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Use of chicken manure ash with the addition of Portland cement for the improvement of clayey subgrades

TRABAJO DE INVESTIGACIÓN PARA OPTAR EL GRADO ACADÉMICO DE BACHILLER EN INGENIERÍA CIVIL AMBIENTAL

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Resumen

Este artículo nace ante el menester de nuevos materiales aprovechables que puedan ser eficaces y cumplan con las propiedades requeridas para el mejoramiento de suelos de baja calidad y así compensar la contaminación ambiental; por ello, se propuso el uso de gallinaza como material sustituto de aditivos usados frecuentemente en el mejoramiento de suelos arcillosos. En esta investigación se pretendió hacer uso de un material producto de criaderos de gallinas y/o pollos y así encontrar el porcentaje óptimo de adición para mejorar la baja capacidad portante (CBR), ensayando adiciones de ceniza de gallinaza (2%, 4% y 6%) junto con 1% de cemento portland tipo I. Para lograr este objetivo se analizó la temperatura óptima de calcinación de la gallinaza y las propiedades químicas de la ceniza de este producto. Durante el procedimiento experimental se llevó a cabo ensayos para determinar las propiedades físicas y químicas del suelo, obteniendo que el porcentaje de adición óptima fue de 4% + 1% alcanzando un incremento significativo de CBR y categorizándose como Sub rasante Excelente (CBR= 31.15% al 95%M.D.S.) según la normativa peruana, teniendo como mínimo un CBR ≥ 6 correspondiente a una subrasante regular.

Palabras clave: Mejoramiento de subrasantes, Suelos arcillosos, Ceniza de gallinaza, Estabilización de subrasante, CBR.

Abstract

This article arises from the need for new usable materials that can be effective and meet the required properties for improving low-quality soils, thus mitigating environmental pollution. Therefore, the use of poultry manure (gallinaza) as a substitute material for additives frequently used in the improvement of clayey soils was proposed. This research aimed to utilize a material derived from chicken and/or poultry farms to determine the optimal percentage of addition for enhancing the low bearing capacity (CBR) by testing various additions of gallinaza ash (2%, 4%, and 6%) along with 1% of Portland cement type I. To achieve this objective, the optimal calcination temperature of the poultry manure and the chemical properties of the resulting ash were analysed. During the experiment's development, tests were conducted to evaluate the physical and mechanical characteristics of the soil. The optimal addition percentage was found to be 4% + 1%, resulting in a significant increase in CBR and categorizing it as an Excellent Sub-grade (CBR = 31.15% at 95% M.D.S.) according to Peruvian regulations, with a minimum CBR ≥ 6 corresponding to a regular sub-grade.

Keywords: Clayey subgrade, Clayey soils, Chicken manure ash, Subgrade stabilization, CBR.

Introduction

The inadequate quality of clayey soils has been a major problem in maintaining transport routes in optimal conditions, as they fail to provide the necessary stability to support structures. In the case of moisture, clay soils are influenced by various factors such as evaporation and precipitation distribution, plasticity, permeability, and groundwater depth, which are challenging to control and often lead to cracks in buildings [1].

A clayey soil has the ability to expand due to its chemical and mineralogical composition. That is why several alternative solutions have been proposed for improving this type of soil in order to give it a structural use, such as soil replacement, soil stabilization, moisture-density control, drainage, structural methods, among others [2].

Among the numerous products recommended for chemical stabilization, the most commonly used ones are lime, cement, asphalt, and a wide range of chemicals [2]. Due to this, there is a search for new products that meet the necessary conditions to replace these materials, which are known to emit large amounts of CO2. Additionally, the variety of raw materials required for their production has become a global issue [3-5].

On the other hand, fresh poultry manure can cause harm to those living near poultry farms as it contains hydrogen sulfide (H2S) and other harmful organic compounds [6]. However, with proper management and various treatment processes, these excreta can be turned into an alternative to mitigate negative impacts while adding significant value [7-18]. Agricultural and poultry waste is being utilized to enhance the mechanical proper-ties of concrete, mortar, and clay soils [8-18]. Studies have con-firmed the feasibility of using these materials, which, when calcined at high temperatures, exhibit high pozzolanic activity, even capable of substituting Portland cement [4,8,19].

