Colegio de Postgraduados

# Chemical Properties of a Water-Eroded Soil Amended with Mixtures of *Dunaliella salina* and Organic Fertilizers

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**ABSTRACT**
**Objective**: Evaluar el efecto de la incorporación de *Dunaliella salina* mezclada con fertilizantes orgánicos en un suelo erosionado hídricamente a través de algunas propiedades químicas, como una alternativa para mitigar los efectos causados por la erosión.
**Design/methodology/approach**: Se tomaron muestras de suelo erosionado, y este fue adicionando con dos dosis de fertilizante equino (C) y bovino (V) mezclado con *D. salina*, teniendo los tratamientos: C (control 0.2% de *D. salina*), Va (70,000 kg ha$^{-1}$ y 0.2% de *D. salina*), Vb (35,000 kg ha$^{-1}$ de abono y 0.2% de *D. salina*), Ca (70,000 kg ha$^{-1}$ y 0.2% de *D. salina*), Cb (35,000 kg/ha$^{-1}$ y 0.2% de *D. salina*). Después de la aplicación de cada tratamiento, se analizó materia orgánica, conductividad eléctrica, pH y mineralización de N a los 15, 30 y 45 días.
**Results**: Los tratamientos con mayor porcentaje de materia orgánica y conductividad eléctrica en todos los tiempos fueron Ca y Va. En los tratamientos Va y Ca, el pH se mantuvo neutro y con los valores más altos respecto a los demás tratamientos a los 15, 30 y 45 días después su incorporación.
**Findings/conclusions**: El tratamiento Va tuvo el mayor contenido de N desde los 15 días hasta los 45 días. Los resultados sugieren que la aplicación de abono orgánico con *D. salina* puede compensar los déficits en las propiedades químicas causados por la erosión hídrica.

**Keywords**: Erosion; organic matter; electrical conductivity; nitrogen mineralization.

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## INTRODUCTION

Erosion is defined as a process of soil wear and degradation, through which the removal of soil particles occurs due to the individual and/or combined action of climatic agents (rain, wind, or ice), influenced by biota (vegetation, human activity), and topography (slope: length, shape, and degree of inclination), acting over time on soil resources (Toledo, 2013). In 2016, Bolaños and collaborators reported a 66% increase in water erosion at the national level, with 6% corresponding to severe or extreme erosion, 24% to moderate erosion, 36% to mild erosion, and finally, 34% classified as stable soil. The latter is characterized by no visible evidence of erosion either in satellite images or in-field evidence of surface runoff affecting the terrain. This typically occurs when vegetation cover is dense, vegetation is pristine, or in a very early stage of succession.

Specifically, the State of Mexico is among the most affected by water erosion, showing extreme erosion in the area of Santa María Zolotepec-Temoaya-Jiquipilco-San Lorenzo Malacota (western slope of the Sierra de Las Cruces) (Bolaños *et al.*, 2016).

The erosive phenomenon has a negative impact on the soil's physicochemical properties, particularly reducing profile depth, infiltration capacity, and water storage. It also leads to a decrease in organic matter and nutrient content, an increase in bulk density, changes in texture, and a reduction in carbon content (Arriaga & Lowery, 2003; Hincapié-Gómez & Salazar-Gutiérrez, 2011). This is reflected in the loss of soil fertility and decreased productivity in agricultural processes such as crop production (Brunel & Seguel, 2011).

An eroded soil has low fertility and is no longer considered agricultural soil. Due to this, the use of biostimulants, which contain substances that promote plant growth, such as auxins, cytokinins, and betaines, proves to be an alternative to mitigate the erosive effects on soil and improve crop yields (Barrios, 2007; Pérez-Madruga *et al.*, 2020). Various studies (Salim *et al.*, 2016; Wafaa *et al.*, 2017; El-Moursy *et al.*, 2019) have demonstrated that the combination of seaweed extracts with inorganic and organic fertilizers can achieve sustainable agricultural productivity (Pérez-Madruga *et al.*, 2020). *Dunaliella* is one of the most commonly used microalgae genera due to its commercial importance in obtaining bioactive compounds. These organisms contain between 50 and 60% protein in green cells based on dry weight and around 30% in red cells, with a high carotenoid content (Fimbres-Olivarría *et al.*, 2010).

