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EVALUATION OF THE EFFECT OF TECNOSOL WITH CONSTRUCTION WASTE ON CORN GOWTH (Zea mays)

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Abstract*– The urbanization process has an impact on the inadequate disposal of construction and demolition waste (CDW), which impacts the reproductive capacity of soils because they are one of the main causes of degradation and contamination of this resource. For this reason, the present study aimed to determine the contribution of CDW, supplied by Construcciones Ecológicas, whose scope is all of Metropolitan Lima, for the elaboration of a technosol; assessing its quality through physicochemical parameters and analyzing the most efficient dose for the growth of hybrid corn under controlled conditions. The results of the characterization of the technosols for each of the three treatments (T) T1, T2 and T3 showed that the greater the CDW in its composition, the greater the number of carbonates, CEC and phosphorus; in addition, it has a basic pH and a higher apparent density. Thus, the selected treatment for dosage was T3, where physicial indicators of hybrid maize growth were assessed using different doses (D) of 3.33%, 6.67% and 10% (w/w) (D1, D2 and D3). The results showed that D2 had the highest values for PHPA, AP, PSR, and TR. Therefore, the study concludes that the technosol formulated with CDW provides favorable conditions for root size when 45% of CDW is included in its composition and applied at a dosage of 6.67% (w/w).

Keywords-- plant development, efficiency, technosol, waste

I. INTRODUCTION

Soil is a vital component of the Earth's crust, essential for human, animal, and plant life. However, over time, anthropogenic activities have significantly reduced its quality at an accelerated rate [1]. This is due to intensive land use, overgrazing, rapid urbanization, and improper disposal of construction and demolition waste (CDW). Therefore, CDW must be controlled as it represents a significant source of environmental pollution affecting soil, air, and water resources. Its impact is particularly evident due to the particulate matter released during demolition, handling, or processing, as well as the associated risks, such as landslides caused by blockages in urban watercourses. For this reason, it is crucial to reduce this type of waste and promote various reuse strategies that positively impact the recovery of degraded areas, with technosol being an alternative that addresses both objectives. These technosols, also referred to as "custom soils," are artificial soils composed of at least 20% inorganic waste manipulated by humans. They are designed to restore heavily contaminated areas in a shorter time than natural biological regeneration, thereby increasing productivity. Their technical composition is the primary factor in categorizing them within soil taxonomy [2]. In their formulation, different types of waste—such as metallic leachates, construction debris, and organic waste—are effectively managed according to the characteristics and purpose of the technosol being used [3].

For example, [4] reported that technosols can be formulated to have a high pH, high carbon content, or large proportions of coarse elements, which can improve the soil's physical properties (texture, structure, and organic matter) as well as its chemical composition and productivity [5]. Reference [6] developed a technosol based on construction and demolition waste to restore degraded urban plots, demonstrating that its application has positive effects on soil treatment, enhancing vegetation growth. Similarly, reference [7] created a technosol using CDW and garden waste to restore degraded areas and improve urban vegetation without affecting natural landscapes. Additionally, this mixture of CDW, compost, and wood waste provided favorable physicochemical conditions for the development of ornamental plants.

Latin America has experienced rapid urban growth in recent decades [8]. Peru is a notable case, where the construction sector has expanded significantly, becoming a key factor in the generation of construction and demolition waste (CDW) nationwide. This is due to the large volumes of excavation debris, infrastructure demolitions, and construction projects [9]. According to data from Reference [10], the construction sector has a concerning level of informal employment, reaching 71.1%. This situation directly affects compliance with CDW management regulations, as labor informality contributes to non-compliance with such standards. Considering technosols as a technological solution, this study aims to propose an alternative for CDW management. Thus, the objective of this research was to determine the contribution of CDW in the production of technosol, analyzing its quality through physicochemical parameters and evaluating the growth of hybrid maize using different technosol dosages.

II. MATERIALS AND METHODS

Study Area

The research was conducted in the locality of Macas, located in the Santa Rosa de Quives district within the Chillón River basin, Canta province, Lima – Peru. The area has an average temperature of 21 ± 0.5°C. The preparation of technosols was carried out at the HECOSAN Agroecological Farm, located in Macas at an altitude of 750 meters above sea level, with UTM coordinates 726184.70 mE – 8708404.70 mS, where agricultural and livestock activities take place. On the other hand, the cultivation and growth of hybrid corn were conducted at the Research Center of the Scientific University of the South, located in the district of Villa El Salvador, Lima – Peru, with UTM coordinates 284803.94 mE – 8648000.01 mS, where the experiment was carried out at an average temperature of 26°C.

