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Soil Quality Assessment in Response to Water Erosion and Mining Activity

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Abstract: Erosion significantly decreases the depth of a soil, the nutrients available for plants, the organic matter and, consequently, the productivity of the edaphic environment. Due to the above considerations, the objective of this study was to evaluate, through various properties, the quality of two eroded soils, one eroded by water and the other by mining activity, amended with biosolids. The quality for both soils was estimated through the selection of a minimum set of data by means of principal component analysis (PCA) and the subsequent realization of correlations, multiple regressions and finally calculations of normalized values (Vn) of those properties considered as indicators of soil quality. According to the results, inorganic nitrogen (NI) and respiratory activity (RA) were the properties selected as indicators to assess quality. For soil eroded by water and by mining activity, NI presented a low and very low quality, respectively (class 4 and 5 of quality according to the calculation of Vn). The quality of RA in soil eroded by mining extraction was very high (quality class 1 according to Vn), and thus it can be considered an ideal indicator for the evaluation of soil quality due to its sensitivity to anthropogenic changes (mining) in soil.

Keywords: biosolids; erosion; inorganic nitrogen; quality index; normalized value (Vn); respiratory activity

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1. Introduction

Erosion refers to the removal of the upper layer of the soil due to the effect of external agents such as wind and water; however, the erosive phenomenon is increased by human activities. The state of Mexico (Central Mexico) ranks fourth nationwide for water erosion (81.19%), with degrees ranging from moderate to extreme [1,2]. Water erosion is the most common form of soil degradation. The process consists of the detachment, transport and deposit of soil particles caused by rain; the process begins with the impact of the raindrops and once the infiltration and surface storage capacity is saturated, the runoff begins, dragging the loose particles and those that its own force detaches; the mechanism ends when the eroded material, also called sediment, is deposited. As a result of the erosive phenomenon, there is a loss of the superficial layer of the soil, which has become a growing concern throughout the world and has been identified as one of the key elements of soil degradation. Soil degradation via erosion involves (a) physical changes, among which are: formation of crusts, loss of structure, compaction and anoxia; (b) chemicals that include salinization and alkalization and (c) biochemicals, presenting a decrease in the diversity and microbial function of the soil. Soil erosion also contributes to climate change, as soil degradation processes caused by erosion often result in the release of soil organic carbon into the air, increasing carbon dioxide in the atmosphere. This, in turn, exacerbates climate change through increased greenhouse gas (GHG) emissions [3–6].

Regarding mining activity, this is one of the factors responsible for the disintegration of the earth's surface, resulting in areas vulnerable to excessive soil erosion, and the State of Mexico, as with water erosion, is affected by mining activity, the main producer of non-metallic minerals used in construction, with sand being one of the most extracted products [7,8]. Opencast mining includes the extraction of sand. Opencast mining involves the removal of large amounts of waste material, dumping, and backfilling in excavated areas. Negative effects are most often manifested by changes in the geological structure and relief; land cover modification, including temporary and permanent disuse of agricultural and forest areas; soil destruction; deterioration of the water regime; contamination of surface and underground waters; degradation of flora and fauna; changes in the microclimate; generation of significant amounts of waste. Specifically, in the soil, the effects that occur due to mining are loss of structure, with chemical deficiencies, extreme pH, and remnants of toxic heavy metals. The removal of vegetation cover reduces biodiversity and the organic matter (OM) content of the soil, increasing soil erosion [9,10].

When the superficial horizon of the soil via erosion of essential nutrients for plants such as nitrogen, phosphorus, and potassium is eliminated and organic matter is removed, this negatively affects soil quality [11,12]. The decrease in organic matter has important consequences, including changes in the soil structure, loss of some cycles, as well as a decrease in the retention of moisture and nutrients such as C and N. These nutrients have a crucial role in the soil environment (set of elements and factors related to soil) since they influence the growth of plants by participating in their productivity and composition; without them, the plants cannot complete their life cycle (vegetative production, flowering and seeds) [13–15]. Due to the above considerations, there is a need to implement measures that are capable of mitigating the damage to the soil caused by erosion. The use of organic amendments turns out to be a good option; the origin of these can be from various sources such as agriculture, forestry, and urban waste streams [16]. From the latter, biosolids are generated, which for restoration purposes are added as a source of organic matter, nutrients (N and P) and micronutrients contributing to the microbial activity of the soil, thus giving them a use as an organic amendment [17,18].

