Australian Journal of Crop Science AJCS

Aust J Crop Sci. 20(03):254-260 (2026) | ISSN:1835-2707
https://doi.org/10.21475/ajcs.26.20.03.pne139

Impact of coffee grounds-infused irrigation on growth performance and quality of lettuce

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Submitted:* *05/10/2025

Revised:* *12/11/2025

Accepted:* *05/01/2026

Abstract: The production and consumption of coffee produce residues that can be harmful to the environment when improperly discarded. This study aimed to identify the effect of coffee grounds on the growth and yield of lettuce plants. The experiment followed a completely randomized design with five treatments and twelve replications, where the treatments consisted of irrigation with a solution containing coffee grounds at concentrations of 0%, 10%, 20%, 30%, and 40%. After 40 days of cultivation, the plants were evaluated. Coffee grounds induced changes in lettuce growth and yield and may serve as an important bio-input for producing this vegetable by promoting vigorous plants with good visual quality. The larger head diameter, leaf area, and fresh mass resulted in a better visual appearance, which certainly makes these plants preferable in the market, with the highest commercial value obtained in plants irrigated with a 36% coffee grounds solution in the irrigation water. However, the direct application of coffee grounds without prior transformation into organic compost requires caution due to the potential phytotoxicity of lettuce plants. Long-term use may lead to soil accumulation, and further studies are needed to assess its viability.

Keywords: Bioinsumption, *Lactuca sativa* L., sustainability.
Abbreviations: (Chl a+b) = leaf chlorophyll concentrations, (N) = nitrogen, (P) = phosphorus, (pH) = hydrogen potential, (H_2O) = water, (K) = potassium, (Al) = aluminum, (Ca) = calcium, (Mg) = magnesium, (ABNT) = Brazilian association of technical standards, (NBR) = Brazilian standard, (ETc) = Crop evapotranspiration, (kc) = Crop coefficient, (ETo) = Reference evapotranspiration, (SPAD) = Chlorophyll Index.

Introduction

Coffee is one of the most popular beverages worldwide and a key commodity for Brazil's socioeconomic development (Freitas & Reno, 2022; Marques & Moreira, 2024). Brazil is the world's largest producer and exporter of coffee, primarily cultivating two species: *Coffea arabica* L., which is used in high-quality blends, and *Coffea canephora* L., commonly known as robusta or conilon coffee, which is primarily used in the instant coffee industry (Thode Filho et al., 2020).
According to data from Conab (2025), Brazil exported 32.1 million 60-kilogram bags of coffee from January to August 2024, marking a 40.1% increase compared to the same period in the previous year. The Southeast region stood out as the leading producer of coffee in the country. Additionally, the data reveal that coffee consumption in Brazil increased by 1.64% between November 2022 and October 2023 compared to the previous period. Per capita consumption reached 6.40 kg per year of green coffee and 5.12 kg per year of roasted and ground coffee (Abic, 2023).
As a result, coffee agribusiness has been expanding, generating large amounts of waste across nearly all coffee-growing regions (TorgA & Spers, 2020). Consequently, these residues have become a significant issue, particularly coffee grounds, which are produced on a large scale in Brazil due to the country's high production capacity and consumption levels (Godinho et al., 2023). This waste, whether in solid coffee grounds or the liquid generated from their decomposition, has posed challenges for industries, as it is generally considered an unusable byproduct. It is often discarded without prior treatment, as appropriate applications or processing methods remain largely unknown to the general public (Silveira et al., 2024).
Given this context and as a potential solution to this issue, some authors suggest the real possibility of valuing and reusing these residues through compost production, providing a low-cost and high-quality resource (Silva-Parra et al., 2024). Corrêa et al. (2020) highlight several possible uses for coffee residues, including their application as a rich source of minerals and organic matter in agriculture. According to Lara-Ramos et al. (2024), coffee grounds can enhance water retention and soil porosity and improve plant nutrition (Caliskan et al., 2020).