In view of the above, it is expected that the incorporation of poultry manure ash with a small addition of Type I Portland cement will improve the mechanical and physical properties of clay subgrades. Therefore, the objective of this research is to enhance clay subgrades through chemical stabilization using a new product called "poultry manure ash" in conjunction with Portland cement. For this purpose, a study area has been delimited in the city of Chiclayo, taking into consideration the expansive potential of the soil, low strength, and evidence of poor-quality clay soil. The results obtained were significantly favorable, increasing the CBR from 5.57% to 31.15% at 95% M.D.S., classifying the improved subgrade as excellent according to the Highway Manual: Soils, Geology, Geotechnics, and Pavements [20].

To achieve this, the natural samples will be characterized, the poultry manure ash aggregate will be classified, percentages of 2%, 4%, and 6% of poultry manure ash with 1% of Type I Port-land cement will be added, and finally, a comparison of the changes produced between the sample without addition and the sample with addition will be presented using tests such as sieve analysis, modified Proctor, Atterberg limits, and California Bearing Ratio (CBR) described in the Materials Testing Manual [21].

Methodology

To carry out this research, a non-probabilistic sampling method has been used since the selection of samples depends on the criteria specified in the CE.010 Urban Pavements regulations, such as low bearing capacity and poor subgrade characteristics. Table 1 shows the minimum number of research points according to the type of road they belong to.

Table 1. Number of points according to the type of Road.

Type of track	Minimum number of research points	Area (m^2)
Express	1 each	2000
Arterial	1 each	2400
Collector	1 each	3000
Local	1 each	3600

Source: CE.010 urban pavements

The streets in La Primavera housing development are of local type and include both paved and unpaved roads. For the purpose of this study, the area encompassing the following streets has been selected: Pauro, Sicuani, Sandia, Acomayo, Quillabamba, Urcos, and Yauri; all of which are unpaved. Table 2 displays the measurements (length and width of roadway) of the selected streets, as well as the total area they cover:

Table 2. Calculation of research points.

Unpaved roads	Road width (m)	Road length (m)	Partial area (m^2)
Pauro	8	128	1024
Sicuani	8	181	1448
Sandia	8	45	360
Acomayo	8	45	360
Quillabamba	8	78	624
Urcos	8	126	1008
Yauri	8	83	664
		Total area	5488

The number of study points will be the quotient between the calculated total area and the area according to the type of road (Table 1), resulting in 1.5 study points. However, the minimum number of study samples is 3.

Sampling of Subgrade Soil

Three excavations were conducted to obtain disturbed samples of clayey subgrade soil from La Primavera urbanization, Chiclayo district and province. Regarding the distribution of the points, their location will be determined conveniently and proportionally to obtain a representative sample in the study area. The sample extractions were carried out at the intersections of Sandía and Urcos streets, Sicuani and Yauri streets, and Yauri and Pauro streets (Figure 1) with a depth of 1.50m and an excavation area of 1.00m x 1.00m.

Figure 1. Location of test pits.

Process of obtaining chicken manure ash

Fresh chicken manure was obtained from a poultry farm called "Agropecuaria Carpinaz", located along the Pimentel - San José highway. After a thorough inspection of the product, it was determined to be free of impurities, and a representative sample of 30kg was extracted.

The fresh poultry manure was then air-dried to reduce its moisture content as much as possible, and subsequently subjected to the Differential Thermal Analysis test to determine the optimal calcination temperature for the manure. Additionally, the X-ray Fluorescence Spectrometry test (Figure 2) was performed to analyze the chemical composition of the poultry manure ash.

Figure 2: Data Collection at "Agropecuaria Carpinaz".

To prepare the specimens, the sample was sieved through a No. 50 mesh, and a quartering technique was employed to obtain characteristic samples for each test.

Dosage of poultry manure ash and Type I Portland cement

Based on the reviewed national and international literature, it was decided to study additions of 2%, 4%, and 6% of poultry manure ash and 1% of Type I Portland cement in order to improve the physical and mechanical properties of the clayey subgrade.

