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# From Waste To Resource: Spent Coffee Grounds As A Soil Fertility Booster

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***Abstract***
*The increase in coffee production has led to a significant rise in the amount of coffee grounds produced. This by-product remains largely underutilised. Recently, using coffee grounds as an organic fertiliser in agriculture has been considered a way to reduce dependence on chemical fertilisers while improving soil quality. This study evaluates the impact of using dried coffee grounds as an organic fertiliser on the soil's physical and chemical properties. Different concentrations of coffee grounds (0%, 1%, 2% and 3%) were applied to the soil, with four replicates per treatment to enable a rigorous comparative analysis of the results. Statistical analysis of the data shows that adding coffee grounds favourably modifies certain physicochemical properties of the soil. Improvements in nutrient levels, such as nitrogen, phosphorus, total limestone, organic matter and electrical conductivity, were observed. A slight acidification of the soil was also noted, particularly at higher doses. Based on these results, it was concluded that coffee ground treatments have a beneficial effect on soil fertility, primarily through enriching organic matter and nutrients. These findings confirm the potential of coffee grounds as an effective organic amendment in sustainable agriculture.*

***Keywords:*** *Coffee grounds, biofertiliser, soil characteristics, green agriculture.*

## 1. INTRODUCTION

Over time, the relationship between humans and their natural environment has changed profoundly, particularly due to agricultural practices. While the advent of intensive agriculture in the 20th century increased yields, it also had negative impacts on ecosystems due to the extensive use of chemical inputs such as fertilisers and pesticides. This has led to soil impoverishment, a loss of microbial biodiversity, and an increased reliance on mineral fertilisers [1].

Against this backdrop, the sustainable management of organic waste is becoming a priority. Agroecology and the circular economy are emerging as viable alternatives that make the most of waste and promote the rational use of natural resources. Of the various solutions being considered, organic farming is notable for its integrated ecological, social and economic approach. It favours the use of organic amendments to restore soil fertility and limit environmental pollution [2].

Organic fertilisation plays a central role in this process, enriching the soil with nutrients and improving its structure. Organic matter promotes the retention and availability of macro- and micronutrients, making them easier for plants to absorb [3]. It also helps maintain moderate soil acidity, which favours plant growth. This organic matter can be derived from plant or agri-food waste [4].

Coffee grounds are a promising but underutilised resource. Every year, millions of tonnes of this residue are produced in homes, coffee shops, restaurants, and industrial settings. They contain a significant proportion of organic matter, as well as essential nutrients such as nitrogen (up to 2.8%), potassium (up to 11.7 g/kg) and phosphorus. They also contain magnesium and other trace elements [5]. Additionally, they are rich in bioactive compounds such as caffeine, polyphenols and certain organic acids, which can have a positive or negative influence on their agricultural use.

Studies have shown that, when properly composted, coffee grounds can improve soil structure, water retention capacity and biological activity. It stimulates microbial communities, promoting a gradual release of nutrients and increased natural fertility [6]. However, its uncontrolled use can lead to phytotoxic effects linked to caffeine and tannins, inhibiting the germination and growth of young plants [7]. In addition, its high C/N ratio can cause nitrogen immobilisation, unless nitrogen supplementation or proper composting is carried out [8].

In this context, the aim of this study is twofold: first, to develop and apply coffee grounds as a biological soil amendment; and second, to demonstrate their ability to enhance the soil's physicochemical properties while eliminating the need for chemical inputs and avoiding the associated long-term adverse effects. This approach is consistent with the principles of sustainable and green agriculture.

## 2. MATERIEL AND METHODS

The study was conducted in a semi-controlled experimental greenhouse at the Higher School of Agronomy in Mostaganem. The site is located at a latitude of 35° 57' 06" N and a longitude of 0° 05' 56" E. The experiment lasted three months, from November 21, 2024, to February 13, 2025. During this time, the temperature varied between 9 ± 2 °C at night and 20 ± 2 °C during the day.

### 2.1. Coffee grounds

In this experiment, the coffee grounds are the residue left over from roasted coffee beans that have undergone processing without the addition of any food additives. The grounds are a 1:1 mixture of two species of coffee: Coffea arabica and Coffea robusta.

