Scientific Papers. Series A. Agronomy, Vol. LXVIII, No. 1, 2025
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

SOIL NUTRITIONAL STATUS FUNCTION OF BIOMASS HARVESTING IN NORTHWESTERN ROMANIA

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Abstract

The removal of biomass disrupts the natural nutrient cycle in forest ecosystems. Organic materials like leaves and branches, which would typically decompose on the forest soil, are essential for replenishing soil nutrients. Key nutrients such as nitrogen, phosphorus, and potassium are particularly affected. These nutrients are vital for plant growth and soil health, and their depletion can lead to reduced soil fertility over time. These nutrients are crucial for maintaining soil health and supporting plant growth. The present study carried out in forest area of Cluj County, Northwestern Romania, during summer and autumn of 2024, explores the relationship between biomass harvesting practices and the nutritional status of soil in forest ecosystems. Raw data collected from field were statistically processed using XLSTAT program. The results of our research show that removal of biomass, including branches, leaves, and other organic materials, can significantly impact soil fertility by depleting essential nutrients such as nitrogen, phosphorus, and potassium.

Key words*: deforestation, forests ecosystem, nutrients, plants growth.*

INTRODUCTION

Biomass harvesting, whether from forests or agricultural systems, plays a pivotal role in the renewable energy sector and sustainable resource management (Bays et al., 2024; Miner et al., 2014; Titus et al., 2021). Meantime, it is well known that biomass removal (especially whole tree harvesting) has detrimental effect on soil productivity. The depletion of soil nutritional satus due to biomass harvesting are more pronounced in the forest floor than in the mineral soil. In the initial years following harvest, biomass removal can significantly impact environment and soil ecosystems by modifying microclimatic conditions and nutritional status (Agbeshie et al., 2025; Bellassen & Luyssaert, 2014; di Maria, 2025; Veldkamp et al., 2020). Over time, reduced nitrogen and/or phosphorus and potassium availability in whole-tree harvested sites has been associated with diminished soil fertility, persisting for at least 20 years in some forest stands (Akselsson & Westling, 2005; Duchesne & Houle, 2008; Thiffault et al., 2011). In North-West Romania, extensive forest biomass removal, mainly whole tree, has become a common practice, driven by both energy needs and the economic benefits associated with biomass-based industries (Andronache et al., 2017; Pintilii et al., 2015). Yet, these practices raise critical questions about the long-term health of the soil. Soil nutritional status is maintained through a continuous cycle of organic matter deposition and microbial decomposition (Dinesh et al., 2003; Khresat et al., 2007). Nitrogen is vital for protein synthesis and plant growth, phosphorus is essential for energy transfer within cells, and potassium regulates enzyme activation and water use efficiency (Kassa et al., 2017). In intact ecosystems, these nutrients are naturally replenished through plant residues, animal activity, and microbial processes. Changes in land use influence stream nutrient chemistry by altering nutrient cycling within vegetation and soil organic matter (Biggs et al., 2004). Biomass removal interrupts this cycle. The loss of organic inputs can lead to a decline in soil organic matter, thereby reducing the soil's capacity to retain and recycle essential nutrients (Biggs et al., 2004; Kučerík et al., 2018). The clearing of forested land may have negative impact on physical and nutritional soil properties, leading to the degradation of nitrogen, when compared to land under natural forests, reforestation, or grassland (An et al., 2008). The study was conducted to analyze the impact of biomass removing on soil physical and nutritional properties by comparing forested areas with those where biomass was removed, deforested, respectively.

MATERIALS AND METHODS

The trial was carried out in forest area of Cluj County, located in Northwestern Romania, populated with deciduous species, during summer and autumn of 2024. According to ISRIC - International Soil Reference and Information Centre (https://www.isric.org/), the soil belongs to Luvisol group. Soil samples were collected from 10 points located in both environments, forested and deforested. Deforested area is the result of whole tree harvesting which was made during 6-8 years ago. In each area, samples were taken from 0- 30 cm depth from the horizon Ao in each soil. The collected soil samples were analyzed for physical parameters: clay, sand, and dust fractions, total porosity, and apparent density. The analyzed soil nutritional properties concern pH, humus content, nitrogen, phosphorus, and potassium levels. Laboratory analyses were conducted using standardized methods. Particle size distribution was determined using the hydrometer method, while total porosity and apparent density were measured through gravimetric techniques. Soil pH was analyzed using a pH meter, and humus content was assessed through wet oxidation. Nitrogen, phosphorus, and potassium levels were determined using Kjeldahl, spectrophotometric, and flame photometry methods, respectively. Climatic variables such as temperature, relative humidity, wind velocity, and precipitation were monitored in the field using a mobile station. Statistical analyses, including descriptive statistics, cluster analysis and PCA, were performed using XLSTAT and Statistica for windows v.18.0 software.