Materials and Technosol Design

For the preparation of technosol treatments, organic residues such as cucumber stubble and goat manure from the locality were used, along with construction and demolition waste (CDW), mainly composed of ground concrete from masonry and excavation debris, which were collected from various locations in the Lima region and supplied by the company "Construcciones Ecológicas." The technosol design was based on the methodology of reference [6] with modifications. To achieve greater differentiation among the treatments containing ground concrete inputs, three treatments with different compositions were formulated and arranged in piles. All mixing proportions were determined by volume; thus, one treatment contained 15% (T1), another 30% (T2), and a third 45% (T3) of CDW (Table 1).

Table 1. Composition of the technosols. T: Treatment; Materials used: CM: recycled ground concrete; RP: cucumber stubble; EL: liquid manure; ES: solid manure.

Treatment	RP	ES	EL	CM
T1	22%	51%	12%	15%
T2	18%	43%	9%	30%
T3	15%	36%	4%	45%

Materials and Technosol Design

The materials described were used according to their composition for each treatment, considering a total weight of 200 kg. The materials were arranged in layers, from the deepest to the most superficial: cucumber stubble, solid manure, ground concrete, and liquid manure. These layers were repeated three to four times as necessary to complete the total weight. Finally, each treatment was covered with a plastic sheet to maintain internal conditions. The maturation time of the technosol was seven months until stabilization. During this period, temperature was monitored every 15 days, humidity was maintained at 60%, and turning movements were performed. Subsequently, samples from each treatment and a control sample (agricultural soil from the HECOSAN Agroecological Farm) were collected for further analysis.

Treatment Analysis

The physical and chemical characteristics of the treatments and agricultural soil were evaluated at the Scientific University of the South (UCSUR) and the Universidad Nacional Agraria La Molina (UNALM) in Lima, Peru. At the Water, Soil, Environment, and Fertigation Laboratory of UNALM, the following parameters were analyzed: pH, electrical conductivity, organic matter percentage (Walkley and Black method), and elements such as phosphorus (Modified Olsen Method), potassium (ammonium acetate extract), calcium carbonate (volumetric method), zinc, and copper (atomic absorption spectrophotometry). Additionally, at the laboratories of the Universidad Científica del Sur, physicochemical characteristics were evaluated, such as bulk density [11], porosity [12] and cation exchange capacity [13]. Furthermore, an analysis of elements such as lead (Pb) and chromium (Cr) was performed using atomic absorption spectrophotometry. This analysis aimed to assess potential health and environmental risks associated with CDW exposure, comparing results with the Soil Quality Standards established in Supreme Decree No. 011-2017-Ministry of the Environment [MINAM] (Perú).

Evaluation of Technosol in corn growth

Based on laboratory results, a preliminary comparative analysis of physicochemical parameters was conducted. Additionally, a multivariate analysis was performed using the InfoStat software [14] to determine the treatment with the most similar properties to agricultural soil (control group). The selected treatment was then used at the Research Center of the Scientific University of the South, where it was applied in doses of 3.33%, 6.67%, and 10% (w/w), mixed with a total of 3 kg of agricultural soil, and stored in 4 kg polypropylene pots with three replicates per dose.

Hybrid Corn Sowing

Hybrid corn "Dekalb 7508" was subsequently sown in pots. The seeds germinated in eight days, and their growth was monitored for four months. Each pot was standardized to contain three plants per unit after the first month of germination. Irrigation was carried out weekly with 300 mL of water, with variations of ±100 mL depending on meteorological fluctuations. The experiment lasted 120 days, during which the stem diameter (cm) was measured using a caliper; the height of the aerial part (cm) and root length (cm) were measured using a measuring tape. Additionally, the fresh weight (g) of the aerial and root parts was determined using an analytical balance. Subsequently, the dry biomass of both aerial and root parts was weighed after oven drying at 65°C for 72 hours.

Dose Analysis

The results were statistically evaluated using analysis of variance (ANOVA) with prior verification of normality and homogeneity of variance assumptions. A Tukey multiple comparison test was conducted among treatments that showed statistically significant differences ($p<0.05$). The statistical software used was SPSS version 21 for Windows [15]. Additionally, a Principal Component Analysis (PCA) was implemented as a complementary tool to explore covariation patterns among measured variables. The software used was InfoStat version 2020 [14].

