Use of banana rachis leachate as fertilizer Characterization and effects on soil and crops.

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ABSTRACT

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| **Aims:** Banana (*Musa paradisiaca*) cultivation plays a significant role in Argentina's regional economies, generating substantial crop residues, including the rachis of the infructescence. The production of leachates from rachis presents an opportunity to enhance sustainability in agricultural systems.  **Study design:** This study aimed to characterize the physicochemical properties of banana rachis leachate produced under controlled conditions in Formosa, Argentina, and evaluate its effects on a reference horticultural crop and its substrate.  **Place and Duration of Study:** Agricultural Technology Validation Center (ATVC) Misión Tacaaglé, Formosa, Argentina; between 2021 and 2023.  **Methodology:** Leachate production followed a standardized protocol, including (i) identification of the fruit’s origin, (ii) processing of freshly cut rachis into sections and (iii) placement of the rachis pieces into a leaching pool equipped with a drainage system. Exhibited the following properties: pH = 8.2, EC = 18.9 dS.m⁻¹, total nitrogen = 392.0 mg.L⁻¹, phosphorus = 124 mg.L⁻¹, and potassium = 4,871.9 mg.L⁻¹. A pot trial with lettuce (*Lactuca sativa*) was conducted on which the evaluated leachate was applied. The treatments were T1 (Control, whit no fertilization), T2 (Urea application), T3 (Leachate application) and T4 (Combined application, leachate and urea).  **Results:** Leachate applications (T3 and T4) had no negative impact on plant survival, whereas T2 (urea-only treatment) caused a 33.33% mortality rate. T3 significantly enhanced lettuce growth, particularly in plant height and leaf number, while T4 did not differ significantly from the control.  T3 had no adverse effects on soil properties and increased K availability. In contrast, urea-containing treatments (T2 and T4) caused soil acidification and increased soluble salts, particularly Ca²⁺ and Mg²⁺, leading to decreased SAR values.  **Conclusion:** The results suggest that leachates produced under controlled conditions can serve as a nutrient source, particularly potassium, for intensive crops. Further research is needed to refine application rates, methods, and their effects on different crops. |

*Keywords: organic fertilizer, physicochemical characterization, horticultural crops.*

1. INTRODUCTION

Banana (*Musa paradisiaca*) cultivation holds significant socioeconomic importance in Argentina, particularly in the provinces of Formosa, Salta, Jujuy, and Misiones. According to Colamarino (2011) in Formosa approximately 4,000 hectares were currently under production in 2009, but now there are 2000 hectares under production (Baridón, personal communication, 2025), primarily managed by small-scale farmers with an average farm size of one hectare. The crop yields an average of 20 tons per hectare, amounting to an annual production of about 40,000 tons of fruit. However, banana cultivation generates substantial crop residues, including discarded fruit, pseudostems (which are renewed annually), and rachis (the stem-like structure that supports the fruit bunches), which typically weigh around 2 kg per plant. These byproducts remain unutilized in Formosa and are usually discarded in the fields.

In contrast, other banana-producing countries such as Ecuador, Costa Rica, and India—the world’s leading producer—actively utilize these residues for applications such as animal feed, bio-inputs and paper production. Banana rachis, for example, contain a high amount of nutrients (Aristizabal & Jaramillo, 2010), which results in their nutritional potential for crops and animals.

According to Meneses *et al.* (2010), leachates are formed through the biological decomposition of organic or biodegradable matter under aerobic or anaerobic conditions. Among the various uses of banana residues, the production of leachates from banana and plantain rachis has gained attention as part of the transition to more sustainable agricultural systems.

Leachates, when properly processed, can contribute to reducing reliance on synthetic agro-inputs and promoting environmentally friendly practices. Additionally, their use minimizes crop residues left in the field, which could otherwise promote the proliferation of pests and diseases such as the banana weevil (*Cosmopolites sordidus*) and sigatoka (*Mycosphaerella spp*.). Leachates contain macronutrients like nitrogen, calcium and potassium, together with numerous micronutrients such as Fe, Mg, B, and Zn, among others, which can be absorbed by crops and contribute to enhancing the physical and chemical properties of the soil (Caicedo *et al.*, 2020).

Recent research by Boulogne *et al.* (2023) has characterized the biological and chemical properties of *Musa spp.* leachates, highlighting their potential as bio-controllers and bio-stimulants. Furthermore, studies have explored the use of leachates to reduce inorganic fertilizer application in various crops, including broccoli (*Brassica oleracea*) (Vázquez Cruz *et al.*, 2019) and maize (*Zea mays*) (Durán & Sánchez, 2018), with promising results. Álvarez *et al.* (2013) and Andrade *et al.* (2019) have demonstrated that leachates provide essential nutrients, particularly potassium (K) and calcium (Ca), for plant growth. Chaves *et al.* (2017) reported a 30% yield in leachate production from fresh banana rachis and documented significant potassium recovery. Recently, Vázquez E. *et al.* (2025), reported responses to the combined soil and foliar application of banana rachis leachate on lettuce (*Lactuca sativa* L.). These authors obtained significant increases in leaf number and plant fresh weight.