Coffee grounds are used as an organic fertiliser due to their high nutrient content, including essential elements such as nitrogen, phosphorus and potassium, which promote soil fertility. They improve soil quality, stimulate microbial activity and act as a natural pest repellent. These properties make coffee grounds a promising ecological alternative in sustainable agriculture.

### 2.2. Soil substrate

The agricultural soil used in this study was taken from the experimental farm of the Department of Agronomy at Mostaganem University. The farm is situated in the commune of Mazagran, approximately 5 km south-west of Mostaganem. It is situated at a latitude of 35° 53′ 27.9″ N and a longitude of 0° 5′ 4″ E.

#### 2.2.1. Physico-chemical characteristics of the soil substrate

According to the physicochemical characteristics of the soil (Table 01), its texture is loamy-sandy clay. The soil contains an average amount of organic matter (3%). The soil pH is slightly alkaline (7.2). The electrical conductivity (0.11 ms) indicates the soil's low salinity. The $CaCO_3$ analysis shows that the soil is moderately calcareous, with a content of 10.64%.

**Table 01: Physico-chemical characteristics of the soil substrate**

| Characteristic | Value |
|---|---|
| **PH** | 7.2 |
| **EC (ms)** | 0,11 |
| **$CaCO_3$ Total (%)** | 10.64 |
| **OM (%)** | 3 |

| | |
|---|---|
| **C** (%) | 1.7 |
| **N** (%) | 0.18 |
| **Phosphorus (ppm)** | 15 |
| **Clay** (%) | 24.24 |
| **Silt** (%) | 3.51 |
| **Sand** (%) | 72.34 |
| **Textural class** | loamy-sandy clay |

### 2.3. Soil substrate preparation

The pots used in this experiment were standard plastic horticultural pots with an approximate volume of 1.5 litres. To ensure good drainage, a layer of gravel was placed at the bottom of each one. The soil placed in these pots was first sieved using a 2 mm mesh sieve. Then, a substrate mixture was prepared by mixing 1 kg of dry soil with different proportions of coffee grounds (1%, 2% and 3%). The control (0%) consisted of soil only, with no coffee grounds added.

### 2.4. Watering

Water is added cyclically to maintain the soil's water retention capacity (the maximum amount of water that the soil can hold due to its microporosity).

#### 2.4.1. Retention capacity measurement

This capacity is determined by the difference between P1 (the weight of a pot containing dry substrate before irrigation) and P2 (the weight after 24 hours of settling). Irrigation was carried out at a frequency of 150 ml per pot, twice a week.

### 2.5. Physico-chemical analysis of the soil

After three months of incorporating coffee grounds into the soil, samples were collected and placed in pre-labelled, airtight plastic bags. These were then transported to the Soil Analysis Laboratory at the National Agronomy School in El Harrach, Algiers, for physicochemical characterisation. Before analysis, the samples were air-dried in the shade at an ambient temperature of 25 ± 2 °C to prevent the thermal degradation of organic compounds. The dried soils were then sieved through a 2 mm mesh to remove coarse fragments. Subsequently, a portion that is homogeneous is taken for analysis.

#### 2.5.1. Granulometry

Soil texture was determined using the Robinson pipette method, which is based on the principle of the differential sedimentation of particles in suspension according to Stokes' law [9]. This method separates the different granulometric fractions: clay, silt and sand.

#### 2.5.2. Total organic carbon content

The total organic carbon content of the soil was estimated using the method developed by Walkley and Black in 1934 [10]. This process involves oxidizing the organic carbon present in the soil with a solution of potassium dichromate ($K_2Cr_2O_7$) in a highly acidic environment, specifically concentrated sulfuric acid.

### 2.5.3. Total nitrogen content

Total soil nitrogen was determined using the Kjeldahl method [11], which measures both organic and ammoniacal nitrogen. This method involves digesting the soil with concentrated sulphuric acid under heat, in the presence of a catalyst (often copper or selenium sulphate), which converts the nitrogen into ammonium ions. After digestion, the released ammonia is distilled and titrated to calculate the total nitrogen content of the soil.