A criterion that helps determine the degree of soil degradation is the assessment of its quality [19]. The soil quality is defined as the capacity of the edaphic environment to function within the limits of an ecosystem, either naturally or managed, with the aim of maintaining crop productivity while reducing soil degradation; in addition, the soil quality concept is functional and includes variables that work to assess the state of a soil [20,21]. Recognize the quality of eroded soils is essential since the erosive phenomenon represents a serious problem for food sustainability, mainly because the soil is a finite resource. In turn, the deterioration of soil quality, through loss of fertility and erosion, can limit self-sufficiency, security and food sovereignty [22–24].

Soil quality indicators (SQI) are measurable tools that offer information about the properties, processes and characteristics of the soil [19]. Soil quality indicators can be physical, chemical and biological properties, or processes that occur in it [25]. Determinations of soil properties such as its physical (texture and bulk density), chemical (pH, electrical conductivity, nitrogen mineralization, organic matter) and biological (microorganism activities) properties serve as SQI [20,26]. It has been proposed to use predefined SQI or to combine a large number of SQI into indices to generate a total data set. One option is to use few but representative indicators, for which it has been proposed to use a minimum data set (MDS). In turn, the MDS contains a selection of parameters that represent the total set of data; thanks to this, the time and money required to achieve this process are reduced. Principal component analysis (PCA) is used to identify the most sensitive SQI or those with the greatest impact on soil quality. For this purpose, the physical, chemical and biological properties of the soil are evaluated [19,27,28].

It is important to mention that the erosive phenomenon is considered a threat to world food security. However, the addition of organic amendments such as biosolids could be beneficial, presenting positive effects on the properties of these degraded soils. There is little information about the generation of quality indices from eroded soils conditioned with biosolids; therefore, the objective of this study was to evaluate, through several properties, the quality of two eroded soils (hydrically and via mining extraction) conditioned with biosolids to be able to suggest properties that result as better quality indicators and, based on these properties, determine the degree of quality that the two eroded soils present. The research questions we have for this study are: What properties can be considered as quality indicators? What will be the degree of quality of the eroded soils due to the addition of biosolids? Our hypothesis suggests that the properties related to the microbial activity will yield data about the quality of both soils and that the quality that is presented will be high due to the effect of the incorporation of the biosolid.

2. Materials and Methods

2.1. Sampling Areas

Two sampling zones were established in the Jiquipilco Municipality, State of Mexico, based on the type of erosion. The area with water erosion was located according to an investigation carried out by Bolaños-González et al. [1], who evaluated organic carbon losses at the national level due to water erosion. According to this research, the soil presents a strong degree of water erosion and is located at the coordinates 19°31′36″ N, 99°41′23″ W, with an altitude of 2723 m. The second zone was located in a mine that is still active and in which sand has been extracted for several years, which has given rise to a soil eroded by mining extraction. The coordinates of the zone are 19°32′35″ N, 99°43′54″ W, with an altitude of 2746 m. The climate of the area is characterized by being temperate sub-humid with summer rains $C(w_2)w$, with an average annual temperature of 16.5 °C and precipitation of 1128 mm. The soil for both sites is classified as Haplic phaeozem [29].

2.2. Soil and Biosolid Sampling

In both areas, preferential sampling was carried out to collect soil blocks (monoliths) measuring 28 cm (length) × 9 cm (width) × 16 cm (height) with the help of a hammer and chisel. Later, the monoliths were placed individually in previously identified plastic containers. The biosolids were taken directly from the filter press of the Toluca Norte municipal wastewater treatment plant belonging to the operator ECOSYS. They were deposited in polyethylene bags until they were used.

2.3. Experiment Design

Three doses of biosolids (0, 25 and 40 t ha^{-1}) were used for each eroded soil, in such a way that there were three treatments for the soil with water erosion (H_0, H_{25} and H_{40}) and three for the soil with mining erosion (M_0, M_{25} and M_{40}); each one had four repetitions. The experiment was carried out under a completely randomized block design at the laboratory level, where temperature and relative humidity were not controlled.

Biosolids were applied in wet weight to the surface of each container (the amount of biosolid was not the same as the weight of each monolith varied) and each container was irrigated with tap water (approximately 500 mL) two to three times each week. The resulting leachates were discarded. It should be noted that the experiment lasted 360 days.