The potential of rachis leachates for fungal disease control has also been explored, particularly in reducing fungicide applications for sigatoka management (Escobar-Vélez & Castaño-Zapata, 2005). However, existing research on banana and plantain rachis leachates is primarily based on studies conducted in tropical regions. Given that banana cultivation in Formosa differs in its edaphoclimatic conditions from tropical areas, it is essential to assess the potential applications of these leachates under local conditions. Therefore, this study aims to (i) determine the physicochemical characteristics of banana rachis leachate produced under controlled conditions in Formosa and (ii) evaluate its effects on a reference horticultural crop and the substrate used.

2. material and methods

The rachis leachates used in this study were obtained from three consecutive crop cycles (2021–2023) using the Musa paradisiaca Williams variety. The study was conducted at the Agricultural Technology Validation Center (ATVC) Misión Tacaaglé, under the administration of the provincial government of Formosa, Argentina. The research site is in the northern subtropical region of the country (24°58'58" S, 58°51'41" W).

Leachate production followed a standardized protocol, including (i) identification of the fruit’s origin, (ii) processing of freshly cut rachis into ~20 cm sections using a machete, and (iii) placement of the rachis pieces into a leaching pool equipped with a drainage system. The leachate was produced under field conditions but sheltered from direct exposure. Throughout the process, no additional water was introduced—only the leachate was recirculated over the rachis pieces. The production cycle lasted 60 days, yielding approximately 30% w/w leachate, consistent with findings by Chaves *et al.* (2017). The collected leachate was stored in plastic containers under cover.

* 1. **Analytical Determinations**

Chemical analyses of the leachates and substrate were conducted at the Soil, Water, and Forage Laboratory (ATVC Ibarreta, Formosa) and the Faculty of Agricultural and Forestry Sciences (National University of La Plata). The following parameters were measured:

* + 1. **Leachate composition:** Density, total solids content (gravimetric method) (Nielsen & Bradley, 2010), pH (potentiometric method) (Thomas, 1996), electrical conductivity (EC, conductimetry), total nitrogen (TN, Kjeldahl method) (Kirk, 1950), extractable phosphorus (ExP, Olsen method) (Olsen, 1954), calcium (Ca) and magnesium (Mg) (EDTA complexometric) (Nielsen, 2009), sodium (Na) and potassium (K) (flame photometry) (Wright & Stuczynski, 1996), and trace metals (Cu, Zn, Fe, Mn) (atomic absorption spectrometry).
    2. **Microbiological analysis:** Presence of coliform organisms using MacConkey broth cultures.
  1. **Pot Experiment**

A greenhouse trial was conducted at the Julio Hirschhorn Experimental Station (UNLP, Buenos Aires) to evaluate the leachate’s effects on lettuce (*Lactuca sativa var. Crespa cv. Brisa*). The trial was initiated in September using two-liter pots filled with a substrate composed of an Ap horizon of a local Argiudol soil depleted with 20% sand. A completely randomized design was used, with 15 pots per experimental unit and three replicates per treatment.

* 1. **Treatments**
     1. **T1 (Control):** No fertilization.
     2. **T2 (Urea application):** 50 ml of 4% w/v urea solution applied at 15 and 29 days after transplanting (DAT).
     3. **T3 (Leachate application):** Four applications of 10% leachate solution at 15, 22, 29, and 36 DAT.
     4. **T4 (Combined application):** 50 ml of 4% w/v urea at 15 DAT + three applications of 10% leachate at 22, 29, and 36 DAT.
  2. **Evaluated Variables**
     1. **Plant growth:** Survival rate, plant height, fresh weight of aerial and subsurface parts, leaf number, and rosette diameter.
     2. **Substrate properties:** pH, electrical conductivity, Ca and Mg content, Na and K concentration, sodium adsorption ratio (SAR), organic carbon (OC, Walkley-Black method) (Walkley, 1947), total nitrogen (TN, Kjeldahl method), and extractable phosphorus (Bray Kurtz 1) (Sparks et al., 2020).

1. result
   1. Leachate characterization

Table 1 presents the physicochemical characterization of the leachate, confirming its high saline content (EC = 18.9 dS m⁻¹), alkaline pH (8.2), and elevated potassium concentration (4,871.9 mg L⁻¹). The absence of coliforms ensures its safe use in leaf crops.