### 2.5.4. C/N ratio

The evolution of the C/N ratio is often viewed as an indicator of how effectively solid organic matter is degraded in soil. This ratio is determined by measuring the amounts of organic carbon and total nitrogen present. The C/N ratio can be calculated using the following formula:

$$\frac{\mathrm{C}}{\mathrm{N}} \text{ ratio} = \frac{\text{Total organic carbon (C\%)}}{\text{Total nitrogen (N\%)}}$$

### 2.5.5. Organic matter content

The soil's organic matter content was estimated by measuring its organic carbon content using the Walkley and Black method. The percentage of organic carbon obtained from this formula was then converted to organic matter using the Van Bemmelen factor (1.724), according to the following formula:

$$\text{Organic matter (\%)} = \text{Organic carbon (\%)} \text{ x } 1.724$$

### 2.5.6. Total limestone content

The total limestone content was determined using calcimetry, according to Bernard's method [12]. This method is based on the reaction of calcium carbonate with hydrochloric acid (HCl), which releases carbon dioxide ($CO_2$). The volume of gas released is proportional to the quantity of limestone present in the sample, enabling the percentage $CaCO_3$ content to be calculated.

### 2.5.7. Assimilable phosphorus content

The Olsen method [13] is utilised to determine the content of assimilable phosphorus, which is recommended for calcareous soils. This method involves extracting available phosphorus using a sodium bicarbonate solution at a pH of 8.5. The resulting extract is analysed using a spectrophotometer once a coloured complex has formed with ammonium molybdate.

### 2.5.8. Soil pH

The soil pH was measured in a soil-water suspension (ratio of 1:2.5) following the ISO 10390 standard [14]. Using a calibrated electronic pH meter. This measurement indicates whether the soil is acidic, neutral or basic, which significantly affects the availability of nutrients.

### 2.5.9. Electrical conductivity (EC)

The salinity of the soil was assessed by measuring the electrical conductivity of an aqueous extract (soil-water ratio of 1:2.5), according to ISO 11265 standard [15]. After stirring and filtering the extract, the EC was determined using a conductivity meter. EC reflects the total concentration of soluble salts in the soil and can affect how plants take up water and nutrients.

### 2.6. Statistical analyses

To evaluate the effectiveness of the results, single-factor statistical analyses were conducted to assess the impact of using coffee grounds as a soil amendment. These results were then analysed using Statbox version 6.4 software.

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## 3. RESULTS AND DISCUSSION

### 3.1. Results

#### 3.1.1. Granulometry

According to the USDA system, all of the analysed soil samples belonged to the 'Loamy Sandy Clay' textural class. The samples were composed of 24.24% clay, 72.34% sand, and 3.51% loam, with a margin of error of ±2%. This type of soil is characterised by good permeability due to its high sand content, as well as relatively good water and nutrient retention capacity thanks to the presence of clay. However, its low loam content may limit its ideal agronomic structure, necessitating the addition of organic matter to enhance fertility.

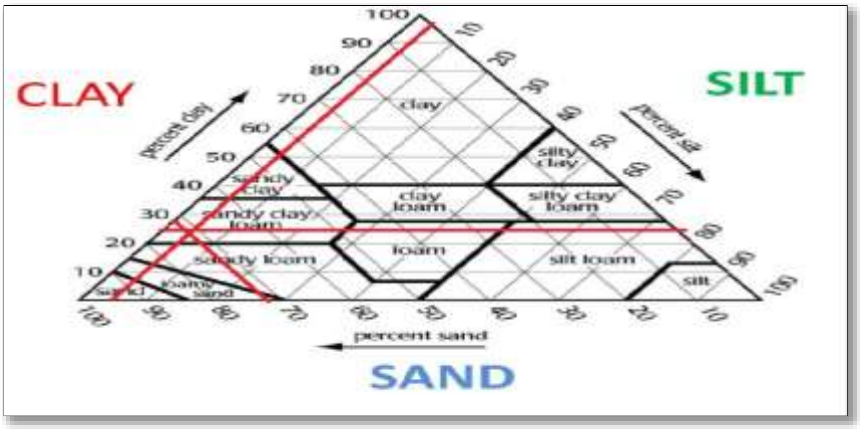


Figure 01: Texture Triangle.

#### 3.1.2. Organic matter content

The results obtained (Fig. 02) demonstrate how the content of organic matter in the soil varies in response to different doses of coffee grounds being applied. It is evident that enriching the soil with coffee grounds results in a gradual and substantial increase in organic matter content.