RESULTS AND DISCUSSIONS

The comparative analysis of the physical characteristics of soil in forested and deforested areas shows the impact of biomass removing on soil structure and composition (Table 1).

Table 1. The physical traits of soil located in forested and deforested areas

Trait	N	X	Min.	Max.	s	CV, %
Forested area						
Raw sand (%)	10	0.32a	0.30	0.33	0.01	3.61
Fine sand (%)	10	2.76a	2.50	3.00	0.21	7.46
Dust I (%)	10	12.49a	12.00	12.90	0.39	3.09
Dust II (%)	10	21.27a	20.00	22.00	0.80	3.78
Clay (%)	10	34.92a	34.00	35.70	0.62	1.76
Hygroscopicity (%)	10	5.68a	5.00	6.20	0.47	8.26
Apparent density (g/cm^3)	10	1.26a	1.00	1.90	0.37	28.88
Total porosity (%)	10	51.30a	49.00	53.00	1.72	3.35
Deforested area						
Raw sand (%)	10	0.55b	0.52	0.57	0.02	3.64
Fine sand (%)	10	2.21a	2.00	2.40	0.16	7.45
Dust I (%)	10	8.62b	8.28	8.90	0.27	3.08
Dust II (%)	10	9.03b	7.80	10.43	0.95	10.55
Clay (%)	10	25.15b	24.48	25.70	0.44	1.76
Hygroscopicity (%)	10	4.41a	3.60	4.96	0.50	11.30
Bulk density (g/cm^3)	10	1.73a	1.37	2.60	0.50	28.88
Total porosity (%)	10	35.91b	34.30	37.10	1.20	3.35

In the forested area the soil has a higher clay content and total porosity (34.92%, and 51.30%, respectively) which contribute to better water retention and aeration.

The apparent density is lower, indicating a more stable and less compacted soil structure. In the deforested area there is an increase in raw sand content (0.55% compared with 0.32 reported in forested area) and a decrease in clay and dust fractions, suggesting soil degradation and erosion. The total porosity is lower while apparent density is higher indicating compaction and reduced water infiltration. The differences between forested and deforested areas are significant for clay content, total porosity and dust fractions. The deforested area shows a marked decline in fine particles that suggest the reducing of its ability to retain moisture and support plant growth.

Similar results concerning clay content are revealed by Hajabbasi et al. (1997) in Iran forest areas, who report a statistically significant decrease from 37.9% in forested soil to 28.6% in deforested soil.

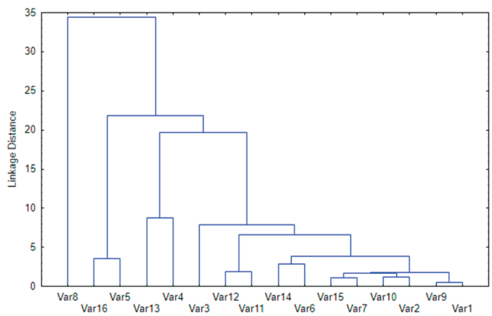
If analyzing the nutritional properties of soil in forested and deforested areas, one may find the biomass removing impacts on soil fertility. In the forested area the pH is higher (6.44 pH units), humus content (1.63%) is more abundant and nitrogen phosphorus and potassium levels (0.13%, 11.94 ppm, and 91.80 ppm, respectively) are significantly greater, indicating a more fertile soil environment capable of supporting plant growth and microbial activity. Similar results concerning nitrogen content are presented by Hajabbasi et al. (1997) in Iran forest areas, who report a statistically significant decrease from 0.164% in forested soil to 0.009% in deforested soil.