III. RESULTS AND DISCUSSION

Physicochemical Characterization of Treatments

As shown in Table 2, T1 and T2 are characterized by low bulk density and high porosity, suggesting a looser structure, whereas T3 and agricultural soil (S.A.) exhibit higher bulk density with lower porosity. On the other hand, organic matter levels are higher in the technosol treatments, with T1 standing out for its elevated content. Additionally, the pH of the technosols is alkaline, while the agricultural soil presents a more acidic pH. The cation exchange capacity (CEC) is similar among the technosols but higher in the agricultural soil; where was followed by T3, this CEC es crucial for improving nutrient retention for plant development. Finally, in terms of electrical conductivity, T1 and T2 s how higher values compared to T3 and S.A. (Table 2).

Table 2. Physical and chemical characterization of the prepared technosol (T) and agricultural soil (S.A)

	Apparent Density ($g.cm^{-3}$)	Porosity (%)	Organic matter (%)	CIC (meq total/ 100g)	pH	CE ($dS.m^{-1}$)
T1	0,80	69,8	9,13	40,00	8,91	3,60
T2	0,82	69,1	7,73	40,00	8,81	3,22
T3	1,16	56,2	6,20	42,50	8,74	2,50
S.A	1,80	32,0	1,32	50,00	6,43	2,15

The analysis of physicochemical indicators among the treatments and agricultural soil, conducted through cluster and principal component analysis (PCA), provided key insights into the similarities and influencing variables of each substrate. In Fig. 1a, the dendrogram clearly shows that treatments T1 and T2 are the most closely related, sharing similar characteristics, and both maintaining partial similarity with T3. However, the agricultural soil (SA) forms a distinct cluster, indicating significant dissimilarity from the technosol treatments. In Fig. 1b, it can be observed that treatments T1 and T2 are grouped on the left side, suggesting they are mainly influenced by organic matter (OM) and porosity. On the other hand, pH does not seem to have a significant impact on any of the treatments, as it is located far from them. In contrast, bulk density (BD) and cation exchange capacity (CEC) show a greater influence on the SA treatment, as they have a shorter distance from it in the graph.

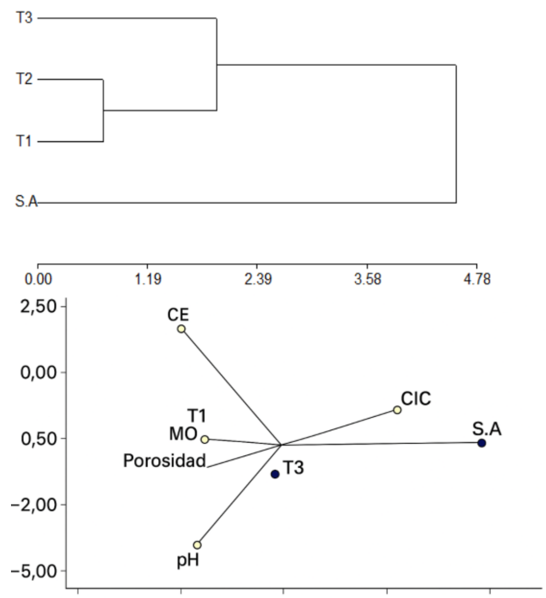

Fig. 1. Evaluation of the physico-chemical indicators between treatments (T1, T2 and T3) and A.S. by a statistical analysis of conglomerates and principal components analysis (PCA).

Research such as that conducted by reference [16] highlights the importance of restoring the specific characteristics and properties of technosols before they can be used for soil restoration with agricultural purposes. This process, which can take up to four years, is essential to ensure that the technosol functions as a restorative agent for degraded ecosystems. In this regard, the physicochemical characteristics of the technosol treatments were evaluated to understand and interpret their processes and behavior for agricultural use [17].

According to the results obtained, all bulk density values fall within the ideal range established by reference [18], which sets the range between 1.1 and 1.6 $g.cm^{-3}$. In the case of T3, the cation exchange capacity (CEC) in this technosol is the highest compared to the rest, meaning it tends to increase as the percentage of CDW (Construction and Demolition Waste) increases in the treatments. However, it does not reach the value obtained by the agricultural soil (AS). The source of the CEC results is attributed to a 15% contribution from clay minerals and an 85% contribution from organic matter due to the presence of humic and fulvic acids in the humus [19]. According to the reference [20], soils with a CEC range of 35-45 meq/100g are considered to have a medium-high level, making them rich soils for all evaluated treatments. This brings benefits such as nutrient retention, reduced leaching, and pH stabilization. Within this range, T3 has the highest value. Regarding pH, all treatments showed alkaline values above 8, which could affect the availability of essential nutrients such as iron, magnesium, and zinc [21]. Additionally, pH plays a crucial role in plant biological processes and microbial activity [7]. In terms of electrical conductivity (EC), it was observed that as the concentration of C&DW decreased, the salt concentration progressively declined (Table 2). According to FAO categories [22], values between 2 and 4 $dS\cdot m^{-1}$ are considered "moderately saline," placing all treatments and the control group within this category (Table 2). It is important to note that EC values in C&DW may be attributed to the presence of 2:1 structured mineral such as vermiculite and illite [23]. Likewise, reference [24] suggest that the presence of manure is a determining factor in achieving high EC values.