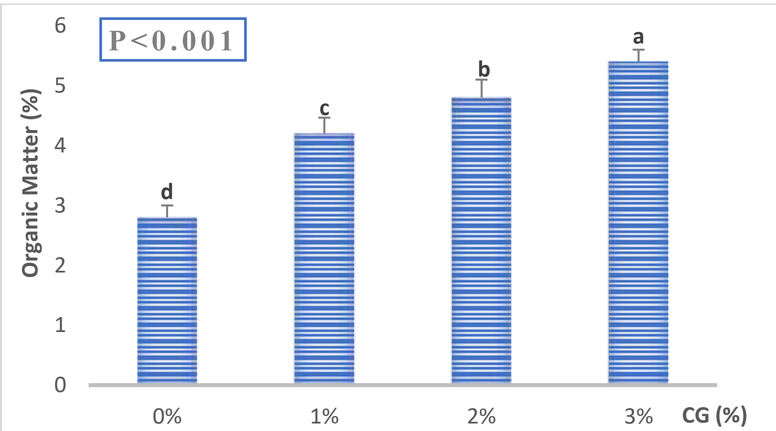


Figure 02: The organic matter content (OM %) of the soil as a function of increasing doses of coffee grounds (CG %).

The control sample (0%) had an organic matter content of 2.8%. The 1%, 2% and 3% doses achieved organic matter contents of 4.2%, 4.8% and 5.4% respectively. This reflects the high organic matter content of the coffee grounds, which improves soil structure and fertility.

### 3.1.3. Total organic carbon content

As shown in Figure 03, the total carbon content results demonstrate a proportional increase with rising doses of coffee grounds applied to the treated soil. The control sample (0%) had a content of 1.62%, while the sample with the highest dose (3%) reached 3.13%, showing a difference of 1.51%. This increase illustrates the impact of coffee grounds on enhancing the soil's total carbon content.

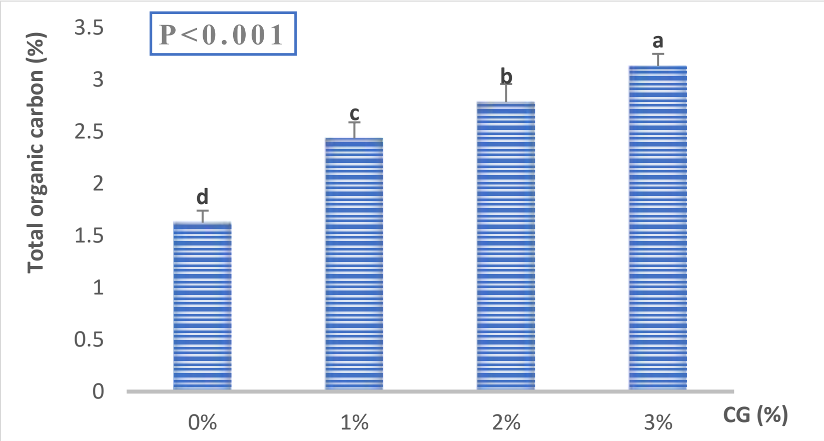


Figure 03: The total organic carbon content (C %) of the soil as a function of increasing doses of coffee grounds (CG %).

The application of coffee grounds was found to have a highly significant statistical effect on soil organic matter and total organic carbon content ($p<0.001$). Analysis of the homogeneous groups, d (0%), c (1%), b (2%), and a (3%), revealed a dose-dependent increase in these parameters. The highest dose (3%) resulted in the greatest accumulation of organic matter and total organic carbon. These findings confirm that coffee grounds, which are rich in organic compounds, can significantly improve soil fertility by enhancing its carbon content.

### 3.1.4. Total nitrogen content

Figure 04 illustrates the change in total nitrogen content of the soil with different doses of coffee grounds used as an organic amendment. A significant increase in nitrogen content was observed as the dose of coffee grounds increased. The control sample (0%) had the lowest nitrogen content at 0.14%. In contrast, incorporating 1%, 2% or 3% coffee grounds gradually increased this level, reaching 0.28% with the highest dose. This demonstrates the effectiveness of coffee grounds in improving soil nitrogen fertility, thanks to their high organic matter and nitrogen content.