In the deforested area there is a notable reduction in humus (1.04%), nitrogen (0.08%), phosphorus (540 ppm) and potassium (49.91 ppm) levels, which suggests depletion of organic matter and essential nutrients. The high variability in phosphorus and nitrogen indicates instability, likely caused by soil erosion and loss of nutrient retention capacity. The pH is slightly lower pointing to potential acidification after biomass removing. The decrease in soil fertility in deforested areas highlights the negative consequences of vegetation removal, reducing the ability of the soil to sustain plant growth and increasing the need for restoration measures to replenish organic matter and essential nutrients (Table 2).

Table 2. The nutritional traits of soil located in forested and deforested areas

Trait	N	X	Min.	Max.	s	CV, %
Forested area						
pH (pH units)	10	6.44a	6.30	6.60	0.11	1.75
Humus (%)	10	1.63a	1.45	1.80	0.16	9.94
Nitrogen (%)	10	0.13a	0.12	0.14	0.01	6.57
Phosphorus (ppm)	10	11.94a	11.00	13.00	0.75	6.31
Potassium (ppm)	10	91.80a	86.00	99.00	5.17	5.63
Deforested area						
pH (pH units)	10	6.13a	6.05	6.24	0.08	1.34
Humus (%)	10	1.04b	0.80	1.26	0.16	15.79
Nitrogen (%)	10	0.08b	0.06	0.08	0.01	13.77
Phosphorus (ppm)	10	5.40b	0.65	7.02	0.70	12.96
Potassium (ppm)	10	49.91b	43.00	53.46	4.57	9.16

The clustering pattern indicates that total porosity in both forested and deforested areas (Var8 and Var16) are represented in distinct groups, suggesting a significant difference in porosity between the two environments. Clay in deforested and forested areas (Var5 and Var13) groups are closely positioned, highlighting their similarity despite environmental changes. Dust I and dust II in both areas (Var3, Var4, Var11, Var12) exhibit related clustering suggesting that these fractions behave similarly under both conditions. Traits related to apparent density (Var7 and Var15) and hygroscopicity (Var6 and Var14) also cluster closely suggesting a relationship between these properties in maintaining soil structure and moisture retention. The raw sand, and fine sand (Var1, Var2, Var9, Var10) are grouped together at lower linkage distances indicating minimal variation in their distribution across forested and deforested soils (Figure 1).

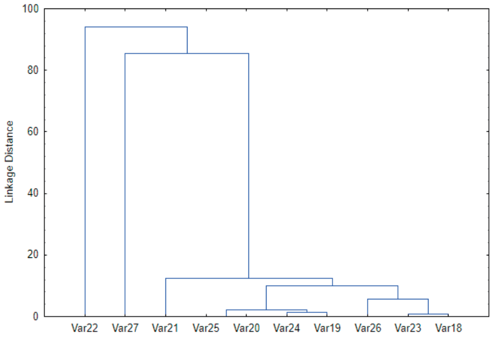


Var1 - raw sand, forested; Var2 - fine sand, forested; Var3 - dust I, forested; Var4 - dust II, forested; Var5 - clay, forested; Var6 -hygroscopicity, forested; Var7 - apparent density, forested; Var8 - total porosity forested; Var9 - raw sand, deforested; Var10 - fine sand, deforested; Var11 - dust I, deforested; Var12 - dust II, deforested; Var13 -clay, deforested; Var14 - hygroscopicity, deforested; Var15 - bulk density, deforested; Var16 - total porosity deforested.

Figure 1. The dendrogram corresponding to physical traits of soil located in forested and deforested areas

Concerning the soil nutritional traits, the cluster analysis shows that the most distinct grouping is observed for potassium in both forested and deforested soils (Var22 and Var27), which cluster at the highest linkage distance. This suggests a strong differentiation in potassium availability between the two environments.

Phosphorus in both conditions (Var21 and Var26) forms a separate cluster at a significant distance, indicating differences in phosphorus levels due to biomass removing (Figure 2).



Var18 - pH, forested; Var19 - humus, forested; Var20 - nitrogen, forested; Var21 - phosphorus, forested; Var22 - potassium, forested; Var23 - pH, deforested; Var24 - humus deforested; Var25 - nitrogen, deforested; Var26 - phosphorus, deforested; Var27 - potassium deforested.

