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Effect of oil palm compost and sandy soil on the growth of cacao (*Theobroma cacao* L.) seedlings*

Efecto del compost de palma de aceite y suelo arenoso sobre el crecimiento de plántulas de cacao (*Theobroma cacao* L.)

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Abstract

Introduction. Low-fertility soils and high logistics costs for seedling production characterize the Peruvian Amazon. **Objective.** To evaluate the effect of a combination of sandy soil and oil palm compost on substrate, growth, and nutrition of cocoa seedlings under greenhouse conditions. **Materials and methods.** The experiment was conducted for 90 days in Yurimaguas-Loreto using a completely randomized design in a 5x5 matrix, with five doses of Oil Palm Compost and Sandy Soil to determine the best combination for cocoa growth and nutrition. Height (cm), diameter (mm), leaf area (cm^2), dry weight of stem and root were measured; soil chemical analysis and plant analysis (macro and micronutrients) were also conducted. **Results.** Sandy soil showed no significant effect on cocoa seedlings, while treatments with oil palm compost promoted shoot and root biomass. Additionally, this compost favored conditions for seedling growth by promoting higher organic matter, available phosphorus, exchangeable calcium, potassium, and higher cation exchange capacity. Regarding cocoa nutrition, it promoted greater absorption of macro and micronutrients in cocoa seedlings. **Conclusions.** These results indicate that the best treatment was the one composed entirely of oil palm compost, as it promotes growth and nutrition by improving substrate conditions.

Keywords: substrate, crops, foliar nutrition, waste management.

Resumen

Introducción. Suelos de baja fertilidad y altos costos de logística para la producción de plántulas caracterizan a la Amazonía peruana**. Objetivo.** Evaluar el efecto de la combinación de suelo arenoso y compost de palma aceitera sobre el sustrato, el crecimiento y la nutrición de plántulas de cacao en condiciones de invernadero. **Materiales y métodos.** El experimento se realizó durante 90 días en Yurimaguas-Loreto bajo un diseño completamente al azar en una matriz de 5x5, con cinco dosis de Compost de Palma Aceitera y Suelo Arenoso para obtener la mejor combinación para el crecimiento y nutrición del cacao. Se midió la altura (cm), diámetro (mm), área foliar (cm^2), peso seco de vástago y raíz; también se realizó análisis químico del suelo y análisis de plantas (macro y micronutrientes). **Resultados.** Los resultados mostraron que el suelo arenoso no tuvo un efecto significativo en las plántulas de cacao, mientras que los tratamientos con compost de palma aceiterapromovieron la biomasa de brotes y raíces. Además, esta composta favoreció las condiciones para el crecimiento de estas plántulas al promover mayor materia orgánica, fósforo disponible, calcio intercambiable, potasio y mayor capacidad de intercambio catiónico. En el caso de la nutrición del cacao, promovió una mayor absorción de macro y micronutrientes en las plántulas de cacao. **Conclusiones.** Estos resultados son indicaron que el mejor tratamiento fue el compuesto en su totalidad por el compost de palma aceitera, ya que promueve el crecimiento y nutrición mediante la mejora de las condiciones de sustrato.

Palabras clave: sustrato, cultivos, nutrición foliar, manejo de desechos.

Introduction

Several crops, such as rice (*Oriza sativa*), maize (*Zea mays*), coffee (*Coffea arabica*), oil palm (*Elaeis guineensis*), and cacao (*Theobroma cacao*), characterize the Peruvian Amazon. The latter has become a crop of national interest due to its main product, the chocolate, and the high quality of Peruvian cacao about other competitors, such as African cacao (International Cocoa Organization [ICCO], 2021). In Peru, there are nearly 180,000 ha of cacao crops from which the San Martin and Loreto region represent 36 % of the nation's production (Dirección de Estadística e Información Agraria [DEIA], 2021). Cacao in Peru is mainly produced by small farmers (<5 ha), generally from former coca producers. Furthermore, this represents a challenge in terms of cost of production since the power of negotiation of these producers is low.

Cacao production directly interacts with natural factors and agronomic practices. One of the essential parts of the crop's success is the seedlings' quality (Sodré Andrade & Gomes Sena, 2019). Therefore, adequate nutrition and substrate are needed to maintain adequate growth and tolerance for abiotic and biotic stress (Marrocos et al., 2020; Neto et al., 2015). The main characteristics of an adequate substrate are good physical conditions and nutrients to sustain the plants during the nursery stage, being the first three months important for good root growth and nutrient acquisition (Reyes Moreno et al., 2021).

Rivers dominate Loreto region, therefore, logistics costs are higher than in other regions of Peru, making commercial substrates inviable, for that reason, alternatives are always promoted. This region also has a prevalence of soils of the type fluvents characterized for good physical conditions and relatively high fertility due to the influence of the rivers. This type of material is generally used for the production of seedlings in many Latin-American countries since it can promote good physical conditions (Sodré Andrade & Gomes Sena, 2019).

This region is also one of the country's leading producers of oil palm (DEIA, 2021). However, this crop has many residues, mainly the empty fruit bunch after the harvest. Nevertheless, many producers have decided to make compost out of this residue, a product nowadays of suitable chemical and physical characteristics at a low price. Consequently, its use as an amendment has increased in the last years in many crops (Supriatna et al., 2022). The compost has many advantages since it can improve the physical and chemical properties of the soil, such as macroporosity, nitrogen and potassium nutrition (da Costa Leite et al., 2023), being the latter, also the most demanded nutrient in cacao (Marrocos et al., 2020).