According to Hechmi et al. (2023), raw coffee grounds improve the biological, chemical, and physical properties of the soil by enhancing microbial activity, increasing organic matter content, improving aggregate stability, and promoting greater water retention. However, for optimal plant growth, vermicompost is recommended, as raw coffee grounds contain toxic polyphenols. Additionally, coffee grounds have significant nutritional value, with substantial concentrations of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), phosphorus (P), and nitrogen, as well as an electrical conductivity ranging from 2.67 mS cm^{-1} to 4.5 mS cm^{-1} (Chrysargyris et al., 2021; Hardgrove & Livesley, 2016; Lara-Ramos et al., 2024; Troung et al., 2018).

Lettuce is considered the most important leafy vegetable in Brazil and is typically consumed fresh (Ferreira et al., 2024). It is a nutritionally significant species, providing a good source of vitamins and minerals (Bester et al., 2024), and is highly responsive to fertilization. As a result, plant height, number of leaves per plant, fresh and dry weights, and overall yield depend on proper fertilization throughout its growth cycle (Abd-Elrahman et al., 2022). However, lettuce is often cultivated by small-scale family farmers with limited financial resources for crop investment, making agricultural residues a viable alternative for fertilization (Souza Júnior et al., 2023).

In this context, bio-inputs represent a sustainable alternative for agriculture, as they are biodegradable and exhibit low environmental toxicity. Additionally, they stand out as one of the pillars of sustainable agriculture, enhancing soil fertility and potentially reducing dependence on industrial synthetic fertilizers (Lorenzoni et al., 2024; Rodrigues et al., 2024). Thus, this study aimed to identify the effect of coffee grounds on the growth and yield of lettuce plants.

Results and Discussion

The regression analysis results for lettuce head diameter, fresh mass, dry mass, and leaf area are presented in Figure 1. The regression equations indicate that at a concentration of 26.6% coffee grounds in the irrigation water, lettuce head diameter was 6% greater than in the control treatment without coffee grounds. Fresh mass increased progressively with higher concentrations of coffee grounds in the irrigation water, with an increase of 1.17 g in fresh mass per percentage unit of added coffee grounds. Dry mass and leaf area also showed improvements with the application of coffee grounds, with the highest dry mass and leaf area values observed at concentrations of 11.65% and 15.5% coffee grounds in the irrigation water, respectively.

