S = 1:4

We tested the mixtures, pure soils and FP for the following parameters: bulk density (Q); relative density (D); soil-hydrological qualities (FH); capacity of active moisture (CAM); soil reaction (pH); humus (as carbon content); total nitrogen; K₂O; P₂O₅; salinization in aqueous extract; and total content of heavy and some other metals.

Subsequently, to determine the density of the mixture of fermentation product and soils in a volume ratio of FP:S = 1:4, an experiment was made with rings with a volume of 100 cm³ - one ring is filled with a fermentation product and 4 - with soils. The five volumes were well mixed and their water properties, volumetric density and pH were reported.

Results and discussion

The physical and chemical properties of the FP, soils and the product obtained after their mixing in certain ratios, show the possibilities for their utilization for reclamation of the Eastern embankment of the Ellatzite mine.

Physical properties.

The density and water properties of the soils and the FP are radically different (Table 3). The FP is analyzed in dry and wet condition. Both the dry and the wet product have the same bulk density (Q) - 0.26 g/cm³ - 5 times smaller than the bulk density of the soils. This density of FP is even lower than the average density of humus in soils at the mining area. When soils are mixed with the FP, the density are going to increase and will reach the density of the humus. For mixture with ratio FP:S = 1:4, the density of the mixture is going to be 1,156 g/cm³.

The analysis shows that the FP is an organic material that has not completed its transformation into humus. The processes of decomposition and turning it into humus will reduce its volume in the future. It's transformation into humus, when it is mixed with soils will be significantly faster than the formation of the natural humus in soils in the area. At the same time, the reclamation layer of FP + soils will become thinner not only due to shrinkage, but also due to the ongoing erosion processes.

Table 3: Density and water indices of the fermentation product and soils							
	Sample	FH (%)	CM (%)	MH (%)	MPW (%)	CAM (%)	Q (g/cm ³)
	Soils	33.83	27.54	3.77	5.05	22.49	1.38
	FP - dry	389.29	338.97	43.79	58.68	280.3	0.26
	FP - wet	335.64	318.94	-	-	-	0.26

Source: Author

Analyses of the water properties of the FP (Table 3) shows, that the common moisture (CM) of the FP is 11.58 - 12.53 times higher than the soil's CM, the maximum hygroscopicity is 11 times higher, the MPW is 11.7 times higher and the capacity of active moisture (CAM) is 12.5 times higher for the FP than for the soil's small fraction. That numbers shows that if we use a 50-cm layer of pure FP for reclamation it will absorb and retain moisture almost five times its own mass, making the reclamation layer unsustainable and the likelihood of slipping or sliding of the layer very high. For that reason, it is appropriate to mix FP with soils in a ratio that will prevent sliding.

Data from the analysis of FP and soils mixed in volume ratios give more favorable results due to better physical properties than FP by itself. The mixture has a density approximately the same as the natural soils of the area ($Q = 1.28 - 1.38 \text{ g/cm}^3$). The water properties are also close to those of the natural soils and considerably more favorable than those of the soils, planned to be used for recultivation and used in our study. Base on the result we assume that the mixture of FP and soils will have better physical properties than pure FP or pure soil because the mixture will retain more water than just FP for a longer time, but will not increase its weight.

Table 4: Density and water properties of a mixture in volume ratios of FP:S=1:4.						
	Sample code	pH	FH (%)	CM (%)	Q (g/cm ³)	Description of the samples
	Attempt 1	6.7	58.64	51.79	1.38	FP:S = 1:4
	Attempt 2	6.8	51.35	48.66	1.28	FP: S = 1:4
	Attempt 3	6.7	53.39	49.48	1.38	FP: S = 1:4
	Average	6.7	54.46	49.98	1.35	FP: S = 1:4
	4-3M	5.8	40.15	32.56	1.52	Soils

Source: Author

During the study we have analyzed other properties of the mixed materials – acidity, electrical conductivity (salinization), content of basic nutrients (CBN). The results are presented in Table 5. Each material and mixture are tested 3 times.