Taking into consideration the demands for alternative substrates in cacao due to higher logistics costs for traditional supplies in this crop, the objective of this work was to evaluate the effect of the combination of sandy soil and oil palm compost on the substrate, growth, and nutrition of cacao seedlings under nursery conditions.

Materials and methods

Localization

The research was carried out at "Rancho Juan Carlos," located in the district of Yurimaguas, Alto Amazonas Province, Loreto Region (0376691 E, 9346375 N) with 185 m a. s. l. The area is characterized by a tropical climate –Af, with an average annual temperature that exceeds 25 °C. The maximum annual temperature is 31°C, and the minimum is 22 °C, with an annual rainfall of 2,000 mm (Escobedo Torres & Torres Reyna, 2014). A significant presence of rivers also characterizes this area; therefore, soils of the type of fluvents are quite frequent. However, Ultisols and Oxisols are also dominant, being mostly acidic with low fertility, high in Al saturation and low in Organic matter (Escobedo Torres & Torres Reyna, 2014).

Experimental design

The experiment was performed between March and June of 2022, with a duration of 90 days. The experimental design was a complete random design (CRD) with a factorial arrangement with two treatments with five doses, each one and three repetitions. The treatments for the substrate for the seedlings were two: Sandy soil with five doses (0 %, 20 %, 60 %, 75 %, 90 %, 100 %) and Oil Palm Compost with five doses (0 %, 10 %, 25 %, 40 %, 80 %, 100 %) and three repetitions, respectively. Each combination of the sandy soil and the oil palm compost treatments totalized 100%. The plant material was obtained from Instituto de Cultivos Tropicales nursery, using synthetic seeds that guaranteed the genetic quality of the clone CCN-51. The seeds were previously pre-germinated in sawdust for three days, after they were seeded in the final pot with the application of Parachupadera® (Flutolanil + Captan), in order to avoid fungal diseases. In the case of the Sandy Soil, the soil was collected from the upper layer (0-20 cm) of fluvent soil. For the compost of the Oil Palm, only the residues of the harvest (bunch) were used and composted for three months in order to achieve the correct size and characteristics for the experiment. The analysis of the soil and the compost of the oil palm is presented in Table 1. Substrates used were maintained at field capacity to avoid drought stress in cacao plants.

Table 1. Results of chemical analysis (pH, Electric conductivity –EC, Organic matter –OM, P, Cation exchange capacity –CEC, Ca, Mg, K, B, Cu, Fe, Mn, Zn) of oil palm (*Elaeis guineensis*) compost and sandy soil used in the experiment with cacao seedlings. Yurimaguas, Perú, 2022.

Cuadro 1. Resultados de análisis químico (pH, conductividad eléctrica –EC, materia organica-OM, P, Capacidad de intercambio catiónico –CEC, Ca, Mg, K, B, Cu, Fe, Mn, Zn) del compost de palma aceitera (*Elaeis guineensis*) y del suelo arenoso usado en el experimento con plántulas de cacao. Yurimaguas, Peru, 2022.

Material	pH	EC*	OM	P	CEC	K	Ca	Mg	B	Cu	Fe	Mn	Zn
		dS cm^{-1}	%	%	$cmol_c$ kg^{-1}	%	%	%			mg kg^{-1}		
Oil palm compost	7.81	0.18	15.39	0.34	22.86	1.56	0.78	0.6	21.05	31.58	3973	337	84.2
		dS cm^{-1}	%	mg kg^{-1}	$cmol_c$ kg^{-1}						mg kg^{-1}		
Sandy soil	6.4	0.03	2.9	2.99	12.13	0.55	6.1	1.88	---	---	---	---	---

*EC: Electric conductivity, OM: Organic matter, CEC: Cation Exchange Capacity, P: Phoshorus, K: Potassium, Ca: Calcium, Mg: Magnesium, B: Boron, Cu: Copper, Fe: Iron, Mn: Manganese, Zn: Zinc. / *EC: conductividad eléctrica, OM: materia orgánica, CEC: capacidad de intercambio catiónico, P: fósforo, K: potasio, Ca: calcio, Mg: magnesio, B: boro, Cu: cobre, Fe: hierro, Mn: manganeso, Zn: cinc.

Biometric variables

At the end of the experiment, for the evaluation of the combination of the Sandy soil and the oil palm compost,

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in each repetition, biometric variables were measured according to Arévalo-Hernández et al. (2022), height (cm) was measured with a ruler, diameter (mm) with a vernier scale, and leaf area (cm^2) with a portable leaf area meter (YMJ-B Luzeren®). Also, plants were sacrificed, and the shot and root were collected and dried at 60 °C in a stove, after, the dried weight (g) was recorded for both shoot and root in all treatments with each repetition using a calibrated balance.

Soil chemical characteristics

Soil chemical analysis was performed following the procedures described in (Arévalo-Hernández et al., 2022). For pH and EC (Electric conductivity), a dilution of 1:2.5 in water was used and then measured in a potentiometer and conductimeter, respectively. For organic matter, organic carbon was determined using the Walkey-Black method and then multiplied by a factor of 1.72. In the case of P, the extraction was performed with Olsen extractant (0.5 M $NaCO_3$), filtered, and determined with the molybdate-ascorbic method in a UV-VIS (880 nm). For determination of CEC (Cation exchange capacity) and the cations (Ca, Mg, K), ammonium acetate 1 M pH 7.0 was used and then measured in an AAS (Atomic Absorption Spectrophotometer). Finally, for extraction of Al, a solution of 1 M KCl was used followed by determination by titration using 0.1 M NaOH.