The general properties of the biosolids were: pH 6.41; electrical conductivity 3.70 ds/cm; organic matter 45.09%; and total nitrogen content 8.5%.

2.4. Laboratory Analysis

For laboratory analysis, a soil sample was taken at 7, 30, 180, and 360 days after the application of the biosolids. Soil was extracted at a depth of 0–20 cm in each of the monoliths with a punch made by PVC base; the samples were placed in previously labeled polyethylene bags and frozen at −4 °C for later analysis.

The physicochemical analyses that were determined were soil moisture (MS) (AS-05 method), inorganic nitrogen (NI), ammoniacal nitrogen (NH_4^+), nitrites, and nitrates ($NO_2 + NO_3^-$) (AS-08 method) [30].

The biochemical analyses carried out were as follows: microbial biomass carbon (MBC) was determined via fumigation with chloroform and extraction with K_2SO_4 [31]. The respiratory activity (RA) was estimated by quantifying the carbon dioxide (CO_2) released by microbial activity in 24 days of incubation at 25° [32]. The metabolic quotient (qCO_2) was calculated as the ratio of respiratory activity to microbial biomass [33].

2.5. Statistic Analysis

After a statistical analysis (ANOVA, Tukey's test with a confidence level of 95%), the variables that showed significant differences were subjected to a principal component analysis in order to obtain a minimum data set through multivariate statistics. The PCA was used to reduce data redundancy and recognize the most appropriate indicators to assess soil quality. It was deduced that those principal components with high eigenvalues are the soil properties that best represent the changes in soil quality.

Therefore, only PCs with eigenvalues > 1 were considered. In each PC, the variables received a weight or factor load that represents their contribution to the composition of the PC. Only highly weighted variables (with an absolute value of at least 10% variance) were kept for each PC and used to define the MDS. When more than one variable was selected within the same CP, correlation coefficients were applied to determine if the variables could be considered redundant and therefore removed from the MDS. Only those variables that had the highest correlation sums were chosen for the MDS.

Subsequently, a multiple regression analysis was carried out for the selection of those variables that were subjected to calculations of normalized values (Vn) to determine the quality of both soils.

2.6. Soil Quality Indicators

The values of the soil properties proposed as indicators were normalized using a scale from 0 to 1 proposed by Cantú et al. [34]. According to these authors, for the SQI, these values represent the worst and best condition from the point of view of quality, respectively. Both in agricultural and degraded soils, the highest value of the indicator I (Imax Vn = 1) refers to the ideal value to be reached or the best soil quality condition. Regarding the minimum value of the indicator I (Imin Vn = 0), it represents the minimum acceptable quality [34].

The calculation of the normalized value of each one of the indicators was made according to the following formula [34]:

$$Vn = (Im - Imin)/(Imax - Imin)$$

where Vn: normalized value of the indicator; Im: experimental measure of the attribute considered as indicator; Imin: minimum value of the attribute considered as indicator; Imax: maximum value of the attribute considered as indicator.

For both soils, 20 and 10 mg kg^{-1} were considered as the maximum and minimum value, respectively for the calculation of the normalized value of the NI indicator, these values were taken into account since the Im values of both soils were within the range 10 to 20 mg kg^{-1} belonging to a low class, according to the scale used in the technique carried out for the analysis of NI [30].

For the RA indicator, the maximum and minimum values proposed were 6564.7 and 2628 $\mu CO_2/g$ soil, respectively. These values were taken from a study previously carried out by De la Portilla et al. [35], where they evaluated the RA of nearby soils with very similar characteristics to the area in the present study.

3. Results

Soil Quality Index

The physical, chemical and biochemical properties were evaluated through the incorporation of biosolids in two eroded soils (by water and mining activity), and later they were considered for the selection of a minimum data set and the subsequent realization of a quality index.

The seven variables selected for the principal component analysis (PCA) in both eroded soils were: soil moisture (MS), microbial biomass carbon (MBC), respiratory activity (AR), metabolic quotient (qCO_2), inorganic nitrogen (NI), ammoniacal nitrogen (NH_4^+), and nitrites and nitrates ($NO_2^- + NO_3^-$).

In the PCA of soil with water erosion, two principal components (PC) with eigenvalues > 1 explained 83.75% of the variance of the data set; therefore, they were chosen as the two principal components for this type of erosion. In PC1 MS, NI and NH_4^+ were the highly weighted variables, with values of 0.467, 0.469, 0.466 and, respectively. For PC2, MBC and qCO_2 were presented as highly weighted variables and their values were −0.578 and 0.645, respectively (Table 1).