Analyses of the acidity of the soils shows that they have an acidic to slightly acidic reaction. The FP, conversely, has a neutral and slightly alkaline reaction. When mixing the two products, the reaction is changed smoothly and comparatively slowly from pH 7.4 to 6.9 according to the change in the ratio from FP:S = 1:1 to Ratio FP:S= 1:4. The pH remains significantly high in any of proposed ratios.

Based on these analyses we conclude that the ratio FP:S = 1:4 is the most appropriate for reclamation purposes.

Unlike acidity, the conductivity of the soils is low, but the conductivity of the FP it high and slightly exceeds the accepted salination limits of 4 dS/m. Mixed, however, in a ratio of 1:4 they do not represent a danger of deterioration of the forestry function of the newly formed substrate.

Carbon content in soils for recultivation is negligible, whereas in the FP it is almost 10 times higher than in the natural soils. In the proposed recultivation ratio FP:S = 1:4 the carbon content is approximately 8.14 %.

The content of the main nutrients in the soils is very low, especially the nitrogen content. On the other hand, the content of the nutrients (nitrogen, phosphorus and potassium) in FP are in a higher concentration

than the recultivation soils and natural soils in the region. When they are mixed in ratio FP:S = 1:4, essential nutrients significantly decrease, but their concentrations remain higher than those in natural soils. Therefore, during the first year, planted vegetation does not need mineral fertilizers.

Table 5. Acidity, electroconductivity, hydrolytic acidity (H), carbon content and main nutrients

Description of the samples	Attempt	pH H ₂ O ISO 10390	Electrical conductivity	H	C	N	P ₂ O	K ₂ O
			mS/cm	meq/100g	%	%	mg/100g	mg/100g
Soils	1	5.8	0.110	2.41	0.13	0.037	4.10	6.1
Soils	2	5.8	0.119	2.50	0.12			
Soils	3	5.9	0.114	2.33	0.13			
FP	1	7.4	4.36		40.44	3.412	199.68	1462.0
FP	2	7.4	4.27		33.46			
FP	3	7.4	4.28		46.70			
FP:S=1:1	1	7.2	2.76			1.651	189.00	721.8
FP:S=1:1	2	7.2	2.63					
FP:S=1:1	3	7.2	2.65					
FP:S=1:1	1	7.1	1.97			1.08	185.50	421.3
FP:S=1:2	2	7.1	1.98					
FP:S=1:2	3	7.1	2.01					
FP:S=1:3	1	7.0	1.60			0.87	183.75	334.5
FP:S=1:3	2	7.0	1.64					
FP:S=1:3	3	7.0	1.61					
FP:S=1:4	1	6.9	1.31	1.59		0.69	78.75	276.5
FP:S=1:4	2	7.0	1.29	1.37				
FP:S=1:4	3	6.9	1.26	1.37				

Source: Author

Regulation of acidity

The results from analyses of acidity of are presented in Table 6.

Table 6: Changes in acidity of mixtures of fermentation product (FP) and soils at different ratios

Sample	Mixture	Ratio FP:S	FP kg/m ³ :EM kg/m ³	pH _{H2O}
Soil	Q = 1.38 (g/cm ³)	-	-	5.8
Fermentation product (FP)	Q = 0.6 (g/cm ³)	-	-	7.4
FP:S=1:1	Mixture 1	1:1	FP 260 kg/m ³ :EM 1380 kg/m ³	7.2
FP:S=1:1	Mixture 1	1:1	FP 260 kg/m ³ :EM 1380 kg/m ³	7.2
FP:S=1:1	Mixture 1	1:1	FP 260 kg/m ³ :EM 1380 kg/m ³	7.2
FP:S=1:2	Mixture 2	1:2	FP 260 kg/m ³ :EM 2760 kg/m ³	7.1
FP:S=1:2	Mixture 2	1:2	FP 260 kg/m ³ :EM 2760 kg/m ³	7.1
FP:S=1:2	Mixture 2	1:2	FP 260 kg/m ³ :EM 2760 kg/m ³	7.1
FP:S=1:3	Mixture 3	1:3	FP 260 kg/m ³ :EM 4140 kg/m ³	7.0
FP:S=1:3	Mixture 3	1:3	FP 260 kg/m ³ :EM 4140 kg/m ³	7.0
FP:S=1:3	Mixture 3	1:3	FP 260 kg/m ³ :EM 4140 kg/m ³	7.0
FP:S=1:4	Mixture 4	1:4	FP 260 kg/m ³ :EM 5520 kg/m ³	6.9
FP:S=1:4	Mixture 4	1:4	FP 260 kg/m ³ :EM 5520 kg/m ³	7.0
FP:S=1:4	Mixture 4	1:4	FP 260 kg/m ³ :EM 5520 kg/m ³	6.9
Average values				
	Mixture 1	1:1	FP 260 kg/m ³ :EM 1380 kg/m ³	7.2
	Mixture 2	1:2	FP 260 kg/m ³ :EM 2760 kg/m ³	7.1
	Mixture 3	1:3	FP 260 kg/m ³ :EM 4140 kg/m ³	7.0
	Mixture 4	1:4	FP 260 kg/m ³ :EM 5520 kg/m ³	6.9