Plant analysis and nutrient uptake

Dried samples were milled and passed through 20 mesh sieves for plant analysis. Afterward, the procedures specified in (Arévalo-Hernández et al., 2022) were used. For N, the Kjeldahl method was used. For the other elements (P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn), digestion with HNO_3 65 % was performed in a hot block at 120 °C until the samples were fully digested. Afterward, P, S, and B were determined using a UV-Vis spectrophotometer, and the cations were determined using an AAS.

For the determination of nutrient uptake (macro in g per plant and micronutrients in mg per plant), the equation 1 was used (Arévalo-Gardini et al., 2021; Arévalo-Hernández et al., 2022).

$$\text{Uptake (g or mg per plant)} = \frac{\text{Element concentration} * \text{Dry weight (g)}}{1000} \quad (1)$$

Element concentration= g kg^{-1} for macronutrients and mg kg^{-1} for micronutrients

Statistical analysis

Statistical analysis was performed with R version 4.2.2 (R Core Team, 2021). Biometric parameters, soil characteristics, and macro- and micronutrient uptake were compared at the end of the experiment using an analysis of variance (ANOVA), and in the case of the significance of both variables' studies, their effect was visualized using the response surface method.

Results

The results of means for biometric measurements are presented in table 2. The analysis of variance showed that only the variables of root volume (cm^2), shoot dry weight (SDw) (g), and root dry weight (RDw) (g) presented significant differences ($p \leq 0.05$). In the case of the other variables studied (height, diameter, leaf area, and root length), not significant differences were observed ($p > 0.05$).

These results indicate that the mixture of compost with sandy soil promoted better growth in cacao seedlings;

Table 2. Results of biometric measurements expressed in terms of mean standard deviation for height (cm), diameter (cm), leaf area (cm^2), root length (cm), root volume (cm^3), shoot dry weight (g), and root dry weight (g) in cocoa seedlings (*Theobroma cacao*) grown in oil palm compost (*Elaeis guineensis*) and sandy soil, used in the experiment. Yurimaguas, Peru, 2022.

Cuadro 2. Resultados medidas biométricas expresadas en términos de promedio desviación estándar para altura (cm), diámetro(cm), área foliar (cm^2), longitud de raíz (cm), volumen de raíz (cm^3), peso seco aéreo (g) y peso seco radicular (g) en las plántulas de cacao (*Theobroma cacao*) bajo crecimiento en compost de palma aceitera (*Elaeis guineensis*) y en suelo arenoso, usado en el experimento. Yurimaguas, Peru, 2022.

Oil Palm Compost	Sandy Soil	Height (cm)	Diameter (cm)	Foliar Area (cm^2)	Root length (cm)	Root volumen (cm^3)	Shoot Dry Weight (g)	Root Dry Weight (g)
0 %	100 %	50.93 ± 2.48	9.99 ± 0.52	136.08 ± 17.87	34.67 ± 1.15	409.67 ± 0.58	19.67 ± 1.53	3.67 ± 0.58
10 %	90 %	51.20 ± 7.10	10.00 ± 0.43	143.15 ± 14.03	38.67 ± 10.26	406.67 ± 2.89	22.67 ± 7.23	2.33 ± 0.58
25 %	75 %	41.93 ± 3.10	9.36 ± 0.33	121.94 ± 6.27	38.67 ± 6.66	406.67 ± 2.89	16.67 ± 0.58	2.67 ± 0.58
40 %	60 %	48.00 ± 5.10	9.44 ± 0.57	112.00 ± 23.28	29.00 ± 19.31	411.67 ± 2.89	18.33 ± 3.51	3.67 ± 0.58
80 %	20 %	40.23 ± 6.14	9.43 ± 0.11	133.02 ± 43.38	37.00 ± 13.86	416.67 ± 5.77	16.00 ± 3.00	5.00 ± 2.65
100 %	0 %	51.73 ± 11.65	10.41 ± 0.52	174.34 ± 19.39	39.33 ± 6.43	413.00 ± 3.46	38.33 ± 6.03	5.00 ± 0.00

this is a positive outcome since sandy soils are readily available for cacao producers in these regions. Likewise, the presence of fruit bunch residues of oil palm for nursery in greenhouse conditions. Since similar results between independent variables were obtained, but only SDw indicated an interaction between the factors studied, this variable

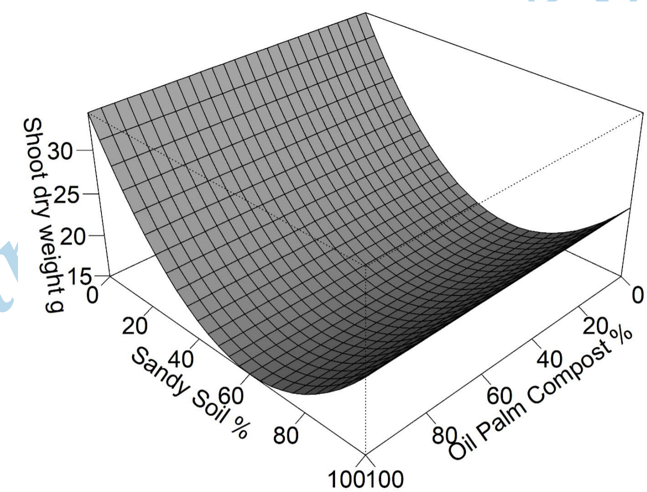

Figure 1. Effect of combinations of oil palm compost (*Elaeis guineensis*) and sandy soil levels on the dry weight of cocoa seedlings (*Theobroma cacao*) under nursery conditions in Yurimaguas, Peru, 2022.