The objective of this study was to evaluate the effect of incorporating *Dunaliella salina* mixed with organic fertilizers on the chemical properties of water-eroded soil as an alternative to mitigate the effects caused by the erosive phenomenon.

## MATERIALS AND METHODS

### Characteristics of the Sampling Area

A preferential sampling was carried out in the town of San Miguel Yuxtepec, located in the municipality of Jiquipilco, State of Mexico. The municipality of Jiquipilco is situated to the north of the Valley of Toluca and to the east of the Valley of Ixtlahuaca, occupying part of the Monte Alto mountain range. Its geographic coordinates are 19° 31' 58" latitude, 99° 41' 15" west longitude, and an altitude of 2723 m. It is characterized by a temperate sub-humid climate with summer rains, classified as C(w2) (Municipal Government Gazette, 2022). This site has soil with a high degree of water erosion (Bolaños *et al.*, 2016).

### Sampling

With the help of a shovel, the first 0-20 cm of the eroded surface were taken, maintaining a cylindrical shape. The soil samples were then placed in containers with a capacity of 4 kg, each containing 3.6 kg of eroded soil. A total of 30 samples were collected.

### Experiment Setup

The experiment was conducted under greenhouse conditions. A mixture of organic fertilizer (equine and bovine) with an extract of the *Dunaliella salina* algae was incorporated. The treatments were as follows: *D. salina* (C), bovine fertilizer at a high dose (70,000 kg $ha^{-1}$)+*D. salina* (Va), bovine fertilizer at a low dose (35,000 kg $ha^{-1}$)+*D. salina* (Vb), equine fertilizer at a high dose (70,000 kg $ha^{-1}$)+*D. salina* (Ca), and equine fertilizer at a low dose

(35,000 kg ha$^{-1}$)+*D. salina* (Cb). Each treatment had six repetitions under a completely randomized block design.

**Sampling for Chemical Analyses**

The sampling for chemical analyses was carried out at 15, 30, and 45 days after the application of each treatment. Approximately 250 grams of soil were collected from each experimental unit, at a depth of 0 to 15 cm, using a garden shovel. Subsequently, the samples were placed in plastic bags, labeled, and transported to the Soil and Environment Laboratory at the Autonomous University of the State of Mexico for further analysis.

**Laboratory Analysis**

Organic matter was determined using method (AS-07), electrical conductivity was measured by method (AS-18) using the CONDUCTRONIC PC18 conductivity meter, and nitrogen mineralization was assessed by method (AS-08) using the UDK139 Labolan distiller. These analyses were conducted following the guidelines outlined in NOM-021-2000-RECNAT.

**Statistical Analysis**

An ANOVA was performed for a completely randomized block design, along with Tukey's test to determine significant differences between the measured chemical properties. Both analyses were conducted with a 95% confidence level, using the Statgraphics Centurion 5.0 statistical package.

## RESULTS AND DISCUSSION

According to the ANOVA test, the treatments that showed the highest and statistically significant values ($p<0.05$) of organic matter (OM) 15, 30, and 45 days after their incorporation were Ca (Horse manure at a dose of 70,000 kg ha$^{-1}$+*Dunaliella salina*) and Va (Cow manure at a dose of 70,000 kg ha$^{-1}$+*Dunaliella salina*). According to the classification of NOM-021-RECNAT-2000, the percentage for Ca (3.98%) was considered high at 15 and 30 days after application, while for Va (2.62%), the percentage was estimated as medium during the same period. At 45 days after the application of the treatments, the percentages for Ca (3.24%) and Va (3.16%) were classified as medium (NOM-021-RECNAT-2000) (Figure 1).

The results show that the treatments with 70,000 kg ha$^{-1}$ of organic manure presented the highest values of organic matter (OM). This is consistent with the findings of Salazar-Sosa *et al.* (2010), who reported that the application of manure to the soil at doses of 40,000 to 160,000 kg ha$^{-1}$ increases organic matter. Regarding the increase in OM in the treatment with horse manure, this can be attributed to the fact that this type of manure contains large amounts of carbon, organic matter, and micronutrients, which are released slowly, facilitating plant uptake (Huachi, 2008; Guzmán, 2021).