Table 1. Principal Component Analysis of a water eroded soil amended with biosolids.

Descriptive Parameter	PC1	PC2
Eigenvalue	4.05	1.81
% of variance	57.92	25.82
Cumulative %	57.92	83.75
RA	0.428	−0.108
MBC	0.264	−0.578
qCO_2	0.091	0.645
MS	0.467	−0.019
NI	0.469	0.0354
NH_4^+	0.466	−0.016
$NO_2^- + NO_3^-$	0.287	0.486

RA, respiratory activity; MBC, microbial biomass carbon; qCO_2, metabolic quotient; MS, soil moisture; NI, inorganic nitrogen; NH_4^+, ammoniacal nitrogen; $NO_2^- + NO_3^-$, nitrites and nitrates.

For soil eroded by mining activity, three principal components (PC) with eigenvalues > 1 explained 91.66% of the variance of the data set. Due to this, they were considered as the three main components for erosion by mining extraction. In PC1, the highly weighted variables RA, MS, NI and NH_4^+ had values of 0.438, 0.471, 0.496 and 0.499, respectively. For PC2, the MBC and qCO_2 variables were considered as the variables with the highest weighting; their values were −0.725 and 0.611, respectively. Finally, in PC3, only NO_2^- + NO_3^- was presented as the highly weighted variable (0.785) among all the variables of said component (Table 2).

Table 2. Principal Component Analysis of eroded soil following mining activity amended with biosolids.

	PC1	PC2	PC3
Eigenvalue	3.65	1.58	1.18
% of variance	52.18	22.57	16.91
Cumulative %	52.18	74.75	91.66
RA	0.438	−0.291	−0.280
MBC	0.089	−0.725	−0.230
qCO_2	0.185	0.611	−0.338
MS	0.471	0.054	−0.276
NI	0.496	0.057	0.228
NH_4^+	0.499	0.077	0.101
$NO_2^- + NO_3^-$	0.220	−0.0610	0.785

RA—respiratory activity; MBC—microbial biomass carbon; qCO_2—metabolic quotient; MS—soil moisture; NI—inorganic nitrogen; NH_4^+—ammoniacal nitrogen; NO_2^- +NO_3^-—nitrites and nitrates.

For both eroded soils, the correlation matrix with the variables that had high weighting under different PC was performed separately and for each one, it was deduced that those variables that presented the highest correlation added up to the best representation of the group.

The significant correlations that were found for the soil components with water erosion were presented, in the case of PC1, between soil moisture with NI (0.760), with NH_4^+ (0.809) and NI with NH_4^+ (0.996). In PC2, there was no correlation between the variables considered highly weighted (qCO_2 and MBC).

In the case of soil eroded by mining extraction, the significant correlations that were presented for these components were, for PC1, MS with NI (0.760), MS with NH_4^+ (0.809), NI with NH_4^+ (0.987), RA with MS (0.816), RA with NI (0.656), and RA with NH_4^+ (0.681). In the case of the PC2 and PC3 components, there were no correlations between the resulting variables for each of them (MBC and qCO_2 for PC2 and $NO_2^- + NO_3^-$ for PC3).

For the soil with water erosion of the three variables in PC1, NH_4^+ and NI were chosen for the minimum data set because both had the highest correlation sums 2.805 and 2.756, respectively. Within this same component, soil moisture presented the lowest correlation sum (2.570), which was also considered redundant for the minimum data set because it was significantly correlated with NH_4^+ and NI ($p < 0.05$). In PC2, MBC and qCO_2 were considered as highly weighted variables; these were considered for the minimum data set because they were not found to be correlated with NH_4^+ and NI ($p > 0.05$) (Table 3).

Table 3. Correlation matrix for highly weighted variables under PCs with high factor loading in a water-eroded soil amended with biosolids.

Variables	MS	NI	NH_4^+
PC1 variables			
Pearson correlations			
MS	1.000	0.760 **	0.809 **
NI	0.760 **	1.000	0.996 **
NH_{4+}	0.809 **	0.996 **	1.000
Correlation sums	2.570	2.756	2.805
PC2 variables	qCO_2	CBM	
qCO_2	1.000	−0.500	
MBC	−0.500	1.000	

MS—soil moisture; NI—inorganic nitrogen; NH_4^+—ammoniacal nitrogen; qCO_2—metabolic quotient; MBC—microbial biomass carbon. ** $p < 0.05$.