Figura 1. Efecto de las combinaciones de los niveles de compost de palma aceitera (*Elaeis guineensis*) y del suelo arenoso sobre el peso seco de plántulas de cacao (*Theobroma cacao*) en condiciones de vivero en Yurimaguas, Perú, 2022.

will be discussed in this research. For this purpose, a response surface was constructed and presented in Figure 1.

In general, the higher accumulation of biomass was observed with the higher dose of oil palm compost (Figure 1), with no indication of toxicity even when the seedlings were directly grown in 100 % compost. However, the lowest growth was recorded at 60 % of sandy soil and 40 % of oil palm compost, this may be related to low input of nutrients. Also, higher macroporosity and high drainage in the soil may have restricted water nutrition in plants,

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especially in high temperature days.

In the case of soil chemical analysis, all the attributes studied presented significant differences ($p \leq 0.05$) between treatments, both for the single factor and the interaction between the two variables. The results of the

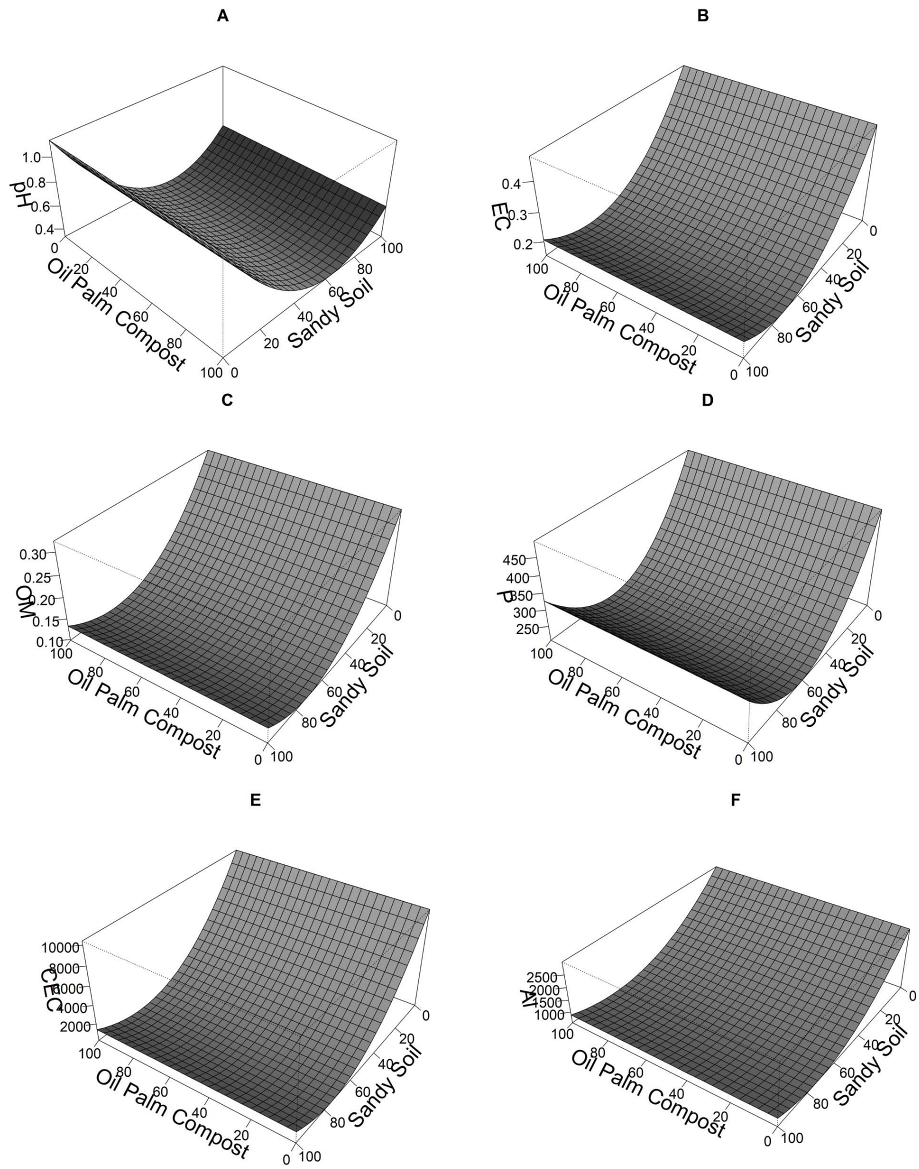

Figure 2. Effect of the interaction between doses of oil palm compost (*Elaeis guineensis*) and sandy soil as substrate on cocoa seedlings (*Theobroma cacao*) under nursery conditions, on the chemical characteristics of the substrate: pH (A), electrical conductivity - EC μs cm-1 (B), organic matter - OM % (C), phosphorus - P mg kg^{-1} (D), cation exchange capacity - CEC cmolc kg^{-1} (E), and Aluminum - Al cmolc kg^{-1} (F). Yurimaguas, Peru, 2022.

Figura 2. Efecto de la interacción de las dosisde compost de palma aceitera (*Elaeis guineensis*) y suelo arenoso como sustrato en plantulas de cacao (*Theobroma cacao*) en condiciones de vivero, en las caracteristicas químicas del sustrato de pH (A), conductividad eléctrica - EC μs cm-1 (B), materia organica - OM % (C), fósforo - P mg kg^{-1} (D), capacidad de intercambio catiónico - CEC cmolc kg^{-1} (E) y aluminio - Al cmolc kg^{-1} (F). Yurimaguas, Perú, 2022.