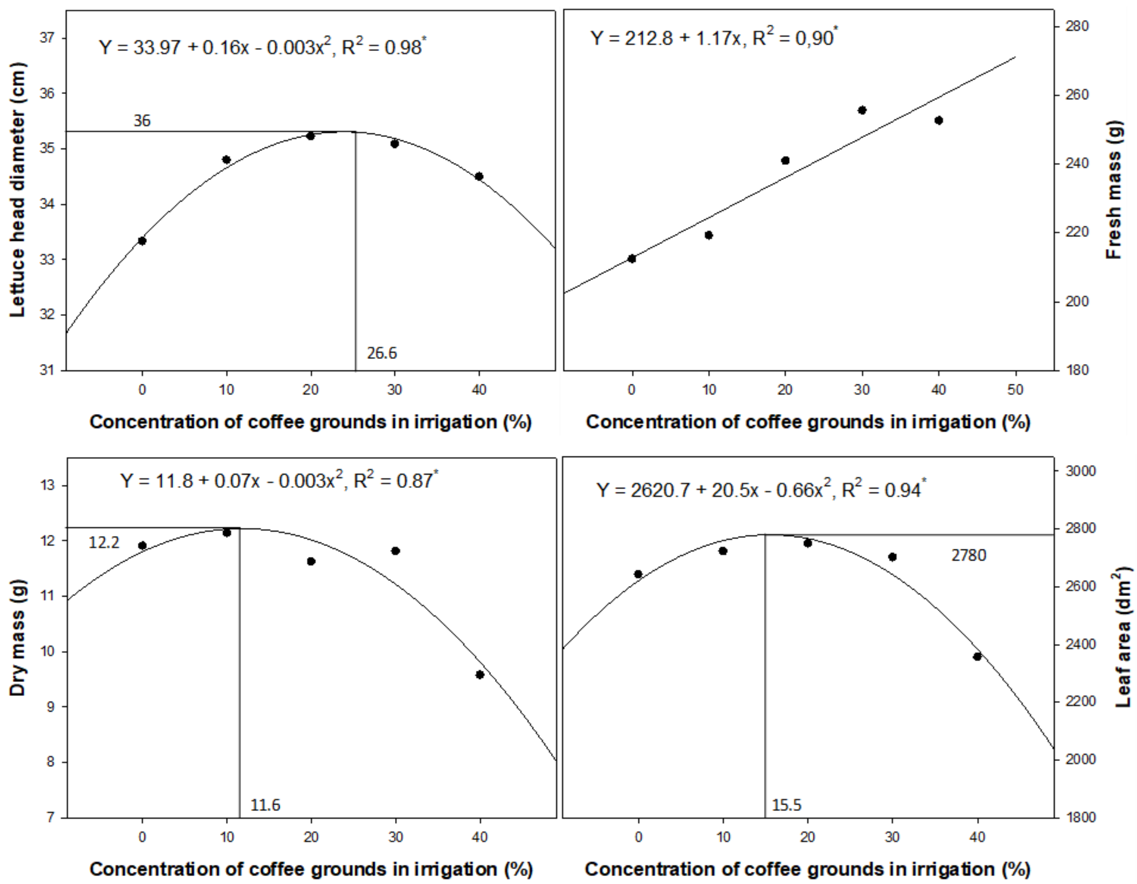

Figure 1. Regression equations for head diameter, fresh mass, dry mass, and leaf area of iceberg lettuce (*Lactuca sativa* L.) plants subjected to different concentrations of coffee grounds in the irrigation water.

The results demonstrate that using coffee grounds in irrigation significantly influenced lettuce growth and yield. The nutrients readily available from the coffee grounds in the soil solution provided benefits to lettuce plant development. The increase in leaf area resulted in higher photosynthetic activity, leading to greater assimilate production, which supported plant growth and was reflected in the increased dry mass and other measured variables.

These findings partially align with Bomfim et al. (2022), who reported successful application of used coffee grounds, making them suitable as a substrate. This success was attributed to their diverse nutrient composition, which can fertilize the soil, accelerate plant growth, and even improve the nutrient content of vegetables. Similar results were observed in studies on broccoli and cabbage, where the application of small amounts of coffee grounds (5% concentration) increased plant biomass (Chrysargyris et al., 2021). When composted, coffee grounds have been shown to promote plant growth and enhance nutritional values without harming the environment, serving as a sustainable alternative to conventional fertilizers (Bomfim et al., 2022).

Figure 2 presents the regression equations for commercial value, leaf chlorophyll concentrations (Chl *a*+*b*), and the number of leaves in iceberg lettuce plants. The commercial value shown in Figure 2 represents the combination of head diameter and dry mass, integrating variables that enhance quality for marketability while also serving as an indicator of growth, as lettuce is primarily consumed fresh.

The commercial value was 13% higher when plants were irrigated with a 36% concentration of coffee grounds than the control treatment without coffee grounds. This result is significant as it combines variables that commercially qualify lettuce for the market. According to Vicentini-Polette et al. (2018), certain variables, such as appearance and weight, are key determinants in consumer purchasing decisions in lettuce marketing.