For the soil with erosion caused by mining extraction, RA, NH_4^+ and NI were chosen for the minimum data set, since they presented the highest correlation sums: 3.153, 2.796, and 2.748, respectively in PC1. In PC2, MBC and qCO_2 were considered for the minimum data set because they were not significantly correlated ($p > 0.05$) with AR, NH_4^+ and NI (Table 4).

The multiple regressions indicated, for both eroded soils, that NH_4^+ is significantly influenced by the type of erosion ($p < 0.01$). In the soil eroded by mining activity, in addition to NH_4^+, RA is also part of the variables that are influenced by the erosive phenomenon ($p < 0.01$) (Tables 5 and 6).

Table 4. Correlation matrix for highly weighted variables under PCs with high factor loading in a soil eroded by mining activity amended with biosolids.

Variables	MS	NI	NH_4^+	RA
PC1 variables Pearson correlations				
MS	1.000	0.760 **	0.809 **	0.816 **
NI	0.760 **	1.000	0.987 **	0.656 **
NH_4^+	0.809 **	0.987 **	1.000	0.681 **
RA				1.000
Correlation sums	2.569	2.748	2.796	3.153
PC2 variables	CBM	qCO_2		
MBC	1.000	−0.454		
qCO_2	−0.454	1.000		
PC3 variables	$NO_2 + NO_3$			
$NO_2^- + NO_3^-$	1.000			

MS—soil moisture; NI—inorganic nitrogen; NH_4^+—ammoniacal nitrogen; RA—respiratory activity; MBC—microbial biomass carbon; qCO_2—metabolic quotient; $NO_2^- + NO_3^-$—nitrites and nitrates. ** $p < 0.05$.

Table 5. Coefficient of determination and multiple regressions of the minimum data set (MDS) variables in a water-eroded soil amended with biosolids.

	R^2	Multiple Regressions	*p* Value
Water erosion	0.994	$NH_4^+ = -1.6331 + 0.0005$ MBC + 0.9324 NI − 0.2141 qCO_2	<0.01

NH_4^+—ammoniacal nitrogen; MBC—microbial biomass carbon; NI—inorganic nitrogen; *q*CO metabolic quotient.

Table 6. Coefficient of determination and multiple regressions of the minimum data set (MDS) variables in a soil eroded by mining activity amended with biosolids.

	R^2	Multiple Regressions	*p* Value
Mining erosion	0.980	$NH_4^+ = -3.4720 + 0.0002$ MBC + 0.8538 NI + 0.1779 qCO_2 + 0.0001 RA	<0.01
	0.768	RA = −8.6643 + 4.4206 MBC + 223.801 NH_4^+ − 5.0841 NI + 261.175 qCO_2	<0.01

NH_4^+—ammoniacal nitrogen; MBC—microbial biomass carbon; NI—inorganic nitrogen; *q*CO_metabolic quotient; RA—respiratory activity.

Since the NI mineralization includes NH_4^+ and $NO_2^- + NO_3^-$ as products resulting from this process, it is for this reason that NI was considered important for the development of the quality index. For water-eroded soil, the NI indicator had a Vn of 0.386, which belongs to class 4, considering the classification of indicators as "low quality". For the soil eroded by mining activity, the NI indicator presented a Vn of 0.107 which belongs to class 5 and is considered according to the classification of the indicators as "very low quality". The second indicator considered for this eroded soil was RA; this had a Vn of 0.840. This value is within class 1, which in the classification of indicators is considered as "very high quality" (Tables 7 and 8).

Table 7. Soil quality classes.

Soil Quality Indices	Scale	Classes
Very high quality	0.80–1	1
High quality	0.60–0.79	2
Moderate quality	0.40–0.59	3
Low quality	0.20–0.39	4
Very low quality	0–0.19	5

The high values of the scale represent better situations in the quality of the soil. Low values on the scale represent worse situations in soil quality.

Table 8. Quality indices of soils eroded by water and mining activity.

Erosion Type (Agent)	Indicator	Vn	Soil Quality Index	Class
Water	NI	0.386	Low quality	4
Mining	RA	0.840	Very high quality	1
Mining	NI	0.107	Very low quality	5

NI—inorganic nitrogen; RA—respiratory activity; Vn—normalized value.