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interactions of each soil factor are presented in Figure 2. In the case of pH, it is possible to observe a decrease as the dose of oil palm stalk increases, from the treatment without application to the treatment with 100 % of the compost, indicating that this substrate tends to decrease soil pH with higher doses. In the case of the EC, OM, Ca, Mg, K, and Al, the opposite happens; with increasing doses of compost, higher values of these variables are observed. In the case of P, it was the only element that presented a quadratic curve in the soil; however, the optimum value achieved for this element was with nearly 80 % of compost and 20 % of the sandy soil, a relation of 1:4.

The results of chemical analyses of the concentration of nutrients (N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, and Zn) in cocoa leaves are presented in Table 3. All the nutrients had significant differences. ($p \leq 0.05$) between the treatments, except Sulfur (S) and Boron (B), where no significant differences were observed ($p > 0.05$). The results of the effect of the doses for N, which presented significance in the main factors, need to be presented since it followed the same trend that the elements that presented interaction. In the case of the elements that showed interaction (K, Ca, Mg, B, Mn, Zn), the results are observed in Figure 3. All the elements followed the same trend, a direct positive correlation between the dose of applied oil palm compost and the nutrient amount. This is related to the highest nutrient composition of the compost (Table 1) in the sandy soil.

Table 3. Nutrient content results, expressed as mean ± standard deviation, for N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn of oil palm compost (*Elaeis guineensis*) and sandy soil used in the experiment with cocoa seedlings. Yurimaguas, Peru, 2022.

Cuadro 3. Resultados de contenido de nutrientes, expresadas en términos de promedio desviación estándar, para N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn de compost de palma aceitera (*Elaeis guineensis*) y suelo arenoso usado en el experimento con plántulas de cacao. Yurimaguas, Peru, 2022.

Oil Palm Compost	Sandy Soil	N*	P	K	Ca	Mg	S	B	Fe	Mn	Zn
%		g per plant						mg per plant			
0	100	0.39 ± 0.08	0.04 ± 0.00	0.48 ± 0.01	0.16 ± 0.01	0.11 ± 0.01	0.05 ± 0.00	311.16 ± 29.72	2,749.44 ± 239.62	804.24 ± 119.70	606.42 ± 75.55
10	90	0.56 ± 0.16	0.06 ± 0.02	0.55 ± 0.21	0.21 ± 0.09	0.13 ± 0.04	0.04 ± 0.01	246.58 ± 49.23	2,134.48 ± 442.57	618.23 ± 59.46	843.67 ± 251.04
25	75	0.46 ± 0.05	0.05 ± 0.01	0.37 ± 0.03	0.16 ± 0.02	0.11 ± 0.01	0.03 ± 0.01	260.88 ± 50.06	5,490.32 ± 1,224.61	972.68 ± 292.10	748.22 ± 78.32
40	60	0.59 ± 0.16	0.04 ± 0.01	0.48 ± 0.16	0.19 ± 0.02	0.13 ± 0.03	0.04 ± 0.02	264.50 ± 112.86	1,775.35 ± 437.42	1,418.64 ± 408.04	872.87 ± 101.08
80	20	0.47 ± 0.04	0.05 ± 0.01	0.43 ± 0.06	0.23 ± 0.06	0.16 ± 0.03	0.03 ± 0.00	220.14 ± 44.13	1,945.47 ± 615.53	3,578.98 ± 987.93	1,201.72 ± 73.53
100	0	0.98 ± 0.28	0.07 ± 0.02	1.28 ± 0.38	0.52 ± 0.16	0.35 ± 0.02	0.07 ± 0.01	556.85 ± 174.79	7,107.58 ± 2,135.47	11,547.03 ± 3,441.71	3,354.53 ± 537.97

Discussion

Oil pam compost increased growth in cacao seedlings, and the highest dose indicated that cacao seedlings could be grown in a pure oil palm compost substrate. In general, compost of any origin promotes growth by increasing plant nutrition, and reduces soil pathogens populations and bacteria (Milinković et al., 2019). The use of compost of this residue represents an opportunity for large-scale waste in the oil palm industry, which can benefit small producers and nurseries dedicated to cacao crops. Also, compost can enhance biomass accumulation and reduce heavy metals such as Cd in cacao (Argüello et al., 2023; Chavez et al., 2016), which is essential regarding