Regarding the treatment with cow manure, it should be noted that this manure harbors a rich microbial diversity that is important in the processes of organic matter mineralization (Behera and Ray, 2021).

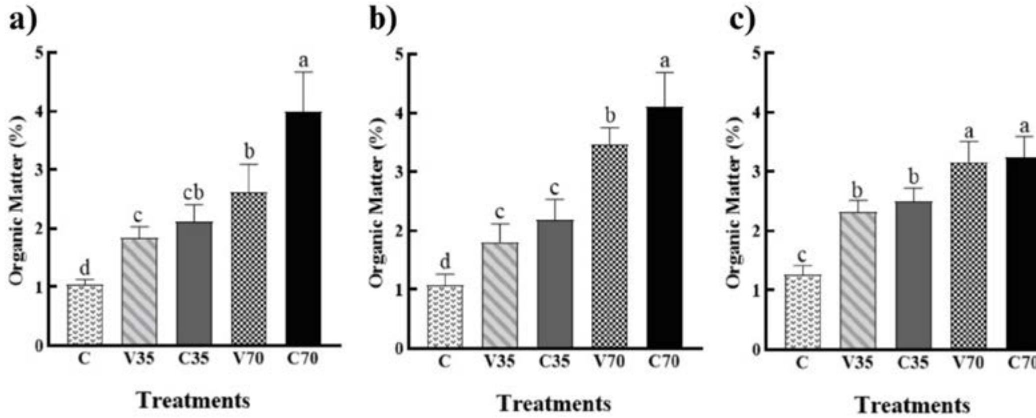


**Figure 1**. Organic Matter of a soil with water erosion treated with organic manure and *Dunaliella salina*. C (control with 0 kg $ha^{-1}$ of manure and 0.2% of *D. salina*), Vb (35,000 kg $ha^{-1}$ of cow manure and 0.2% of *D. salina*), Va (70,000 kg $ha^{-1}$ of cow manure and 0.2% of *D. salina*), Cb (35,000 kg $ha^{-1}$ of horse manure and 0.2% of *D. salina*), Ca (70,000 kg $ha^{-1}$ of horse manure and 0.2% of *D. salina*) at a) 15, b) 30, and c) 45 days after application. Average ± standard deviation, bars with different letters denote significant differences ($p<0.05$).

As mentioned, the treatments consisted of a mixture of organic fertilizer and algal paste from the species *Dunaliella salina*. Regarding the latter, it has been found that algal-based biostimulants maintain the gradual release of nutrients, preventing their loss. Furthermore, it has been demonstrated that metabolites from microalgae improve soil fertility and nutrient absorption (Zhang *et al.*, 2024). According to the characteristics of *Dunaliella salina*, this is a microalga that can develop in extreme and deficient conditions. It has been primarily cultivated for the extraction of $\beta$-carotene and glycerol (Mendoza *et al.*, 2011). Glycerol serves as a suitable source of carbon for microorganisms and can increase microbial activity in the soil, thereby enhancing nutrient availability. This compound increases the soil's retention capacity and aids in nutrient absorption, enhancing the organic matter content of the soil (Betancourt-Aguilar *et al.*, 2016). Another property analyzed during this research was electrical conductivity (EC), where significant differences ($p<0.05$) were also observed among the treatments. The highest EC values were recorded in the treatments Ca and Va at 15, 30, and 45 days after their application (Figure 2).

At 15 days, the values for Ca (477.49 $\mu$S/cm) and Va (327.89 $\mu$S/cm) were classified as saline and moderately saline, respectively, according to the classification of NOM-021-RECNAT-2000. At 30 days after applying the treatments, the values for Ca (320.46 $\mu$S/cm) and Va (294.94 $\mu$S/cm) were considered moderately saline (NOM-021-RECNAT-2000). The Ca treatment recorded the highest electrical conductivity value at 45 days after application, measuring 324.56 $\mu$S/cm, which was classified as moderately saline according to NOM-021-RECNAT-2000.