4. Discussion

Soil quality indicators are tools that provide a current diagnosis of soil condition by analyzing its physical, chemical, and biochemical properties which are able to serve or function as quality indicators [19]. In eroded soils, the determination of quality is essential to evaluate the conditions in which the soil is found due to the erosive phenomenon either caused naturally or anthropogenically and to identify the properties that are more sensitive due to erosion, which can provide information about soil quality [36]. Quality indices are a useful way to generate information about soil properties, processes, and characteristics. One of their objectives is to provide a response to changes that may occur in the soil and to indicate whether soil quality improves, remains constant, or decreases, and thus propose alternatives to improve soil conditions, mainly in terms of fertility [37]. Generally speaking, the steps for calculating the quality index include a) selection of indicators by principal component analysis, scoring of indicators using the normalized value (Vn), and integration of scores into an index showing the degree of quality present [38].

In this research, the physical, chemical and biochemical properties of the soil were used with the objective of identifying those that function as quality indexes and the degree of this in eroded soils conditioned with biosolids. These properties have been taken into account as indicators of soil quality since they are capable of presenting changes easily due to alterations in soil conditions [39]. In addition, the need to evaluate the quality of two eroded soils in this work turned out to be important since the erosive phenomenon is considered one of the main causes of environmental degradation, in turn causing the loss of soil quality [24,40].

Moisture, CBM, RB, qCO_2, NI, NH_4^+ and NO_2^-+NO_3^- were subjected to Principal Component Analysis (PCA). Our number of properties falls within the range used by other authors [41,42], who subjected between 4 and 9 soil properties to PCA. The purpose of PCA is to identify, among all the properties considered, those that are more sensitive or have a greater impact on soil quality; hence, the importance of evaluating the physical, chemical and biochemical properties of the soil [19], PCA in conjunction with correlation analysis has been taken into account as optimal for choosing the key indicators of soil quality [27,28,39].

For both eroded soils, in PC1, moisture was significantly correlated ($p < 0.05$) with NI and NH_4^+. This is attributed to the fact that soil moisture is one of the main abiotic factors that influence N availability from organic sources of soil. Soil moisture is capable of modifying soil aeration and influencing N transformation and dynamics, including mineralization, nitrification, and denitrification processes [43,44]. It is worth mentioning that water is essential for all reactions catalyzed by microorganisms; nitrogen mineralization is included within these reactions [45].

The second variables that were significantly correlated ($p < 0.05$) in both soils within the same component (CP1) were NI with NH_4^+. This is because ammonium is one of the soluble forms that constitute NI. The first product of mineralization is ammonia (NH_3). This can acquire hydrogen and form NH_4^+, which can be fixed by soil clay or organic matter, volatilized as ammonia, assimilated by plants or microorganisms, leached, or oxidized by autotrophic bacteria through the nitrification process, where it loses two hydrogen atoms to form NO_2^- and then nitrate NO_3^- [46–48].

In both soils, the variable considered for the evaluation of soil quality was NI, due to the fact that its mineralization and availability are processes determined by the erosive phenomenon. This element responds very well to the disturbance of the site; therefore, it is considered as a key indicator in determining soil quality [43,49]. In addition, nitrogen is one of the chemical properties that are considered for quality assessment because this element is an important indicator of fertility and one of the essential macroelements for many aspects of plant life [50]. Nitrogen is one of the most critical nutrients affecting the primary productivity of terrestrial ecosystems, and it is also an essential driving factor for plant growth and microbial function [48].

In soil eroded by mining activity, in PC1, there was also a significant correlation ($p < 0.05$) between respiratory activity with soil moisture, NI and NH_4^+. Regarding this, respiratory activity is influenced by biotic and abiotic factors. The latter mainly includes soil moisture [51], because soil microorganisms are capable of responding quickly to changes in the humidity, generating rapid responses in respiration [52]. Regarding the correlation of RA with NI and NH_4^+, it has been reported that the incorporation of N can affect soil processes, including its respiratory activity, since the latter is stimulated by the presence of said element and also turns out to be extremely sensitive to changes that may occur in the soil; therefore, the N content may have an impact on respiratory activity [52–54].

The multiple regressions revealed for both types of erosion that the NH_4^+ variable is influenced by the erosion process; however, since this compound is one of the products resulting from the mineralization of the NI, it was decided to consider the latter as the most important for the evaluation of soil quality.