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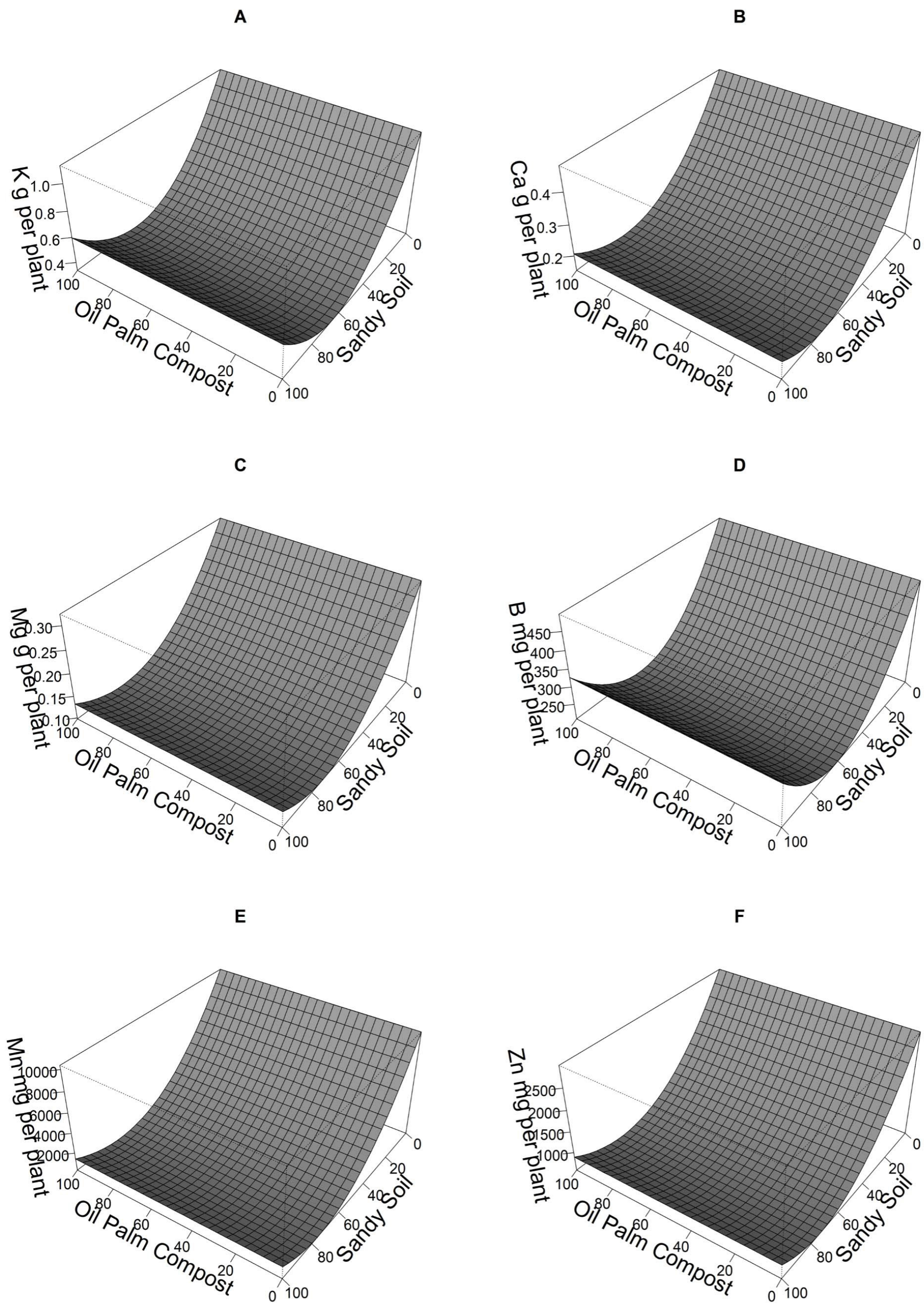

Figure 3. Effect of the interaction of doses of Oil Palm Compost and Sandy Soil on Nutrient contents: Potassium - K (3A), Calcium - Ca (3B), Magnesium - Mg (3C) in g per plant and Boron - B (3D), Manganese - Mn (3E) and Zinc - Zn (3F) in mg per plant of cacao seedlings in nursery conditions in Yurimaguas, Peru, 2022.

Figura 3. Efecto de la interacción de las dosisde compost de palma aceitera y suelo arenoso en el contenido de nutrientes: Potasio – K (3A), calcio - Ca (3B), magnesio - Mg (3C) en g por planta y Boro - B (3D), Manganeso - Mn (3E) y cinc - Zn (3F) en mg por planta en plántulas de cacao en condiciones de vivero en Yurimaguas, Perú, 2022.

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seedling quality. Also, higher doses of compost improve the C stocks in the soil and the plant, which is generally related to higher plant growth (Zhang et al., 2020) as seen in this study.

The substrate chemical results indicate that the main differences in growth in plants in cacao seedlings, especially with higher Oil Palm compost rates, may be related to the improvement of the conditions of the substrate in these seedlings, this is related to the higher quantity of nutrients, cations, and OM of the compost. Also, the high Al concentration in excessive doses of compost may restrict plant growth, photosynthesis, and nutrition (Arévalo-Hernández et al., 2022; Siecińska & Nosalewicz, 2016). The low effect on plant growth despite Al may be related to the higher concentration of Ca with increasing doses of compost and this element is known to reduce the stress generated by aluminum, reducing its activity in soils (Takala, 2019). Also, the higher concentration of OM reduces the acidity's activity by complexing Al (Lazicki et al., 2022).

Also the compost has increased N uptake in plants, which may be related to the organic forms of N that have a lower energetic cost in comparison to inorganic forms such as NO_3^- or NH_4^+ and enhance nutrient use efficiency (Franklin et al., 2017), while improving overall soil conditions since this type of amendment does not impact on soil pH as common nitrogen fertilizers such as Urea or Ammonium sulfate that commonly used in tropical soils.

Oil compost has also improved P availability in the soil, in general, organic forms tend to have a higher solubility in comparison to inorganic sources which can explain the higher P uptake in the seedlings. Also, among the main nutrients in plant nutrition, P is significant for plant growth and root development in the early stages (Cellier et al., 2014). Tropical soils have, in general, low available P in the soil, and in many cases, it may restrict plant growth (Viana Cunha et al., 2022). The use of this product provides readily available P for plant growth, so it may constitute an effective amendment source to improve nutrition of this element in tropics (Smitha et al., 2016).

These results indicate that the promotion of growth of cacao seedlings is not only explained by better substrate conditions but also by higher nutrition in the plants. Especially N and K are the main nutrients this crop requires (Carmona-Rojas et al., 2022; Marrocos et al., 2020). However, even though P was affected by the different treatments at a soil level, in the plant, this was not observed. These contradictory results may be related to the P requirements at the seedling level that are significantly lower at the nursery stage (Marrocos et al., 2020). Also, in the case of K, not only is the element the highest ratio of cycling in comparison to other nutrients at the compost level (Cavalcante Santos et al., 2021), but it's also related to biotic and abiotic stress tolerance (Sardans & Peñuelas, 2021).