Source: Author

Adding the FP to soils for embankment reclamation will increase the pH by about one unit. With regard to reclamation, this change will not have a significant impact on acidity of the reclaimed territory because the main negative factor affecting vegetation is the pH of the dumped mining waste underneath. However, if we use the FP:S=1:4 ratio, during the first year of grassing and afforestation of the embankment, there will be no need of liming.

Content of heavy metals

Analyzes of heavy and some other metals content in FP and Soil are presented at Table 7. The results are compared with soil quality standards in Bulgaria, defined by Ordinance № 3 on the standards for permissible content of hazardous substances in soils/August 2008.

Table 7: Content of heavy and some other metals in FP and soils									
Sample code	Fe	Pb	Cu	Mn	Zn	Cd	Mg	Ca	Na
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Soils	70671	49.8	449.4	627.9	37.4	2.26	2503	579	132
FP	3786	5.1	36.3	232.8	140.9	1.14	3579	6620	315
Precautionary values		40	50		110	0.6			
MPC		130	140		390	2.5			

Source: Author

The results show that the FP does not contain heavy metals above the precautionary values except zinc and cadmium.

Only iron is noted in quantities well above the average soil content, both in the soil and in the FP. Unusual is the Ca:Mg ratio where the content of Mg is almost 5 time higher than Ca. In soils under normal condition the ratio of Ca:Mg should be 4:1. In the soils, the calcium content is significantly below the average soil content, which is due to the soil - forming rock and is a prerequisite for acidification. More favourable is the ratio of the FP, where Ca:Mg is almost 2:1, but still far from natural soils (4:1). Based on these finding, during the first years of reclamation, while the processes of transformation of the FP into humus are running, the level of acidity and conductivity of the soil-forming material must be monitored.

Recommendations for reclamation

The study on properties of soils that are going to be used for reclamation, FP and mixtures at different ratios of both products give us a reason to conclude that the FP can be used as soil-forming material and a catalyst of the soil-forming processes of the embankment reclamation. The main issues that need to be addressed with the reclamation project are:

- What should the mixing ratio of the FP with the soils be, so to be a good root layer for the growth and development of the tree-shrub vegetation and to accelerate the ecosystem development;
- How thick could be the reclamation layer be without disturbing the long-term stability of the reclaimed slopes at the different angles of inclination.

The present study answers these questions and, based on the results obtained, we can streamline the basic requirements for the reclamation of the Eastern embankment when FP is used.