For water erosion, the Vn of NI was 0.386 belonging to class 4, indicating that this variable has a low quality in soil eroded by water. According to a study carried out by Qiu et al. [55], the decrease in nitrogen mineralization was from 37% to 52% due to the erosive agent water, which causes a decrease in the quantity and quality of organic matter in the soil. Organic matter is important because it is an essential deposit for N; therefore, microbial activity is fundamental in N mineralization. Changes in N reserves may be associated with simultaneous changes in communities due to the fact that this element can affect the decomposition of the recalcitrant organic carbon fractions by changing the efficiency of C use by microbial communities, and thus is able to alter the N mineralization of the soil [43,56].

For the soil eroded by mining extraction, NI had a Vn of 0.107 (class 5 according to the Vn) considered as a variable that presents a very low quality. Regarding this, it is known that N is part of the essential macronutrients that plants and crops need for their growth and development and the main source of this nutrient in the soil corresponds to the decomposition of organic matter. However, mining activities eliminate the first soil horizon, an essential site for nutrient storage and exchange. Therefore, the nutrient holding capacity is drastically reduced after mining disturbance [57,58].

Respiratory activity was the second variable that was taken into account for the evaluation of the quality of the soil eroded by mining extraction. The Vn of this variable was 0.840 (class 1 according to the calculation of Vn); according to this value, AR presented a very high quality. Soil microorganisms play an important role in nutrient mineralization, organic matter decomposition, soil microbial physiology and ecology, and microbial diversity, quantity and structure in soil ecosystems and plant growth promotion. Therefore, soil microorganisms are important indicators reflecting soil quality and health [59]. The microbial activity is part of the components responsible for carrying out respiration. Said activity is sensitive to changes in the soil environment; therefore, this parameter is capable of providing exact and immediate information on soil quality. Microbial activity is an adequate index for the evaluation of soil quality, since this property is sensitive to changes caused by both natural and anthropogenic factors, such as erosion in this case. Variations in biochemical indicators of soil quality provide key information on soil functions that is complemented by physical or chemical data [21]. In general, soil quality indicators can be physical, chemical, and biological properties capable of easily changing in response to variations in soil conditions [39,60–63].

5. Conclusions

The quality of two eroded soils (by water and mining activity) was evaluated through a minimum set of data that included physical, chemical, and biochemical properties. The properties considered as indicators of soil quality were inorganic nitrogen (for both eroded soils) and soil respiratory activity (only for erosion for mining extraction).

According to the Vn obtained, NI had a low and very low quality in soil eroded by water and by mining activity, respectively. Low and very low N quality in eroded soils will affect soil fertility, which will impair future plant growth and microorganism activities. The respiratory activity presented a very high quality in the soil eroded by mining extraction according to the calculation of Vn. A very high quality in the respiratory activity indicates high microbial activity, which is beneficial for the transformation of organic matter. This is important for the supply of nutrients to the plants and is reflected in the fertility and quality of the soil.

5.1. Limitations and Practical Implications of the Study

One of the limitations that could have influenced this study was the duration of the experiment and the fact that only one application of the biosolid was made. Therefore, in our future research, we would like to extend the duration of the experiment and conduct more than one application of the biosolid for periods of every six months in addition to carrying it out in the field.

5.2. Future Perspectives

We believe that the series of steps we carried out to evaluate the quality of both eroded soils can be applied to different soils such as agricultural, horticultural, forestry, and others. The objective of any quality index is that it is easy to elaborate and can be used by different users. Depending on the objective of the study, certain soil properties can be considered for the generation of the quality index. Not all properties or indices will be suitable for all purposes and contexts, hence the importance of not only relying on a single type of properties but of using the physical, chemical and biochemical properties of the soil. We are very interested in being able to propose alternatives to mitigate the erosive effects on soil properties through the addition of organic amendments, so our next step is to be able to apply different organic amendments (compost, vermicompost, green manures, etc.) to evaluate the effect of these on the physical, chemical, and biochemical properties and also to generate quality indexes in order to establish the properties that are the most optimal as indicators of soil quality. The next step for us would be to extend the time of the study with the objective of monitoring the quality by analyzing the properties at different times. In addition to this, we want to conduct pilot tests in the field. Finally, we hope and expect that our study will be the guideline for future research directed at different needs, and especially to eroded soils.

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