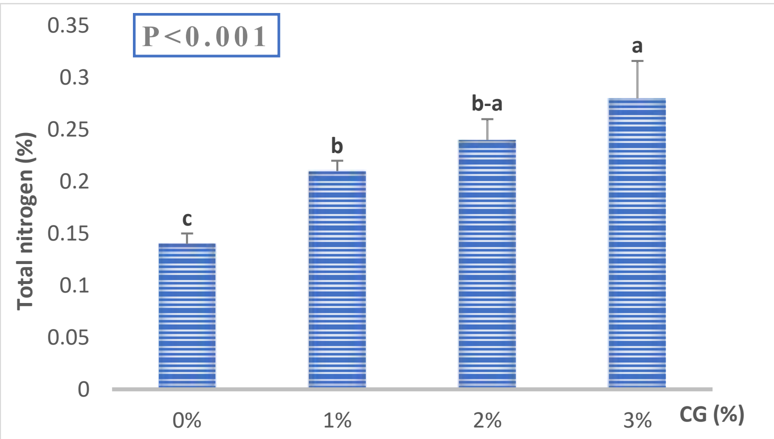

Figure 04: The total nitrogen content (N %) of the soil as a function of increasing doses of coffee grounds (CG %).

The effect of coffee grounds on total nitrogen was statistically highly significant ($p < 0.001$). The homogenous groups c (0%), b (1% and 2%), and a (2% and 3%) indicate a substantial rise from 1%, with a stabilisation at higher doses (2% and 3%). This suggests that coffee grounds gradually release nitrogen, but their uptake by soil or microorganisms could reach saturation above 2%.

### 3.1.5. C/N ratio

The C/N ratio values of the different treated soil samples (Fig. 05) show a slight decrease as the dose of applied coffee grounds increases. These values range from 11.61 for the 0% control dose to 11.28 for the 3% dose. This decrease suggests a slight intensification of the degradation of organic matter. C/N ratios between 5 and 15 are generally associated with rapid decomposition of organic matter.

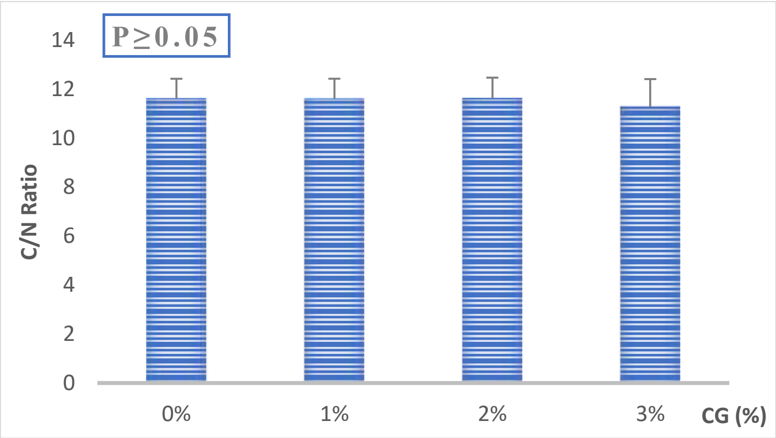


Figure 05: The C/N ratio of the soil as a function of increasing doses of coffee grounds (CG %).

### 3.1.6. Soil pH

Figure 06 above illustrates how the pH of the soil changes with different quantities of coffee grounds used as an organic fertiliser. The pH varies according to the quantity used. The control soil (0%) had a pH of 7.2, close to the neutral point. Adding 1% coffee grounds resulted in a slight increase in pH to 7.31, reflecting a slight alkalising effect. However, at higher doses of 2% and 3%, the pH decreased to 7.01, indicating slight acidification of the soil.

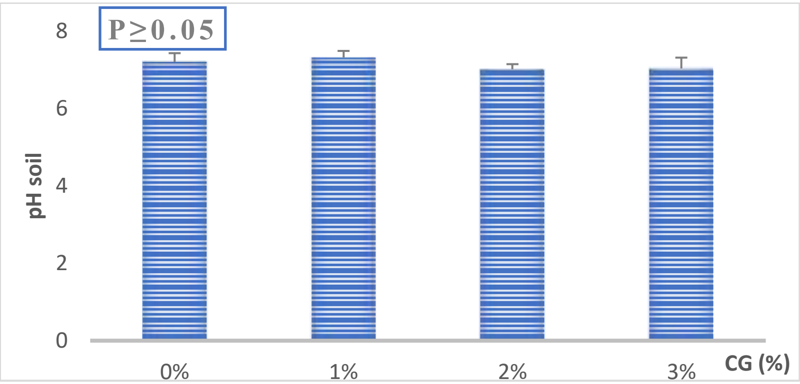


Figure 06: The pH of the soil as a function of increasing doses of coffee grounds (CG %).