**Table 1. Leachate Characterization**

|  |  |  |  |
| --- | --- | --- | --- |
| **Analysis** | **Unit** | **Mean value** | **S** |
| pH | --- | 8.2 | 0.2 |
| EC | dS.m-1 | 18.9 | 0.9 |
| TN | mg.l-1 | 392 | 9.8 |
| ExP | mg.l-1 | 124 | 2.5 |
| K | mg.l-1 | 4,871.9 | 15.3 |
| Ca | mg.l-1 | 74.5 | 3.2 |
| Mg | mg.l-1 | 35.6 | 1.8 |
| Na | mg.l-1 | 7.8 | 0.5 |
| Fe | mg.l-1 | 2.1 | 0.1 |
| Cu | mg.l-1 | 0.2 | 0.05 |
| Mn | mg.l-1 | 0.2 | 0.05 |
| Zn | mg.l-1 | 0.1 | 0.05 |
| density | g.cm-3 | 1.03 | 0.01 |
| TSC | g.l-1 | 21 | 0.9 |
| Coliforms |  | Not detected |  |

* 1. Crop Response to Treatments

Leachate applications (T3, T4) had no negative impact on plant survival, whereas T2 (urea-only treatment) caused a 33.33% mortality rate. T3 significantly enhanced lettuce growth, particularly in plant height and leaf number, while T4 did not differ significantly from the control.

**Table 2. Crop responses**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Treatment 1 | | Treatment 2 | | Treatment 3 | | Treatment 4 | |
|  | Average | S | Average | S | Average | S | Average | S |
| Dead plants (%) | 0 a | - | 33.33 b | - | 0 a | - | 2.78 a | - |
| Aerial part weight (g) | 41.33 b | 4.18 | 18.89 a | 5.91 | 52.57 b | 4.18 | 45.51 b | 4.23 |
| Subsurface part weight (g) | 16.24 b | 1.96 | 7.92 a | 0.96 | 14.23 b | 1.96 | 11.96 b | 1.42 |
| Height (cm) | 12.31 b | 0.31 | 9.17 a | 0.43 | 13.06 c | 0.31 | 12.06 b | 0.31 |
| Rosette diameter (cm) | 22.36 bc | 0.56 | 17.78 a | 0.79 | 23.33 c | 0.56 | 20.91 b | 0.56 |
| Leaf number | 17.25 b | 0.49 | 13.94 a | 0.69 | 18.83 c | 0.49 | 17.4 b | 0.49 |

*S: standard deviation.* *Different letters indicate statistically significant differences (p≤ 0.05)*

Table 2 shows that applying banana rachis leachate at the T3 dose tended to produce larger and heavier lettuce plants, with statistically significant differences in plant height and leaf number compared to the control (T1). In contrast, the urea solution treatment (T2) had a negative impact on the crop, leading to high mortality and smaller plants across the evaluated parameters. Meanwhile, the combined application of urea and leachate (T4) did not result in significant differences compared to the control treatment.

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**Fig. 1. Effect of treatments on lettuce root development.**

Figure 1 shows that, although no significant differences were obtained in the subterranean biomass, the application of leachate in treatment 3 resulted in the production of roots of greater length than in the control, T1. It also shows the roots of T2 as a result of the overdose of urea applied.

* 1. Effects on Substrate

T3 had no adverse effects on soil properties and increased K availability. In contrast, urea-containing treatments (T2, T4) caused soil acidification and increased soluble salts, particularly Ca²⁺ and Mg²⁺, leading to decreased SAR values.

**Table 3. Substrate Effects**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **T1** | | **T2** | | **T3** | | **T4** | |
| **Variable** | **Mean** | **S** | **Mean** | **S** | **Mean** | **S** | **Mean** | **S** |
| pH | 6.58 b | 0.22 | 5.59 a | 0.23 | 6.67 b | 0.11 | 5.51 a | 0.17 |
| EC (dS.m-1) | 0.81 a | 0.09 | 4.31 c | 0.53 | 0.93 a | 0.06 | 2.97 b | 0.41 |
| OC (%) | 1.63 a | 0.14 | 1.61 a | 0.14 | 1.64 a | 0.16 | 1.61 a | 0.11 |
| TN (%) | 0.14 a | 0.01 | 0.19 b | 0.01 | 0.15 a | 0.02 | 0.16 ab | 0.01 |
| Ca+2 + Mg+2 | 2.12 a | 0.41 | 24.42 c | 6.26 | 2.15 a | 0.17 | 17.03 b | 3.34 |
| Na+ | 5.36 a | 0.48 | 7.96 b | 0.62 | 5.67 a | 0.42 | 7.69 b | 0.51 |
| K+ (meq.l-1) | 0.31 a | 0.04 | 2.23 d | 0.26 | 0.54 a | 0.06 | 1.74 c | 0.36 |
| SAR | 5.23 a | 0.33 | 2.33 a | 0.37 | 5.48 b | 0.31 | 2.67 a | 0.33 |
| ExP (mg.Kg-1) | 17.16 a | 3.76 | 19.09 a | 3.48 | 17.34 a | 8.48 | 14.86 a | 2.98 |