Nutrient Characterization in the Treatments

Table 3 shows that the treatments contain higher phosphorus concentrations compared to agricultural soil, with values ranging from 149.00 ppm in T1 to 153.55 ppm in T3. Similarly, the presence of calcium carbonate is also higher in the treatments, with T3 having the highest percentage (13.32%). Regarding potassium, its concentrations are higher in the treatments compared to AS. In the case of zinc, AS has values similar to T1; however, for copper, AS has higher values than the treatments.

Table 3. Nutrient characterization of the prepared technosol (T) and agricultural soil (S.A)

	Phosphorus (ppm)	Calcium carbonates (%)	Potassium (ppm)	Zinc (ppm)	Copper (ppm)
T1	149,00	11,99	32000	10,00	2,29
T2	152,35	12,44	21400	8,40	1,99
T3	153,55	13,32	17700	7,06	1,85
S.A	56,66	-	330	9,55	8,27

For nutrient characterization, it was observed that in all technosol samples, there is a trend where a higher concentration of CDW leads to increased phosphorus and carbonate content (Table 3). It is essential to highlight that phosphorus is one of the essential macronutrients for plant growth. According to reference [25], the total phosphorus concentration in agricultural soil should range from 149 to 555 ppm to facilitate plant metabolism, mediate carbohydrate synthesis, promote germination, and support root growth. Additionally, reference [26] states that phosphorus plays a role in energy transfer processes such as photosynthesis. The results obtained align with T3 (153.55 mg P/kg), indicating an adequate phosphorus content necessary to support these vital processes in plants.

Regarding carbonate results, their presence is closely related to the origin of the CDW used. According to reference [27], the most common carbonate concentrations in construction materials range from 15% to 35%. Additionally, their presence is due to calcium carbonate used in concrete production for its resistance properties [28]. This finding matches the observed trend of increasing carbonates as the amount of CDW in the technosol composition increases, with T3 containing the highest amount. The three results obtained fall within a normal range (10%-20%), which benefits soil structure and microbial activity [3]. Furthermore, reference [29] indicate that carbonate solubility decreases when pH is above 8, which is reflected in the results (Tables 2 and 3). However, it is crucial to mention that for healthy agricultural soil, carbonate levels must be controlled. Excessive carbonate accumulation can affect certain chemical and physiological soil properties, such as pore occlusion, potentially hindering root growth in plants [30]; [31]. It can also cause nutritional imbalances due to antagonistic relationships with other elements [3]. On the other hand, potassium levels significantly decrease among technosol treatments, although they remain higher than those in the agricultural soil sample (Table 3). Reference [32] note that due to the nitrogen and potassium content in goat manure, its amendment is classified as a nitro-potassic fertilizer, as these two nutrients contribute the highest nutrient percentages. This aligns with the potassium results (Table 3), as higher values were obtained in technosols containing greater amounts of goat manure, as observed in T1. Likewise, reference [33] demonstrated that potassium plays a role in root system development and stem diameter during plant growth in the vegetative phase. Therefore, higher potassium levels are expected to enhance plant growth. For copper and zinc, a continuous decrease in concentrations was observed in technosol treatments. However, in the case of agricultural soil, zinc concentration increases compared to T3, and copper concentration is higher than in all treatments (Table 3). Reference [34] evaluated organic amendments used in crop production, where manure-based amendments provided the highest nutrient supply. These findings align with the results obtained, confirm the relationship between increased manure content and a positive trend in nutrient concentrations such as copper and zinc. Reference [35] reported a trend of 53 ppm for zinc and 18.5 ppm for copper in agricultural soils. The values obtained in Table 3 are significantly lower than this trend. Thus, it is concluded that T3 exhibits the most favorable properties, improving the necessary conditions for plant development. It is the most representative treatment for progressing to the next stage of the study: technosol dosage and maize growth.