The highest values found in the Ca and Va treatments can be attributed to the mineralization of manure, which releases high amounts of anions and cations, resulting in an increase in soil salinity. It has been reported that for every ton of manure applied to the soil, it receives between 15 to 50 kg of salts, depending on the quality of the manure (Trejo-Escareño *et al.*, 2013). Salazar-Sosa *et al.* (2010) and Cervantes-Vázquez *et al.* (2022) report

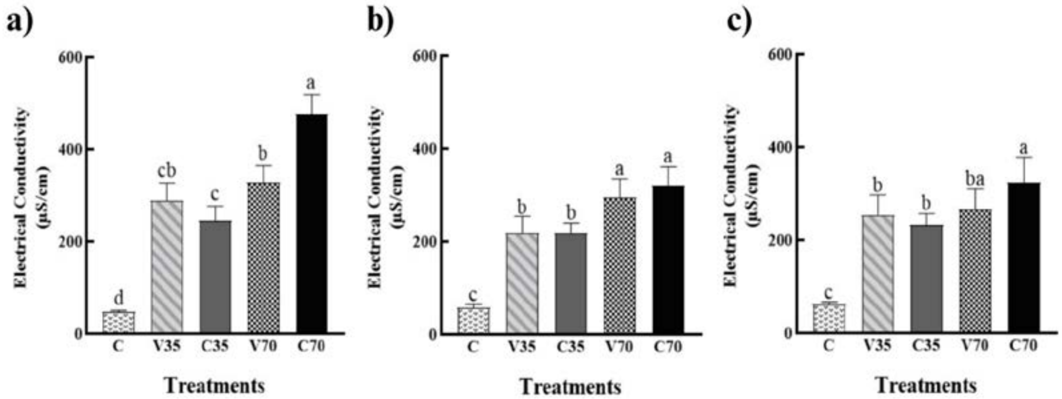


**Figure 2**. Electrical conductivity of a soil with water erosion treated with organic fertilizer and *Dunaliella salina*, C (control with 0 kg ha$^{-1}$ of fertilizer and 0.2% of *D. salina*), Vb (35,000 kg ha$^{-1}$ of cow manure and 0.2% of *D. salina*), Va (70,000 kg ha$^{-1}$ of cow manure and 0.2% of *D. salina*), Cb (70,000 kg ha$^{-1}$ of horse manure and 0.2% of *D. salina*), Ca (35,000 kg ha$^{-1}$ of horse manure and 0.2% of *D. salina*) a) 15, b) 30, and c) 45 days after application. Mean ± standard deviation; bars with different letters indicate significant differences ($p<0.05$).

that the highest concentrations of salts are found in treatments with 80,000, 120,000, and 160,000 kg ha$^{-1}$ of manure. Therefore, the treatments used in this study were less than 80,000 kg ha$^{-1}$ to avoid increasing the amount of salts during the mineralization of organic matter, as the increase in $Na^+$ in the soil can lead to structural losses or inhibition of plant growth, affecting agricultural yield.

As with the content of organic matter and electrical conductivity, the highest pH values were observed in the Ca and Va treatments at 15, 30, and 45 days after application (Figure 3).

According to the classification of NOM-021-RECNAT-2000, the pH values were classified as neutral at all times (15, 30, and 45 days). At 15 days, the values were 6.96 and 6.71 for Ca and Va, respectively. At 30 days, the value for Ca was 6.87, and for Va, it was 6.70. At 45 days, the values for Ca and Va were 6.76 and 6.67, respectively. This