*S: standard deviation. Different letters indicate statistically significant differences (p≤ 0.05)*

Table 3 presents the effects of the treatments on various chemical and physicochemical properties of the substrate. The application of rachis leachate at the T3 dose did not negatively impact the substrate, showing no significant differences compared to the control (T1). However, T3 led to a statistically significant increase in K+ content in the substrate’s saturation extract.

In contrast, treatments involving urea (T2 and T4) caused substrate acidification by more than one pH point and increased soluble salt content. This rise in salts was particularly evident in the combined Ca+2 and Mg+2 levels, which reached 24.4 meq.L⁻¹ in T2, compared to 2.12 meq.L⁻¹ in the control (T1). Consequently, these treatments resulted in lower RAS values, despite the increase in Na content. Similarly, though to a lesser extent, Na+ and K+ concentrations increased significantly compared to the control and T3.

No significant differences were observed in extractable phosphorus content.

1. discussion

Andrade *et al.* (2019), in their physicochemical characterization of banana leachates, reported analytical data like those obtained for the banana rachis leachates evaluated in this study. Their findings included mean total solids of 18,379 mg.L⁻¹, a pH of 8.63, and a high potassium content of 4,890 mg.L⁻¹, which closely aligns with the mean value of 4,871.9 mg.L⁻¹ presented in Table 1. Additionally, they reported a sodium content of 7.8 mg.L⁻¹, lower than the 23.33 mg.L⁻¹ found in this study, which is consistent with the lower pH of the leachate produced in Formosa, Argentina.

The nutrient composition of leachates varies significantly, depending on the nutritional status of the plant from which the rachis originates. Chávez-Estudillo *et al.* (2014), studying plantain leachates in Mexico, found nutrient concentrations much higher than those in this study and concluded that their leachates could serve as an excellent complement to fertilization in plantain crops. Similarly, Álvarez *et al.* (2013) reported the chemical composition of plantain rachis leachates from three locations in Colombia, all of which had higher potassium levels. In leachates with a pH of 10, 0they found 22,428.6 mg.L⁻¹ of K, 48.5 mg.L⁻¹ of Ca, and 27.2 mg.L⁻¹ of Na. Vázquez E. *et al.* (2025) reported characteristics of a banana leachate produced in Ecuador. They found K contents of 14,000 mg.L-1 of K, also higher than those of this work, however the total nitrogen value was 245 mg.l-1, lower than 392 mg.l-1 of our leachate (Table 1). These significant differences across regions are likely due to the intensive fertilizer use in tropical areas and the reduced climatic stress experienced by these crops.

There is limited research on the application of *Musa sp.* leachates—whether from banana or plantain—on crops other than their own species. However, the characteristics of banana rachis leachates show promise. Duran & Sánchez (2018) observed positive responses in yield components of a maize hybrid following foliar applications of high leachate concentrations (70% and 30%). Vásquez Cruz *et al.* (2019), working with potted broccoli, applied leachates directly to the substrate at the base of the stem. They reported significant yield increases with applications of 15 mL of undiluted leachate per plant at 15-day intervals. In this study, which focused on lettuce—a crop highly sensitive to soil salinity—low doses of leachates were used, yet they still led to significant improvements in plant height and leaf number, as observed in T3. In this treatment, where the best crop responses to leachate application were obtained (Table 2), the fresh weight of the plants, 52.57g, and the leaf number, 18.83, were much lower than those reported by Vázquez E, *et al.* (2025). Even when these authors worked with a similar variety of lettuce and equivalent growing cycle, they worked directly on the soil. In our work, the impoverished substrate, the use of pots and the different composition of the leachates would be the factors responsible for these differences.

The discussion should not repeat the results but provide detailed interpretation of data. This should interpret the significance of the findings of the work. Citations should be given in support of the findings. The results and discussion part can also be described as separate, if appropriate.

1. Conclusion

Under trial conditions, the leachates produced at ATVC Misión Tacaaglé provide a viable source of nutrients, particularly potassium, and their application in lettuce cultivation showed beneficial effects without compromising soil properties. Further research should explore optimal application rates and effects on diverse crops.

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