### 3.1.7. Electrical conductivity (EC)

The changes in soil electrical conductivity in relation to the quantity of coffee grounds used as an organic amendment, as shown in Figure 07, illustrate a progressive increase in electrical conductivity with each successive dose. The control sample (0%), to which no coffee grounds were added, exhibited the lowest electrical conductivity at 0.13 ms. Adding coffee grounds at 1%, 2% and 3% doses gradually increased electrical conductivity, reaching a maximum of 0.19 ms at the 3% dose.

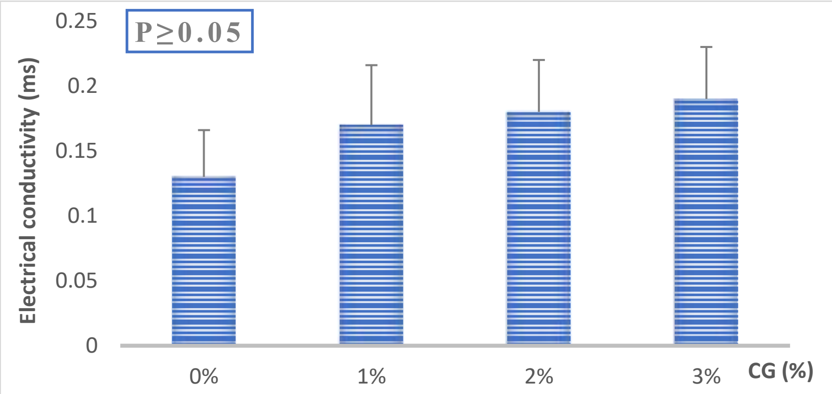


Figure 07: The electrical conductivity (CE ms) of the soil as a function of increasing doses of coffee grounds (CG %).

No statistically significant effect of coffee grounds was observed concerning the C/N ratio, pH, or electrical conductivity ($p \geq 0.05$). This indicates that the amendment does not lead to soil acidification or salinization, and the decomposition of organic matter does not disrupt the carbon-nitrogen balance. These findings are encouraging regarding the use of coffee grounds as an amendment, as there is no risk of significant chemical imbalances arising.

### 3.1.8. Total limestone content

Figure 08 above shows how the total limestone content of the soil changes with various amounts of coffee grounds used as an organic fertiliser. The control sample (0%), which did not contain coffee grounds, had a limestone content of 11%. Adding 1% coffee grounds increased the limestone content to 17%, whereas the 2% dose resulted in a slight decrease to 16%. The most significant effect, however, was produced by the 3% dose, which resulted in a notable increase in limestone content to almost 28%.

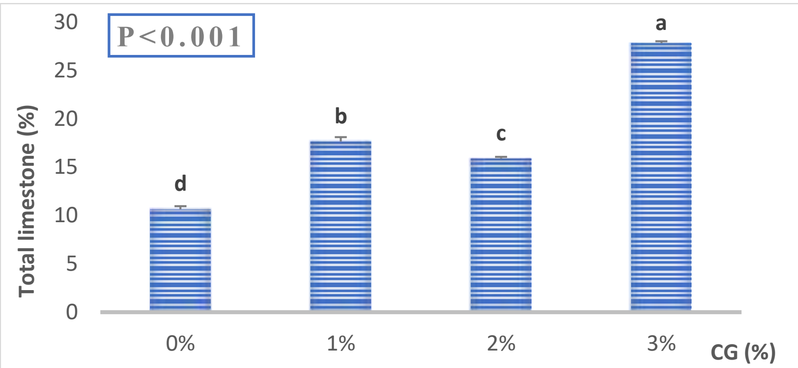


Figure 08: The total limestone content (L %) of the soil as a function of increasing doses of coffee grounds (CG %).