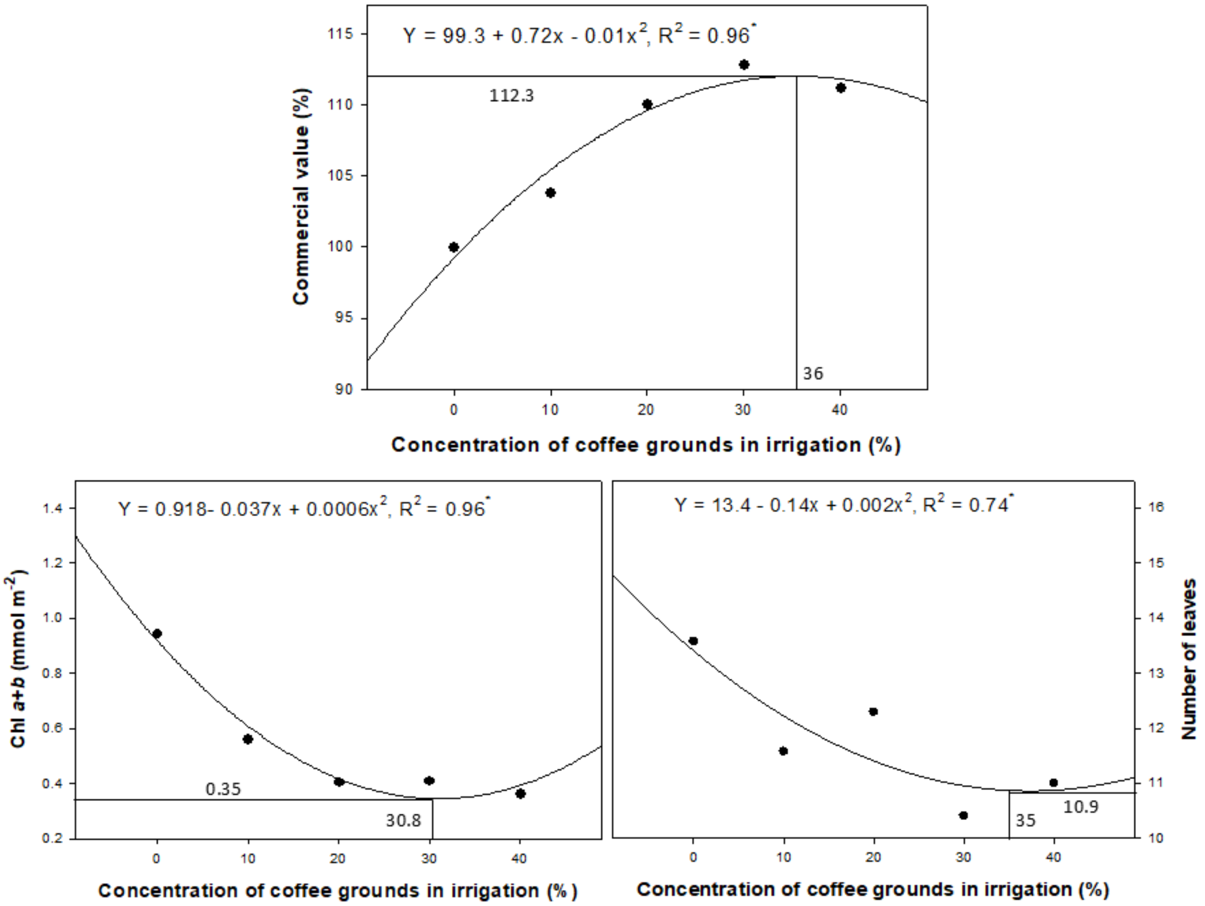

Figure 2. Regression equations for commercial value, leaf chlorophyll concentrations (Chl *a*+*b*), and number of leaves in iceberg lettuce (*Lactuca sativa* L.) plants subjected to different concentrations of coffee grounds in the irrigation water.

It is important to highlight that the quadratic regression adjustments for most variables indicate the existence of an optimal level and the presence of toxicity. Total chlorophyll contents and the number of leaves showed sharp declines of 68% and 18% respectively when comparing the control with the minimum point for each variable. These results suggest that coffee grounds have a toxic effect on lettuce plants when used at high concentrations.

These findings reinforce the need for caution when applying this material to lettuce crops. Pérez-Burillo et al. (2022) reported a negative effect on lettuce growth with higher coffee grounds, attributing this to caffeine, tannins, and polyphenols, which can induce plant toxicity. Additionally, these compounds may inhibit the bioavailability of nitrogen (N) and phosphorus (P), limiting plant development. According to Jeon et al. (2024), the lower agronomic performance of lettuce plants may be associated with higher levels of phytotoxic substances, including caffeine, chlorogenic acid, and tannins, found in used coffee grounds. Thus, it is evident that the application of this residue is beneficial in smaller amounts but becomes toxic at higher concentrations.