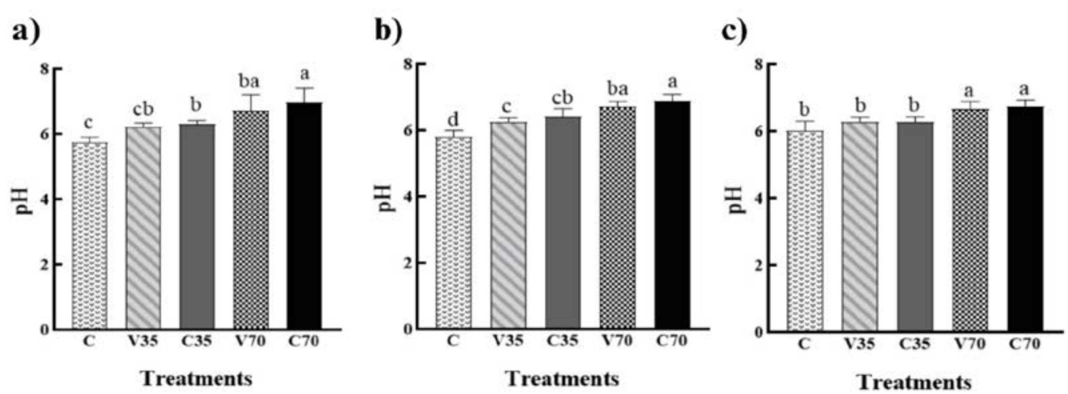


Figure 3. pH of an soil with water erosion treated with organic fertilizer and D. salina, C (control with 0 kg ha-1 of fertilizer and 0.2% D. salina), Vb (35,000 kg ha-1 of cow manure and 0.2% D. salina), Va (70,000 kg ha-1 of cow manure and 0.2% D. salina), Cb (70,000 kg ha-1 of horse manure and 0.2% D. salina), Ca (35,000 kg ha-1 of horse manure and 0.2% D. salina) at a) 15, b) 30, and c) 45 days after application. Average ± standard deviation, bars with different letters indicate significant differences ($p<0.05$).

can be explained by the findings of Trejo-Escareño *et al.* (2013), who reported that in soils treated with organic fertilizers, the pH increased due to the enrichment of cations and the ammonification of the organic matter present, as organic fertilizers promote proton attraction (Cervantes-Vázquez *et al.*, 2022). Finally, inorganic nitrogen was determined, and an increase in this element was observed in the treatments Va (23.27 mg $kg^{-1}$; 28.25 mg $kg^{-1}$ at 15 and 30 days) and Ca (16.82 mg $kg^{-1}$; 15.32 mg $kg^{-1}$ at 15 and 30 days after application) (Figure 4).

At 45 days, only the Va treatment presented the highest nitrogen value. This may be due to the concentrations of inorganic nitrogen depending on the activity of microorganisms under aerobic and anaerobic conditions. This process accelerates with an increase in temperature and is enhanced by adequate moisture and good oxygen availability. Cow manure has a more abundant and diverse microbiota compared to horse manure (Tian *et al.*, 2015; Pacheco-Torres *et al.*, 2021). However, the use of the algal paste can have a significant influence due to the glycerol it produces. Betancourt-Aguilar *et al.* (2016) report that glycerol serves as a suitable source of carbon for microorganisms and can increase microbial activity in the soil, leading to nitrogen being immobilized by microorganisms. Conversely, its wide range of pH values (ranging from acidic to alkaline) can affect the processes of denitrification and nitrogen immobilization differently and, in general, the soil biochemistry. This could explain the different concentrations of inorganic nitrogen in the soil.