In the case of micronutrients, both B and Zn nutrition was improved by oil palm compost, even though the concentrations in the compost were low. This may be explained to the chelated forms of this elements that are present in the compost that have higher uptake in plants (Rosa et al., 2022). B is very important in the early stages of growth of plants, since it promotes higher root development (Wang et al., 2015). Also, these elements are scarce in tropical soils, so amendments that promote better nutrition should be used. B is essential for root development since many plants have specific B transporters, which are crucial in plant metabolism (Pereira Leal et al., 2021). At the same time, Zn acts mainly as a transporter and in hormonal control of plants affecting cacao seedlings' overall growth and development (Neto et al., 2015). However, is important to apply these elements with caution since research suggests that they have an antagonistic effect but under high application ratios the use of Zn or B may enhance balance of these nutrients (Long & Peng, 2023).

Conclusions

This study demonstrated that utilizing 100 % compost derived from oil palm empty fruit bunches significantly enhanced the overall growth of cacao seedlings. Furthermore, this compost, at this particular dosage, created favorable conditions for the growth of these seedlings by enhancing substrate fertility and promoting better nutrition for the cacao plants. These findings set a precedent for utilizing oil palm bunches as compost, thereby reducing waste in this crop and enhancing the conditions for high-quality cacao seedling production in Peru.

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Interests conflict

The authors declare that they have no conflicts of interest.

References

Arévalo-Gardini, E., Farfán, A., Barraza, F., Arévalo-Hernández, C. O., Zúñiga-Cernades, L. B., Alegre, J., & Baligar, V. C. (2021). Growth, physiological, nutrient-uptake-efficiency and shade-tolerance responses of cacao genotypes under different shades. *Agronomy 2021, 11*(8), Article 1536. https://doi.org/10.3390/AGRONOMY11081536

Arévalo-Hernández, C. O., Arévalo-Gardini, E., Farfan, A., Amaringo-Gomez, M., Daymond, A., Zhang, D., & Baligar, V. C. (2022). Growth and nutritional responses of juvenile wild and domesticated cacao genotypes to soil acidity. *Agronomy*, *12*(12), Article 3124. https://doi.org/10.3390/AGRONOMY12123124

Argüello, D., Chavez, E., Gutierrez, E., Pittomvils, M., Dekeyrel, J., Blommaert, H., & Smolders, E. (2023). Soil amendments to reduce cadmium in cacao (*Theobroma cacao* L.): A comprehensive field study in Ecuador. *Chemosphere*, *324*, Article 138318. https://doi.org/10.1016/j.chemosphere.2023.138318

Carmona-Rojas, L. M., Gutiérrez-Rodríguez, E. A., Henao-Ramirez, A. M., & Urrea-Trujillo, A. I. (2022). Nutrition in cacao (*Theobroma cacao* L.) crops: What determining factors should be considered?. *Revista de La Facultad de Agronomía*, *121*(Esp. 2), 1-21. https://doi.org/10.24215/16699513e101

Cavalcante Santos, V., Dos Santos, M. L., Cotta, L. C., Neves Lima, J. C., & Soares Barros, E. M. (2021). Clonal teak litter in tropical soil: Decomposition, nutrient cycling, and biochemical composition. *Revista Brasileira de Ciencia Do Solo*, *45*, e0200071. https://doi.org/10.36783/18069657RBCS20200071

Cellier, A., Gauquelin, T., Baldy, V., & Ballini, C. (2014). Effect of organic amendment on soil fertility and plant nutrients in a post-fire Mediterranean ecosystem. *Plant and Soil*, *376*(1), 211–228. https://doi.org/10.1007/S11104-013-1969-5

Chavez, E., He, Z. L., Stoffella, P. J., Mylavarapu, R., Li, Y., & Baligar, V. C. (2016). Evaluation of soil amendments as a remediation alternative for cadmium-contaminated soils under cacao plantations. *Environmental Science and Pollution Research, 23,* 17571–17580. https://doi.org/10.1007/s11356-016-6931-7

Cruz Neto, R. O. , De Souza Jr, J. O., Sodré Andrade, G., & Baligar, V. C. (2015). Growth and nutrition of cacao seedlings influenced by zinc application in soil. *Revista Brasileira de Fruticultura, 37*(4), 1053-1064. https://doi.org/10.1590/0100-2945-238/14 da Costa Leite, R., Reis Lucheta, A., Barata Holanda, R., Pereira Silva, P. M., Vilaça do Carmo, A. L., Gama Gomes, F., da Costa Leite, R., Amorim de Melo, C. C., Vieira da Costa, R., Montini, M., & Rodriguez Fernandes, A. (2023). Environmental and agronomic assessment of soil conditioners produced from bauxite residue and oil palm wastes. *Environmental Research*, *233,* Article 116474. https://doi.org/10.1016/j.envres.2023.116474

Dirección de Estadistica e Información Agraria. (2021). *Datos de producción agrícola del Perú del 2021*. Recuperado mayo 20, 2023 de. https://siea.midagri.gob.pe/portal/publicacion/boletines-anuales/4-agricola

Escobedo Torres, R., & Torres Reyna, M. (2014). *Zonificación ecologica y economica de la provincia de Alto Amazonas. Departamento de Loreto. Suelos y capacidad de uso mayor de las tierras*. Instituto de Investigaciones de la Amazonía Peruana http://terra.iiap.gob.pe/assets/files/meso/11_zee_alto_amazonas/04_Suelos_y_CUM.pdf

Franklin, O., Aguetoni Cambui, C., Gruffman, L., Palmroth, S., Oren, R., & Näsholm, T. (2017). The carbon bonus of organic nitrogen enhances nitrogen use efficiency of plants. *Plant, Cell & Environment*, *40*(1), 25-35. https://doi.org/10.1111/pce.12772

International Cocoa Organization (2021). *Quarterly bulletin of cocoa statistics* (Vol. 1). https://www.icco.org/quarterly-bulletin-cocoa-statistics-feb-21.