The effect of coffee grounds on total limestone is statistically highly significant ($p < 0.001$). However, the arrangement of homogeneous groups d (0%), c (1%), b (2%) and a (3%) does not follow a linear progression, which could suggest complex interactions between the grounds and calcium dynamics. One possible explanation is that the dose of coffee grounds influences whether limestone is solubilised or precipitated.

### 3.1.9. Assimilable phosphorus content

The content of assimilable phosphorus in the soil increases with higher doses of coffee grounds applied as an organic amendment (Fig. 09). The control sample has the lowest value, with a concentration of 13.4 ppm. Adding 1% coffee grounds results in a slight increase to 13.8 ppm. This steadily rises to 14.3 ppm with a 2% dose, peaking at 15.6 ppm with a 3% dose.

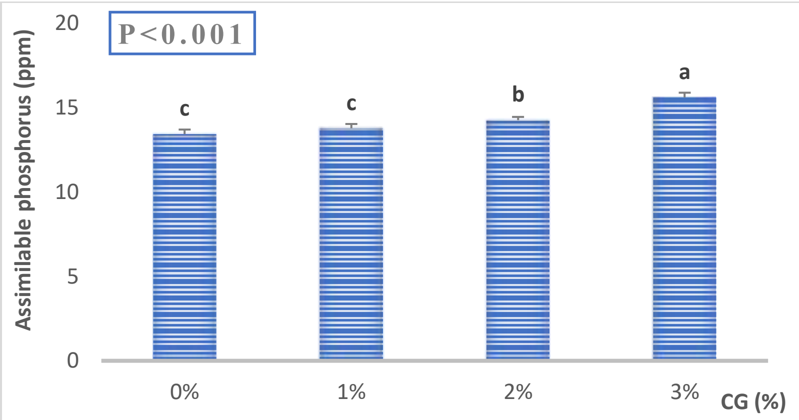


Figure 09: The assimilable phosphorus content (P ppm) of the soil as a function of increasing doses of coffee grounds (CG %).

A statistically significant influence of coffee grounds on assimilable phosphorus was observed ($p < 0.001$). The homogeneous groups c (0% and 1%), b (2%) and a (3%) showed a progressive increase with the applied coffee grounds doses, with the highest content obtained at 3%. These results suggest that coffee grounds increase the availability of phosphorus, possibly through gradual release or stimulation of microbial activity that facilitates mineralisation.

### 3.2. Discussion

This study demonstrates that applying increasing doses of coffee grounds (1-3%) significantly improves several soil fertility parameters, including organic matter, total carbon, nitrogen and assimilable phosphorus. This is achieved without adversely affecting pH or salinity. These findings are consistent with those of Hu et al., (2025) [7], who concluded that the application of raw coffee grounds could enhance some soil properties. Taken together, these results support the use of coffee grounds as a promising biological soil amendment for enriching soils with organic matter and essential nutrients.

The increase in organic matter, total carbon and total nitrogen corroborates the findings of Sinclair et al., (2024) [16], who reported significant improvements in these parameters in soils amended with coffee grounds. The increased nitrogen content promotes plant growth, particularly in crops that require high nitrogen levels. Gradually adding organic matter promotes water and nutrient retention, which contributes to beneficial microbial activity.

The significant impact of coffee grounds on organic matter and total carbon content corroborates the findings of Hardgrove and Livesley (2016) [17], who demonstrated that adding coffee grounds to soil increases its organic carbon content, thereby improving its structure and fertility. Our observation of a dose-dependent relationship within homogeneous groups indicates that the grounds act as a consistent source of organic matter, in line with the findings of Cervera-Mata et al., (2021) [18] regarding lignin- and cellulose-rich organic residues.

Although total nitrogen increased significantly, the lack of effect on the C/N ratio suggests that the decomposition of the coffee grounds did not result in the excessive immobilisation of nitrogen by microbes. This finding differs from that of some studies [19], which reported a high C/N imbalance when raw coffee grounds was added. However, it aligns with the findings of Park et al., (2022) [20], who observed that prior composting of coffee grounds mitigated this risk. Our study suggests that, in the medium term, even when uncomposted coffee grounds are applied at moderate doses, they do not significantly disrupt nitrogen availability.