The extracted natural samples were examined, and it was determined that the excavation with the lowest CBR value at 95% was Excavation No. 3 with a value of 5.6%, classifying it as a low plasticity clayey soil with A-6(9) sand (Table 4). For mass dosing, the amount in grams that fits a Proctor and CBR mold is taken as reference (Table 3); and similarly, for the other tests, the weight proportion will be used according to the specific test being conducted.

Table 3. Weight dosage for Modified Proctor and CBR tests.

Sample	Natural soil (g)	Poultry manure ash (g)	Type I Portland cement (g)
100% SN + 0% SACG + 0% SACI	5500	0	0
97% SN + 2% SACG + 1% SACI	5335	660	330
95% SN + 4% SACG + 1% SACI	5225	1320	330
93% SN + 6% SACG + 1% SACI	5115	1980	330

Where:

- SN: Natural Soil
- SACG: Soil Added with Chicken Manure Ash
- SACI: Soil Added with Portland Type I Cement

Tests conducted

The following tests were conducted in accordance with the current Peruvian regulations, both for the samples without addition and for the three samples added with Poultry Manure Ash plus Type I Portland cement:

- Granulometry (MTC E107)
- Moisture content (MTC E108)
- Atterberg limits (MTC E110, E111)
- Modified Proctor (MTC E115)
- California Bearing Ratio (CBR) (MTC E132)

Justification of the research

The research aims to explore a new approach in soil stabilization by examining the potential benefits of using and applying waste produced by poultry farms in the improvement of substrates with low bearing capacity for pavement. Additionally, this study has the potential to address environmental and visual pollution issues by utilizing this input, which in its fresh state emits foul odors and contaminates soil and water.

By harnessing the potential of these waste materials, the aim is to mitigate the adverse effects on the environment and reduce the spread of diseases associated with soil contact. In summary, this study aims to provide an innovative solution that benefits both the improvement of the soil's physical and mechanical characteristics (subgrades) and the preservation of the natural environment.

Results

The results of the tests carried out to characterize and classify the clayey soil samples without addition are described in Table 4. It can be observed that all the CBR values are lower than 7%, indicating that the subgrade is considered inappropriate according to the Highway Manual. The test pit with the lowest 95% support capacity at 0.1" was test pit 3, with a value of 5.6%, indicating that it is the most unfavorable sample in terms of support capacity. Therefore, this sample will be selected to carry out soil improvement by adding poultry manure ash with Type I Portland cement and evaluate the effect on the increase or de-crease in the support capacity of the studied soil.

Table 4. Results of physical and mechanical tests on natural samples.

Test	**Samples**		
	C1	**C2**	**C3**
Moisture content (%)	9.43	21.08	13.31
Sieve analysis			
SUCS	CL	CL	CL
AASHTO	A-6 (8)	A-6 (10)	A-6 (9)
Plasticity index	13.68	14.58	14.89
Modified Proctor test			
Maximum dry density (gr/cm3)	1.85	1.86	1.91
Optimum moisture content (%)	13.3	13.3	14.84
CBR (0.1") al 95%	6.8	6.4	5.6

The results obtained from the Differential Thermal Analysis (DTA) and Thermogravimetric Analysis (TGA) tests can be observed in Figure 3. For analysis purposes, a range of 25 to 920°C was evaluated, revealing that the mixture composed of chicken manure ash had an ash percentage of 0.26% according to the burn emission analysis. Additionally, it can be observed that the thermogravimetric analysis shows a peak temperature of 522.5°C for chicken manure ash over a period of 2 hours.

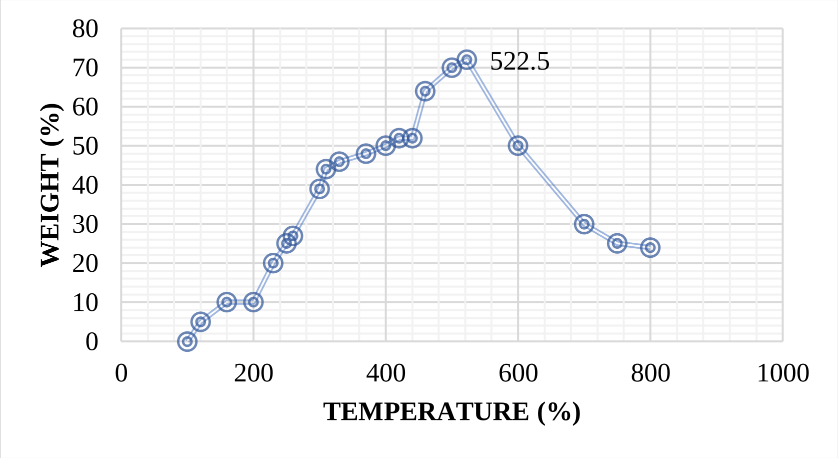

Figure 3: TGA and DTA Curve.