The principal component analysis shown in Figure 3 illustrates the ordering of variables and applied treatments, representing 96.8% of the data variation. The results demonstrate the clustering of treatments in different quadrants, with a clear displacement of variables along Axis 1.

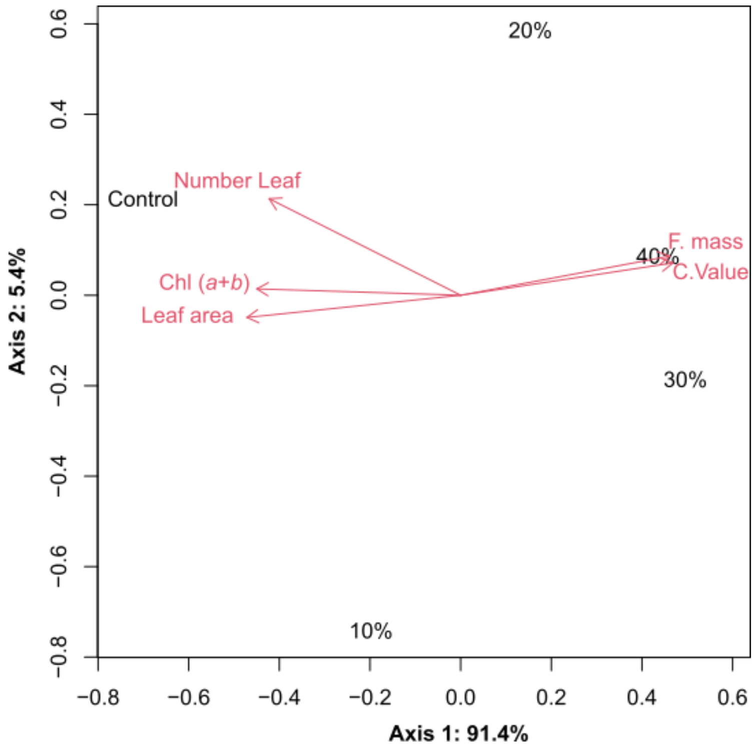

Figure 3. Principal component analysis for the number of leaves, leaf area, leaf chlorophyll content (Chl *a*+*b*), fresh mass, and commercial value of iceberg lettuce (*Lactuca sativa* L.) plants subjected to different concentrations of coffee grounds in the irrigation water.

The grouping of chlorophyll concentration, number of leaves, and leaf area variables with the control treatment indicate that these traits are more sensitive to the toxicity caused by coffee grounds. In contrast, fresh mass and commercial value (a combination of head diameter and dry mass), which are more resistant to higher concentrations of coffee grounds, are clustered to the right of Axis 1.

This result aligns with the findings of Hu et al. (2024), who stated that large amounts of coffee grounds can improve certain soil attributes, but plant growth is often limited due to their phytotoxicity caused by polyphenols and nitrogen immobilization. Additionally, some studies have shown that increasing the application of coffee grounds significantly enhances the soil water retention capacity but also reduces the growth of vegetable crops and subsequently limits weed development (Hardgrove et al., 2016).

Materials and methods

Plant materials

The study was conducted in a shaded environment covered with a 50% shading screen, located at the Goias State University (Universidade Estadual de Goiás), South Campus, UnU-Ipameri (17°43'19'' S, 48°09'35'' W, and an altitude of 773 m), in Ipameri, Goiás. This region has a tropical climate with dry winters and humid summers (Aw-type), according to the Köppen classification, with an average temperature of 20°C (Alvares et al., 2013).

The experiment was set up in a vegetable production bed, where chemical analysis revealed the following values: pH (H_2O) 5.82; 2.28 dag/kg of organic matter; 18.3 mg/dm^3 of P; 155 mg/dm^3 of K; 3.5 $cmol_c/dm^3$ of H+Al; 2.12 $cmol_c/dm^3$ of Ca; 0.62 $cmol_c/dm^3$ of Mg; 3.14 $cmol_c/dm^3$ of sum of bases; 6.64 $cmol_c/dm^3$ of CEC; and 47.3% base saturation. The experiment followed a completely randomized design with five treatments and twelve replications. The treatments consisted of irrigation with a solution containing coffee grounds at concentrations of 0%, 10%, 20%, 30%, and 40%, with 25 iceberg lettuce seedlings planted for each treatment.