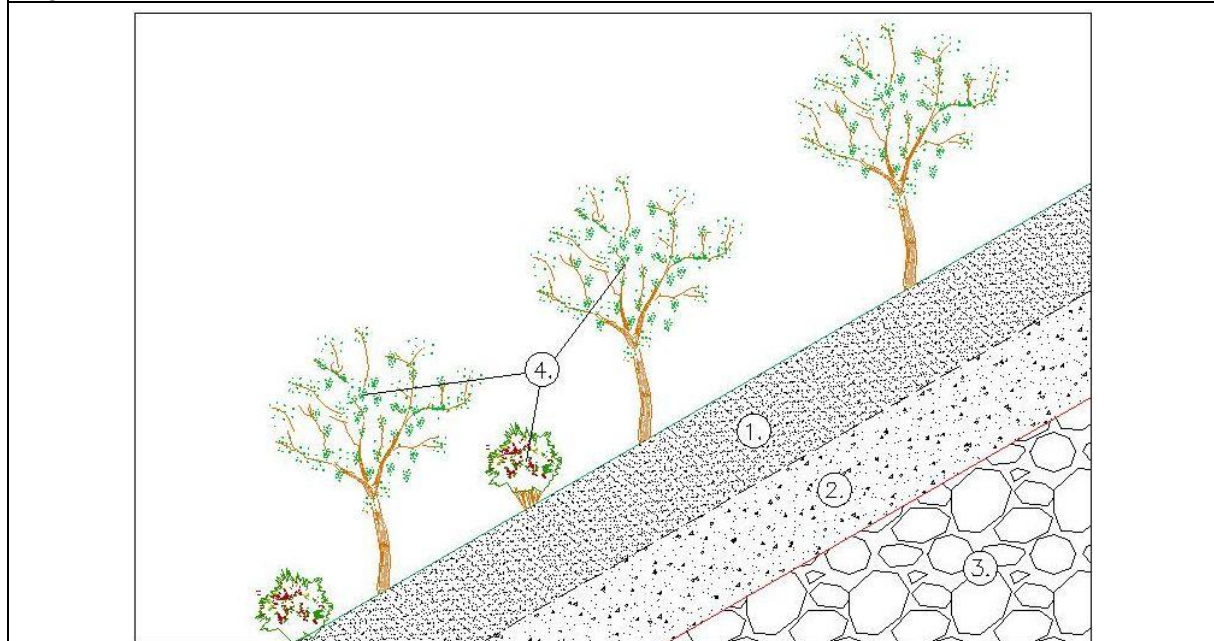
FP added to soils in a 1:4 ratio (FP:S) will improve the physical and chemical properties of the reclamation layer without endangering the stability of the terrain.

Based on physical properties of the FP and the mixture of FP and soil we recommend the thickness of the infilling on the slopes without additional reinforcement measures to not exceed 40 cm, due to the risk of slipping. From the point of view of bio-reclamation efficiency, a 50 cm embankment thickness would be much more appropriate, but in this case additional reinforcement measures are obligatory. In flat areas this thickness may be even greater. Strengthening the slopes can be done by building of strengthening matting. The expected behavior of the recultivated embankment slope with soils and FP are shown on Figure 1.

Figure 1A shows the embankment after its covering with a FP:S recultivation layer and afforestation: 1. Upper reclamation layer containing FP and soils (thickness 0.40 – 0.50 m); 2. Underneath layer

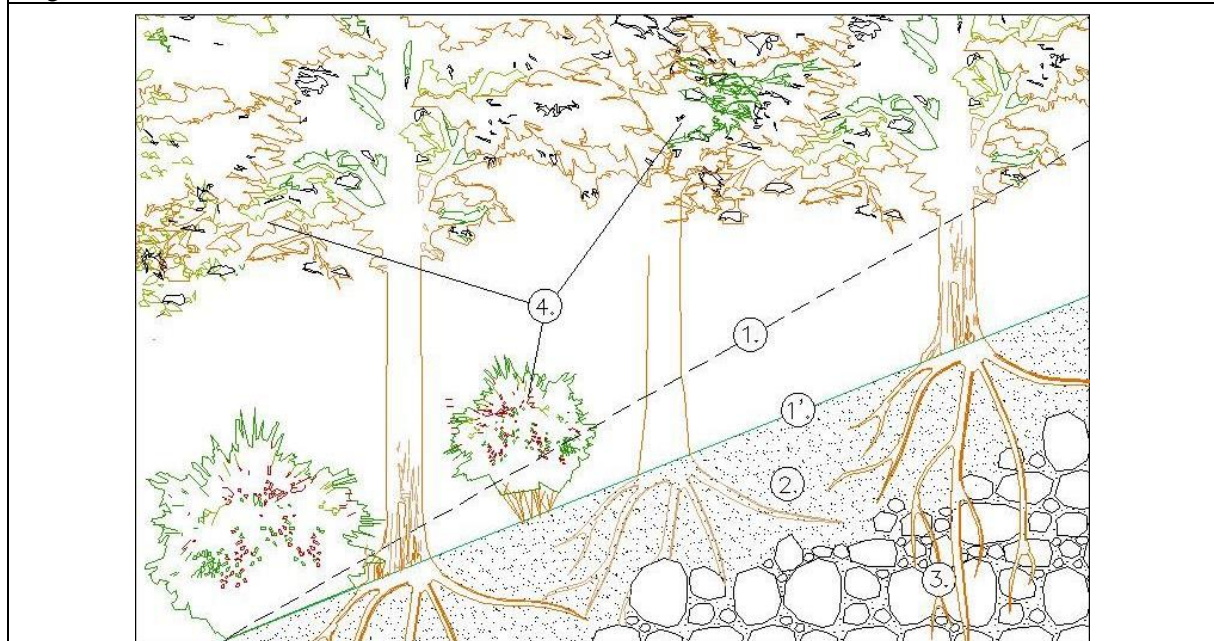
containing small fraction mining waste mixed with lime (thickness 0.50 – 0.70 m); 3 Embankment surfaces; 4. Afforested saplings.