Figure 2. The dendrogram corresponding to nutritional traits of soil located in forested and deforested areas

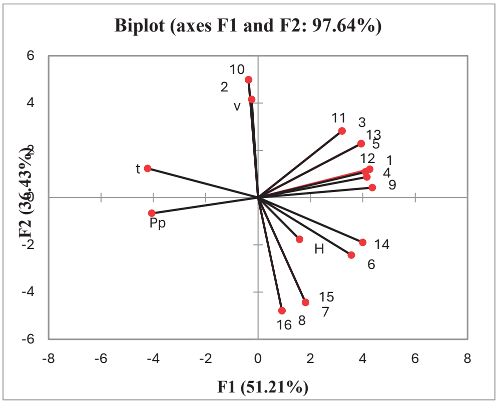
Nitrogen in forested and deforested areas (Var20 and Var25) correspond to separate clusters. Humus (Var19 and Var24) and pH (Var18 and Var23) exhibit the smallest linkage distances suggesting that these traits remain relatively stable between forested and deforested conditions compared to other nutrients. The clustering pattern indicates that potassium, phosphorus nitrogen and humus soil contents changed due to biomass removing, while pH shows relatively smaller variations, thus reinforcing the importance of these elements in assessing soil fertility degradation and the need for nutrient restoration in deforested areas.

PCA was conducted, considering the results of the Bartlett ($p<0.001$) and Keiser - Meyer - Olkin (KMO) tests (Merce & Merce, 2009). We identified three principal factors affecting soil physical and nutritional traits, in both forestation and biomass removing conditions. These factors are: Factor 1, environmental conditions (forestation and biomass removal), Factor 2, climatic conditions, and Factor 3, soil status (structural and nutritional). According to PCA, Factor 1 - Environmental conditions explains 56.20% of the total variance indicating that it captures most of the information concerning the soil physical traits in both analyzed environmental conditions, forestation and biomass removing, respectively. Factor 2 - Climatic conditions, accounts for 41.43% bringing the cumulative variance explained to 97.64%, which suggests that these two factors are determinant for the soil physical traits. Factor 3 contributes only 2.36% to the total variance, indicating minimal additional information beyond the first two factors and confirming that most of the variability in the data is well represented by the first two principal components (Table 3).

Table 3. The Eigenvalues and total variance for physical traits of soil located in forested and deforested areas

Eigenvalue	% Total - variance	Cumulative - Eigenvalue	Cumulative - %
11.2417	56.2087	11.2417	56.2087
8.2859	41.4324	19.5276	41.4324
0.4724	2.3600	20.0000	100.0000

Soil variables such as total porosity (8 and 16) and apparent density (7 and 15) exhibit strong contributions along PC1 suggesting significant differentiation between forested and deforested areas. The clay (5 and 13) and dust fractions (3, 4, 11, 12) align in a way that highlights their role in soil composition and aggregation. Environmental factors, temperature (t) relative humidity (H) wind velocity (v) and precipitation (Pp), respectively, show distinct orientations indicating their independent influence on soil properties (Figure 3).



1-raw sand, forested; 2-fine sand, forested; 3-dust I, forested; 4-dust II, forested; 5-clay, forested; 6-hygroscopicity, forested; 7-bulk density, forested; 8-total porosity forested; 9-raw sand, deforested; 10-fine sand, deforested; 11-dust I, deforested; 12-dust II, deforested; 13-clay, deforested; 14-hygroscopicity, deforested; 15- bulk density, deforested; 16-total porosity deforested; t-temperature; H-relative humidity; v-wind velocity; Pp-precipitations. The arrow represents the direction of the weighting of soil analyzed traits.

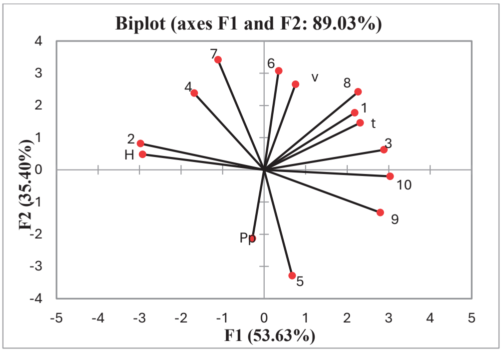
Figure 3. The representation in PC1 x PC2 plans of the variables corresponding to physical traits of soil located in forested and deforested areas

The clear separation of soil traits between forested and deforested areas underscores the impact of biomass removing on soil structure porosity and density while climatic factors play a role in shaping these physical characteristics.