Toxicity Evaluation in Treatments

Regarding the concentration of heavy metals in the samples, it was found that higher amounts of ground CDW resulted in lower lead concentrations in technosol samples, ranging from 7.48 to 10.29 ppm. These values are well below Peru's soil environmental standard of 70 ppm [36]. Similarly, chromium concentrations in technosols were minimal and did not exceed standards, with a limit of 0.4 ppm and values below 0.05 ppm. Following the evaluation of physicochemical parameters, the results of the second stage of this study are presented. In this stage, the treatment that most closely resembles the conditions of agricultural soil—represented by T3 based on the characterized parameters—was selected for dosage evaluation.

Evaluation between doses per treatment according to indicators

Table 4 presents the variable measurements for different doses and control, along with significance differences based on ANOVA analysis.

Table 4. Results of the indicators evaluated between doses (D) and control (C). PHPA (Wet weight of the aerial part); PSPA (Aerial Dry Weight); c: PHR (Wet Root Weight); PSR (Root Dry Weight); TR (Root Size); AP (Plant Height); DT (Stem Diameter).

Treatment	p	Control	T3		
Sample			D1	D2	D3
PHPA	0,00	38,22 ±0,12	29,70±1,71	39,36±1,77	18,23±2,18
AP	0.00	94,88±0,12	95,02±5,74	103,42±3,26	78,18±3,48
PSR	0,23	3,91±0,12	4,37±0,31	7,11±0,42	3,73±0,43
TR	0,34	24,25±0,12	24,03±1,60	29,13±0,85	27,48±0,44
PHR	0,00	11,39± 0,12	9,01±0,44	5,1±0,50	6,63±1,06
PSPA	0,00	3,91±0,12	2,17±0,04	1,78±0,27	0,87±0,39
DT	0,47	1,08±0,04	1,06±0,06	0,99±0,05	0,99±0,03

As part of this study, PHPA showed significant differences (p<0.05) only between the control and D3; however, D2 exhibited a 3% increase compared to the control (Fig. 3a). AP showed differences (p<0.05) between D3 and all other groups; however, D2 showed a 9% increase without statistical differences compared to the control (Fig. 3b). PSR did not show significant differences (p> 0.05) between treatments or the control; even so, D2 exceeded the control value by 74% (Fig. 3c). A similar trend was observed for TR, where D2 exceeded the control by 20% without showing significant differences (p>0.05) (Fig. 3d). Regarding PHR, significant differences (p < 0.05) were observed between the doses and the control (Fig. 3e). In the case of PSPA, D3 differed (p<0.05) from the other doses and the control group, showing lower values. The remaining measurements had a DT with no statistical differences or variations in the recorded values.

The results show how maize growth varies when using different doses of technosol as part of its substrate, reflecting differences in plant growth. According to the evaluated literature, the importance of using technosols to improve soil quality for agricultural purposes lies in their ability to meet the necessary physicochemical conditions and parameters to enhance and optimize crop yields [6]; [37]. Given this, D2 showed a higher average value compared the control group (2a, b, c, d). However, after applying the corresponding statistical analysis, this difference was not significant (p>0.05).

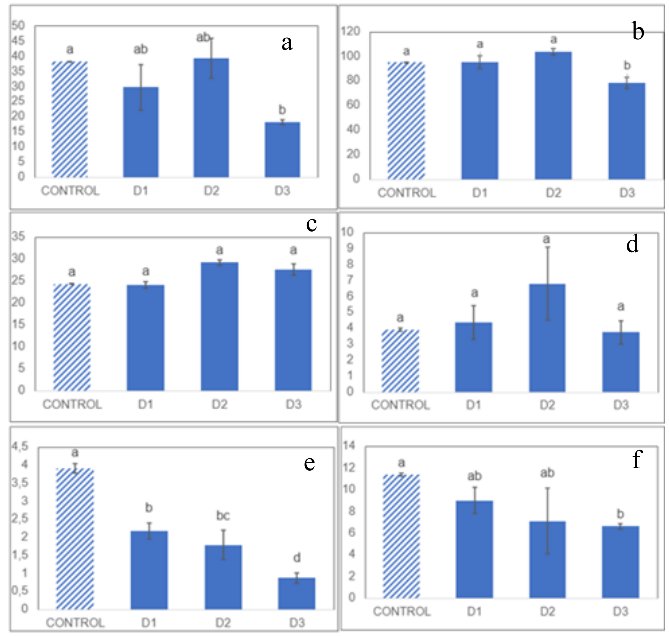

Fig. 3. Analysis of the indicators evaluated between doses (D) and control (C). a: PHPA (Wet weight of the aerial part); b: AP (Plant Height); c: PSR (Root dry weight); d: TR (Root Size); e: PHR (Root wet weight); f: PSPA (Dry weight of the aerial part). Different letters indicate significant differences using the Tukey post hoc test (p<0.05).