Figure 1: Expected shrinkage of the embankment during development of the soil formation process
 Figure 1A



Source: Author

Figure 1: Expected shrinkage of the embankment during development of the soil formation process
 Figure 1B



Source: Author

Figure 1B shows the embankment after a period of 2-5 years after reclamation:

1. The angle of surface layer of reclaimed slope at the beginning of the reclamation;
- 1'. The angle of surface layer of reclaimed slope after shrinkage on the embankment;
2. Soil-forming layer from the weathering FP:S mixture, mixed with the small fraction that has penetrated between the rocks and the weathering rock products;

3. Rock embankment and leeward rock products mixed with penetrated small fraction of mining waste.
4. Trees, whose roots have penetrated between rock materials.

Fertilization norms

When the fermentation product is mixed with soil mass in FP:S = 1:4 ratio, the essential nutrients are significantly reduced but still their concentrations remain higher than those in the natural soils. For these reasons, in the first years (1 - 2) of the biological reclamation the plants do not need mineral fertilizers. However, in the years to come, the growth of grass and tree-shrub vegetation will probably require the introduction of combined mineral fertilizers. Their norms should be determined after analysis of the humus and essential nutrients content in the root layer of vegetation. Soluble fertilizers should be introduced two or three times a year in small doses as the saplings are still small and the absorption becomes slow, and the wash water regime will aid the washing of larger quantities of fertilizers to the catchment area below the embankment.

Conclusion

FP is a proper product to be used as a soil enhancer for recultivation of disturbed areas affected by mining, and characterized with high pH and low nutrition properties.

The best ratio FP:S is 1:4, because it presents the good positive influence on pH, nutrition properties and at the same time does not put at risk the stability of the embankment.

The use of FP for reclamation reduces the need to add additional meliorants, such as lime and fertilizer for at least the first years after recultivation;

For application of the FP for reclamation of embankments with acidic rocks and steep slopes, we can make the following recommendations to the reclamation technology:

Before backfilling the reclamation mixture (Soils + FP), must be insert lime, on the deposited rock materials at a norm of 30-50 % of the calculated amount necessary to neutralize a 30 cm layer of rock material, i.e. 2.5 - 3 t/ha. The aim is to build a film that prevents the acidification of an upper reclamation layer. There is no need to introduce lime in the mixture of FP and soils, because the reaction is neutral. In this case, for 4 to 5 years there will be no need for liming. After this period has elapsed, the acidity analysis of the root layer will show the need for liming;

To minimize the risk of sliding and slipping, it is necessary to ensure the stability of the slopes;

After the first year observations of the recultivated terrain should be provided in order to assess the behavior of the FP in real conditions. The observations shall include at least: changes in pH and the determination of the need for additional liming; stability of recultivated terrain, risk assessment of landslides and erosion, analysis of the need for further strengthening; and nutrient content after the first growing season, incl. an assessment of the need and fertilization norms for the coming years.

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