The variation in soil pH, showing slight alkalinisation at low doses and acidification at higher doses, is consistent with the observations of Morikawa and Saigusa (2011) [21]. The reason for this change is the decomposition of organic compounds in coffee grounds, which releases acidic substances in high concentrations. Therefore, coffee grounds influence soil pH in a dose-dependent manner, impacting nutrient availability and plant growth.

Increased electrical conductivity indicates the release of mineral salts, which increases nutrient availability. However, as Antunes et al., (2022) [22] point out, this rise in electrical conductivity is due to the release of mineral salts and soluble compounds contained in the coffee grounds, which enrich the soil solution. Moderately high electrical conductivity generally favours nutrient availability. However, values that are too high can lead to excessive salinity, which can adversely affect the growth of sensitive plants. Consequently, while coffee grounds have the potential to enhance the ionic richness of soil, particular consideration must be given to the amounts utilised to preserve a balanced environment for crops.

The lack of effect on pH and electrical conductivity contradicts concerns about the potential acidity of coffee grounds [16]. Our study supports Chalker-Scott (2021) [23] assertion that the acidifying effects of fresh coffee grounds are often neutralised by soil buffer systems in real conditions.

The increase in calcium and phosphorus content, coupled with the addition of coffee grounds, confirms their enriching effect. Studies such as those by Ballesteros et al., (2014) [24] have shown that coffee grounds release minerals gradually, thereby improving plant mineral nutrition and root development. This suggests that coffee grounds promote the release of calcium and phosphorus into the soil due to their mineral content and their effect on the decomposition of organic matter. Therefore, moderate to high levels of coffee grounds appear to be beneficial in enhancing the overall fertility of the soil by improving the availability of calcium and phosphorus.

The results of this study are in line with those of Reyes-Torres et al., (2018) [25], who found that adding coffee grounds to soil led to a significant increase in the amount of phosphorus that could be absorbed by the plants. They explained that this was because the coffee grounds released organic acids during decomposition, which encouraged the plants to absorb more phosphorus. However, the absence of any effect on pH in our study suggests that other mechanisms may be more significant. These could be organo-mineral complexation or microbial stimulation [26].

The significant change in total limestone, with no clear dose-dependent trend, is a novel result. One possible explanation is that the phenolic compounds in the coffee grounds interfere with the precipitation of $CaCO_3$, as discussed by Schjønning et al., (2018) [27] in the context of other organic amendments.

The physicochemical soil results obtained in this study are consistent with those of Maktouf et al., (2019) [28], who concluded that coffee grounds are the most effective organic soil amendment compared to manure, compost and crop waste. Mesmar et al., (2024) [29] therefore suggest in their study that coffee grounds have the potential to serve as a sustainable alternative to fertilisers, thereby promoting plant growth and soil quality, supporting sustainable agricultural practices, and contributing to the circular economy.

Another study by Cervera-Mata et al., (2022) [30] found that using coffee grounds as an organic soil amendment is sustainable because it recycles biomass (around 15 million tonnes per year) and increases the soil's organic carbon content (coffee grounds contain around 50% carbon), thus enhancing its physical and chemical properties. Physico-chemical analyses of the soil suggest that coffee grounds could be an effective biological soil amendment in agriculture. This is particularly true when they are well-treated during torrification [31].

## 4. CONCLUSION

The application of organic amendments is a recognised agronomic practice that plays a vital role in improving soil fertility and quality. Against this backdrop, our study aimed to evaluate the potential of coffee grounds as an organic soil improver, examining their ability to improve the physicochemical properties of the soil. The study demonstrated the effectiveness of coffee grounds in this regard, showing a significant increase in essential nutrients and organic matter. Interestingly, incorporating coffee grounds did not result in a substantial increase in soil electrical conductivity. These results confirm the value of coffee grounds as a means of enriching soil without causing the hydric or saline imbalances that are often associated with other amendments. Furthermore, soil analyses revealed an appropriate increase in pH value, which can benefit certain crops in initially acidic soils. In conclusion, coffee grounds significantly improved the quality of the soil's nutrients and some of its chemical properties. Given these positive results, we advise farmers to consider using coffee grounds as an organic fertiliser in precise doses.

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**6. DATA ACCESSIBILITY:** The datasets used and/or analyzed during the study are available from the first author on reasonable request.

**7. DISCLOSURE:** The authors report no conflicts of interest in this work.

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