The following presents the principal component analysis. In this analysis, the results of PHR, PSPA, and DT are found to be related. Specifically, PSPA and DT show a strong association with the control group, while PSR, AP, and PHPA are also interrelated. For D1, PHR and PSPA stand out compared to the other parameters, although they exhibit low influence and align with the general trends of the dataset. In the case of D2, PSR and TR stand out due to their association, although it is not particularly strong. On the other hand, in D3, no parameters stand out for the given concentration, indicating that this dose differs significantly from the others (Fig. 4).

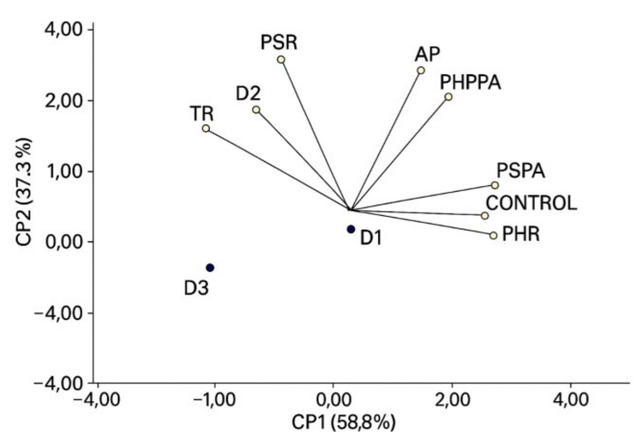

Fig. 4. Evaluation of the characterization of measured parameters of corn growth (D1, D2, D3 and Control) through a principal component analysis.

The results reveal which growth parameter is impacted when applying different doses in the experiment. The discriminant analysis indicated a positive correlation, attributed to the alignment of the vectors in the same direction (Fig., 4), in the case of PSPA for D1 and the control; however, the highest values are particularly attributed to D2 (Table 4), which exhibited higher PSPA, AP, PSR, and TR. These parameters stand out among those evaluated, suggesting that a dose of 6.67% p/p of technosol could be beneficial for ensuring the growth of maize organs. Regarding PSPA and AP, reference [38] mention that technosol, composed of construction and demolition waste, inert soil, and compost, is a viable option for improving soil quality. They observed an increase in the dry weight of the aerial part of two different species that grew under the mentioned technosol substrate compared to the control (Handroanthus impetiginosus and Copaifera langsdorf). Likewise, reference [46] found greater maize biomass by adding a calcium carbonate source to the substrate.

For PSR and TR, reference [39] revealed that nitrogen deficiency and water availability are key factors hindering root growth. In oligotrophic soils, plants typically develop less root biomass compared to more fertile soils, leading to elongation and thinning of roots, as these roots must explore larger soil volumes to meet the plant's nutritional needs [40] (Table 3). In this sense, numerous authors support the evaluation of technosols as an effective technology for restoring degraded and contaminated soils through recycling waste [20]. This study has long-term potential, using technosol for revegetation purposes, as recent studies [41]; [23]; [42] demonstrate that constructed technosols can provide an efficient substrate for planted and native plants free from deficiency symptoms; therefore, these artificial soils could be an ecological medium for recovering a degraded state [16]).

IV. CONCLUSIONS

This research concludes that the use of construction and demolition waste (CDW) as input for the preparation of technosols can improve the quality of soil for agricultural purposes in a specific composition, due to the values obtained in bulk density, CEC, and EC. In this sense, treatment (T3) was selected to be used in the maize dosing and germination due to its adequate phosphorus content and high levels of essential carbonates for healthy plant development, as well as for the growth of the plant and leaves. Regarding the evaluation of the applied doses and hybrid maize growth, it was concluded that the D2 dose showed a higher value in PHPA, AP, PSR, and TR compared to the control, without showing statistical differences. Therefore, the results indicate that the technosol made with CDW provides favorable conditions for root size when 45% CDW is used in its composition (T3) and a dose of 6.67% (p/p) is implemented. For future studies, it is recommended to work with more repetitions and increase the maturation time of the technosol, which will allow for robust validation of the findings through more detailed statistical analyses.

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