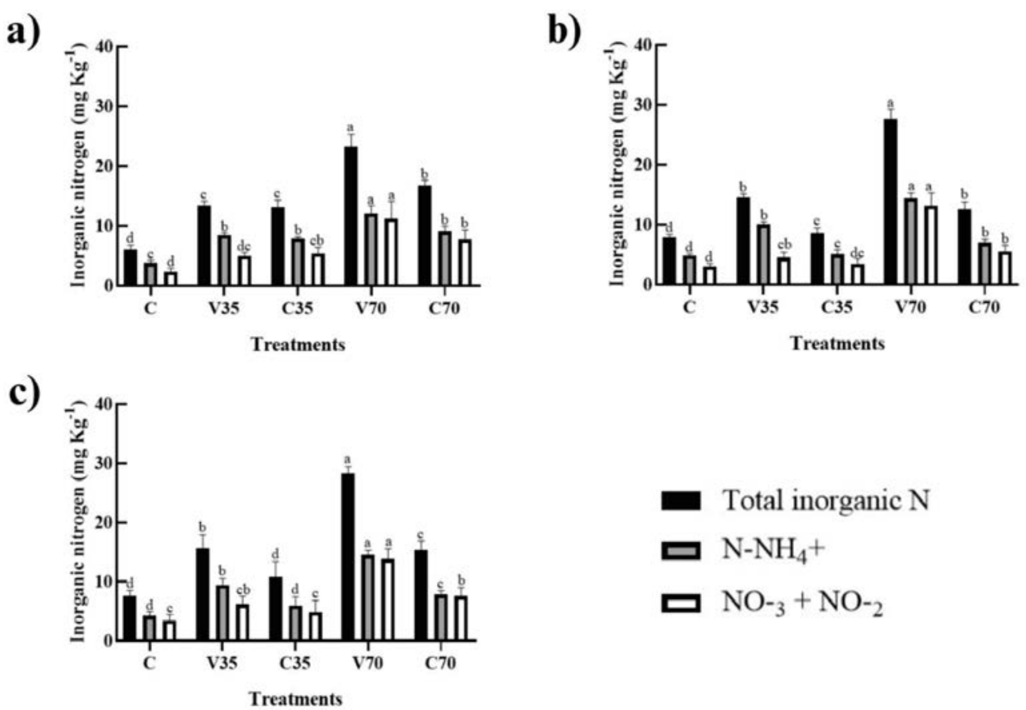


**Figure 4**. Nitrogen Mineralization of a soil with water erocion treated with organic fertilizer and *Dunaliella salina*: C (control with 0 kg $ha^{-1}$ of fertilizer and 0.2% of *D. salina*), Vb (35,000 kg $ha^{-1}$ of cow manure and 0.2% of *D. salina*), Va (70,000 kg $ha^{-1}$ of cow manure and 0.2% of *D. salina*), Cb (70,000 kg $ha^{-1}$ of horse manure and 0.2% of *D. salina*), Ca (35,000 kg $ha^{-1}$ of horse manure and 0.2% of *D. salina*) at a) 15, b) 30, and c) 45 days after application. Average ± standard deviation; bars with different letters indicate significant differences ($p<0.05$).

In the case of the inorganic form $NH_4^+$, the highest values were recorded starting on day 30 in the treatments Va (7.80 mg $kg^{-1}$) and Vb (9.45 mg $kg^{-1}$). This increase may be due to the fact that cow manure contains 5.6% microorganisms, primarily ammonifying microorganisms that degrade nitrogen-containing compounds into smaller molecules that can be absorbed and utilized. Most of the ammonifying microorganisms found in this manure (fungi, bacteria, etc.) exhibit ammonification activities, particularly *Bacillus* spp., which shows high ammonifying activity and plays an important role in the nitrogen cycle. However, it has been found that temperature has a significant effect on ammonifying microorganisms, affecting the decrease in microbial activity at high temperatures. Many other studies have also demonstrated that inoculation with thermophilic microorganisms is effective for converting nitrogen in composting processes (Behera and Ray, 2021; Zhang, 2023).

For nitrates and nitrites, the highest values were recorded 30 days after the application of the treatments, with Ca (7.52 mg $kg^{-1}$) and Va (13.78 mg $kg^{-1}$) showing the highest values. This can be attributed to the findings of Salazar *et al.* (2007), who found that $NO_3^-$ and $NO_2^-$ increase with more than 60,000 kg $ha^{-1}$ of manure applied to the soil. These results indicate that an increase in the dosage of manure application results in greater mineralization, increasing the amounts of $NO_3^-$ and $NO_2^-$ in the soil. However, they also reported a significant effect when applying manure at more than 40,000 kg $ha^{-1}$, resulting in an increase in all macronutrients necessary for plant development and production.

## CONCLUSIONS

An increase was observed due to the application of the mixture of *Dunaliella salina* and organic fertilizers (cow and horse) on the chemical properties (organic matter, electrical conductivity, and nitrogen mineralization) of a water-eroded soil in the Ca and Va treatments.

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