Lazicki, P., Mazza Rodrigues, J. L., & Geisseler, D. (2022). Acid stress and compost addition decouple carbon and nitrogen cycling in an agricultural soil : An incubation study. *Applied Soil Ecology*, *169*, Article 104219. https://doi.org/10.1016/j.apsoil.2021.104219

Long, Y., & Peng, J. (2023). Interaction between boron and other elements in plants. *Genes*, *14*(1), Article 130. https://doi.org/10.3390/genes14010130

Marrocos, P. C. L., Loureiro, G. A. H. de A., de Araujo, Q. R., Sodré Andrade, G., Ahnert, D., Escalona-Valdez, R. A., & Baligar, V. C. (2020). Mineral nutrition of cacao (Theobroma cacao L.): relationships between foliar concentrations of mineral nutrients and crop productivity. *Journal of Plant Nutrition*, *43*(10), 1498–1509. https://doi.org/10.1080/01904167.2020.1739295

Milinković, M., Lalević, B., Jovičić-Petrović, J., Golubović-Ćurguz, V., Kljujev, I., & Raičević, V. (2019). Biopotential of compost and compost products derived from horticultural waste—Effect on plant growth and plant pathogens' suppression. *Process Safety and Environmental Protection*, *121*, 299-306. https://doi.org/10.1016/j.psep.2018.09.024

Pereira Leal, G., Siqueira, J. A., Batista-Silva, W., Cardoso Barcellos, F., Nunes-Nesi, A., & Araújo, W. L. (2021). Boron : More than an essential element for land plants ? *Frontiers in Plant Science 11*, Article 6100307. https://doi.org/10.3389/fpls.2020.610307

R Core Team (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.r-project.org/

Reyes Moreno, G., Fernández, M. E., & Darghan Contreras, E. (2021). Balanced mixture of biochar and synthetic fertilizer increases seedling quality of *Acacia mangium*. *Journal of the Saudi Society of Agricultural Sciences*, *20*(6), 371–378. https://doi.org/10.1016/J.JSSAS.2021.04.004

Rosa, A., Pereira, N., Martins Damaceno, F., & Zanão Júnior, L. A. (2022). Pig slurry improves the productive performance of eucalypt and exceeds the mineral fertilization. *Revista Arvore*, *46*, Article e4624. https://doi.org/10.1590/1806-908820220000024

Sardans, J., & Peñuelas, J. (2021). Potassium control of plant functions: Ecological and agricultural implications. *Plants*, *10*(2), Article 419. https://doi.org/10.3390/plants10020419

Siecińska, J., Nosalewicz, A. (2016). Aluminium toxicity to plants as influenced by the properties of the root growth environment affected by other co-stressors: A review. In P. de Voogt (Ed.) *Reviews of environmental contamination and toxicology* (vol 243, pp.1-26). Springer, Cham. https://doi.org/10.1007/398_2016_15

Smitha, J. K., Sujatha, M. P., & Sureshkumar, P. (2016). Availability and uptake of P from organic and in organic sources of P in teak (*Tectona grandis*) using radio tracer technique. *African Journal of Agricultural Research*, *11*(12), 1033–1039. https://doi.org/10.5897/ajar2014.9001

Sodré Andrade, G, & Gomes Sena, A. R. (2019). Cocoa propagation, technologies for production of seedlings. *Revista Brasileira de Fruticultura, 41*(2), Article e-782. https://doi.org/10.1590/0100-29452019782

Supriatna, J., Setiawati, M. R., Sudirja, R., Suherman, C., & Bonneau, X. (2022). Composting for a more sustainable palm oil waste management : A systematic literature review. *The Scientific World Journal*, *2022*, Article 5073059. https://doi.org/10.1155/2022/5073059

Takala, B. (2019). Soil acidity and its management options in Western Ethiopia. *Journal of Environment and Earth Science, 9*(10), 27-35. https://doi.org/10.7176/JEES/9-10-04

Viana Cunha, H. F, Andersen, K. M., Figueredo Lugli, L., Delgado Santana, F., Fonseca Aleixo, I, Martins Moraes, A., Garcia, S., Di Ponzio, R., Oblitas Mendoza, E., Brum, B., Schmeisk Rosa, J., Cordeiro, A. L., Tanaka Portela, B. T., Ribeiro, G., Deambrozi Coelho, S., Trierveiler de Souza, S., Siebert Silva, L., Antonieto, F., Pires, M., … Quesada, C. A. (2022). Direct evidence for phosphorus limitation on Amazon forest productivity. *Nature*, *608*(7923), 558–562. https://doi.org/10.1038/s41586-022-05085-2

Wang, N., Yang, C., Pan, Z., Liu, Y., & Peng, S. (2015). Boron deficiency in woody plants: Various responses and tolerance mechanisms. *Frontiers in Plant Science*, *6*, Article 916. https://doi.org/10.3389/FPLS.2015.00916

Zhang, Q., Song, Y., Wu, Z., Yan, X., Gunina, A., Kuzyakov, Y., & Xiong, Z. (2020). Effects of six-year biochar amendment on soil aggregation, crop growth, and nitrogen and phosphorus use eficiencies in a rice-wheat rotation. *Journal of Cleaner Production*, *242*, Article 118435. https://doi.org/10.1016/j.jclepro.2019.118435