The methodology proposed by NBR 10.006 (ABNT, 2004b) was adopted, adding 100 g of coffee grounds to 1000 mL of tap water, followed by agitation. A modification was introduced by incorporating heating to enhance the extraction of the solubilized extract. The mixture was heated, and after 10 minutes of boiling, it was left to rest for 24 hours, during which filtration was performed using a membrane filter. The resulting liquid was then mixed with irrigation water at 0%, 10%, 20%, 30%, and 40%. For irrigation at a 10% concentration, 100 mL of the coffee grounds solution was mixed with 900 mL of locally supplied water.

The irrigation volume was gradually increased throughout crop development due to the higher water demand. The applied water volume was calculated based on the reference evapotranspiration and the crop coefficient using the following equation:

ETc = ETo x kc, Where:

ETc = Crop evapotranspiration

kc = Crop coefficient

ETo = Reference evapotranspiration

The daily ETo calculation was performed using the Qirriga application (Santos et al., 2023) based on the Penman-Monteith method recommended by FAO (Smith et al., 1991). This calculation utilized daily data on maximum and minimum air temperature, relative humidity, sunshine duration, and wind speed, which were collected from the INMET meteorological station in Ipameri, GO. The crop coefficient (Kc) for lettuce ranged from 0.29 in the first week after transplanting to 1.02 in the final week of the cycle, following the recommendations of De Santana et al. (2016).
At 40 days of cultivation, the following variables were analyzed: head diameter, fresh mass, dry mass, leaf area, leaf chlorophyll content (Chl a+b), number of leaves, and root length.

Growth variables

Head diameter was measured using a graduated ruler, assessing the lettuce head from one end to the other. The total number of leaves was determined by counting all the leaves on the plant. Root length was measured with a graduated ruler from the root-stem transition zone to the root tip. Leaf area analysis was performed using the CI-202 Portable Laser Leaf Area Meter with fully expanded leaves. Fresh mass was obtained by weighing the plant immediately after harvest, while dry mass was determined by weighing the samples after 72 hours in an oven at 70°C.
Head diameter and dry mass were combined to calculate the commercial value of the lettuce plant. The values of these variables were converted into percentages to ensure equal weight in the final result. The control treatment (zero) was set as the reference, corresponding to 100% commercial value, and all other treatments were calculated relative to the control. Subsequently, the two variables were summed, and the average commercial value was determined for each coffee ground dosage.

Chlorophyll Index

The chlorophyll index was determined using a portable chlorophyll meter, ClorofiLOG model CFL 1030, which provided values for chlorophyll a, chlorophyll b, and total chlorophyll, expressed in units known as the SPAD Chlorophyll Index.

Statistical procedures

The variables were subjected to analysis of variance, as well as linear and quadratic regression. In cases where the regression was significant according to the F-test, the coefficient of determination (R^2) was calculated as the ratio of the regression sum of squares to the total sum of squares. Principal component analysis was also performed using the statistical software R 4.0.1 (R Core Team, 2020) and RBio (Bhering, 2017).

Conclusion

Coffee grounds may serve as an important bio-input for lettuce production by promoting vigorous plants with good visual quality. The larger head diameter, leaf area, and fresh mass resulted in a better visual appearance, which certainly makes these plants preferable in the market, with the highest commercial value obtained in plants irrigated with a 36% coffee grounds solution in the irrigation water. The use of coffee grounds is a rational practice for the sustainable management of a byproduct that constantly pollutes the environment due to improper disposal. However, directly applying coffee grounds without prior transformation into organic compost requires caution due to their toxic effects on lettuce plants. Chlorophyll concentration, leaf area, and number of leaves are strong indicators of toxicity in lettuce plants.

Acknowledgments

To the Research Dean's Office of Goiás State University for funding the grant under the Institutional Strategic Bio-Inputs Program.

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