Similarly with results concerning the physical soil trats, when analyzing nutritional soil status, PCA shows that most of the variability in the data is well represented by the first two principal factors. Factor 1 explains 53.63% of the total variance and Factor 2 accounts for 35.40% (Figure 4). Factor 3 makes a 10.97% contribution to the total variance (Table 4).

Table 4. The Eigenvalues and total variance for chemical traits of soil located in forested and deforested areas

Eigenvalue	% Total - variance	Cumulative - Eigenvalue	Cumulative - %
7.8077	53.6315	7.8077	53.6315
5.2562	35.4022	13.0639	89.0337
0.9361	10.9663	14.0000	100.0000



1-pH, forested; 2-humus, forested; 3-nitrogen, forested; 4-phosphorus, forested; 5-potassium, forested; 6-pH, deforested; 7-humus deforested; 8-nitrogen, deforested; 9-phosphorus, deforested; 10-potassium, deforested; t-temperature; H-relative humidity; v-wind velocity; Pp-precipitations. The arrow represents the direction of the weighting of soil analyzed traits.

Figure 4. The representation in PC1 x PC2 plans of the variables corresponding to nutritional traits of soil located in forested and deforested areas

Potassium (5 and 10) shows a strong contribution along PC1 indicating significant variation between forested and deforested soils phosphorus (4 and 9) and nitrogen (3 and 8) also display distinct orientations emphasizing their role in differentiating soil fertility conditions pH (1 and 6) and humus (2 and 7) exhibit moderate variability suggesting that these traits are influenced by biomass removing but to a lesser extent. Environmental factors indicate their individual influence on soil nutritional dynamics. The separation of soil traits between forested and deforested areas highlights the nutrient depletion and soil fertility decline associated with biomass removing while climatic factors contribute to additional variability in soil composition.

CONCLUSIONS

The comparative analysis of soil properties in forested and deforested areas reveals the profound impact of biomass removing on soil structure and fertility. In forested areas, the soil maintains a higher clay content and total porosity, which contribute to improved water retention and aeration, while the lower apparent density ensures a more stable and less compacted structure. In contrast, deforested areas experience an increase in raw sand content and a decrease in fine particles, leading to soil degradation, compaction, and reduced infiltration capacity. The marked decline in porosity and the increase in apparent density highlight the detrimental effects of vegetation removal on soil stability.

The analysis of soil fertility further confirms the negative consequences of biomass removal. In forested soils, higher pH, greater humus content, and significantly increased nitrogen, phosphorus, and potassium levels indicate a nutrient-rich environment capable of sustaining plant growth and microbial activity. However, deforested areas show a notable reduction in these essential nutrients, with humus depletion and increased variability in phosphorus and nitrogen suggesting instability due to erosion and diminished nutrient retention. The lower pH in deforested areas points to potential acidification, reinforcing the idea that biomass removing accelerates soil degradation and reduces its ability to support vegetation.

Cluster analysis and principal component analysis (PCA) confirm that biomass removing introduces significant structural and compositional changes in the soil.

The hierarchical clustering of soil physical traits reveals strong differentiation in total porosity and clay content, while dust fractions, sand distribution, and apparent density exhibit internal similarities across environments. Nutritional trait clustering highlights potassium and phosphorus as the most affected elements, with nitrogen, humus, and pH showing smaller variations. PCA results indicate that environmental factors, particularly biomass removing and climatic conditions, account for most of the variance in soil properties.

The findings emphasize that biomass harvesting, which is not followed by reforestation or other land use in agroforestry sector, leads to soil compaction, reduced porosity, and significant nutrient depletion, ultimately decreasing soil fertility and increasing susceptibility to erosion. The interaction between environmental and climatic factors further influences soil dynamics, reinforcing the importance of sustainable land management strategies.

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