Table 5 presents the chemical composition of the chicken manure ash determined through X-ray Fluorescence Spectrometry analysis. When comparing the spectrum of the analyzed sample with the characteristic energies of the elements from the periodic table starting from sodium, mainly silica (Si), calcium (Ca), potassium (K), and aluminum (Al) were identified with a high percentage. In lower percentages, phosphorus (P), iron (Fe), magnesium (Mg), manganese (Mn), copper (Cu), sulfur (S), and zinc (Zn) were found.

The analyzed sample was sieved through mesh No. 200, and based on the chemical elements present in the periodic table, it can be affirmed that the addition will improve the soil's mechanical properties.

Table 5. Chemical composition of chicken manure ash.

Chemical composition	**Results (%)**	**Method Used**
Silicon Dioxide (Si O2)	47.59	X-ray Fluorescence Spectrometry
Calcium Oxide (Ca O)	14.33	
Aluminum Trioxide (Al2 O3)	11.84	
Iron Trioxide (Fe2 O3)	6.14	
Potassium Oxide (K2 O)	8.96	
Magnesium Oxide (Mg O)	1.17	
Phosphorus Pentoxide (P2O5)	3.97	
Copper Oxide (Cu O)	0.68	
Sulfur Trioxide (SO 3)	0.02	
Zinc Oxide (Zn O)	0.018	
Manganese Oxide (Mn O)	0.01	
Loss on Ignition	5.27	

Figure 4 demonstrates that adding 4% or more of chicken manure ash with 1% of Portland Type I cement results in a decrease in the plasticity index. The untreated sample shows a value of 14.89%, while with a 6% improvement, it decreases to 13.74%, falling into the category of medium plasticity, which is characteristic of clayey soils. According to the highway manual, a plasticity index between 7 and 20 corresponds to a soil with medium plasticity, and a plasticity index greater than 20 corresponds to a highly plastic clayey soil.

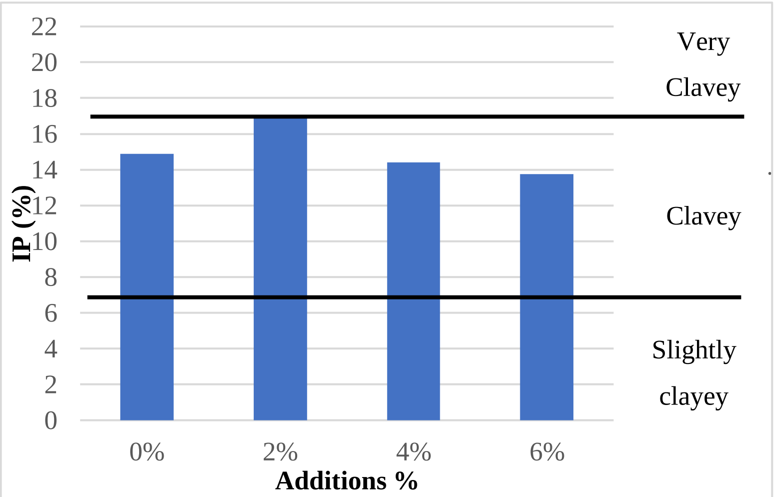

Figure 4: Plasticity Index Results.

The results of the Modified Proctor test are measured in terms of the optimum moisture content and the maximum dry density. Figure 5 shows that as the dosage of gallinaza ash with Portland Type I cement increases, the moisture content decreases. Considering that higher moisture content results in greater compaction energy and therefore lower bearing capacity, it can be observed that by incorporating the additives, the moisture content decreases from 14.84% to 11.54% with a 6% addition. Similarly, Figure 6 demonstrates a decrease in the maximum dry density, which starts to increase again when 4% of gallinaza ash is added.

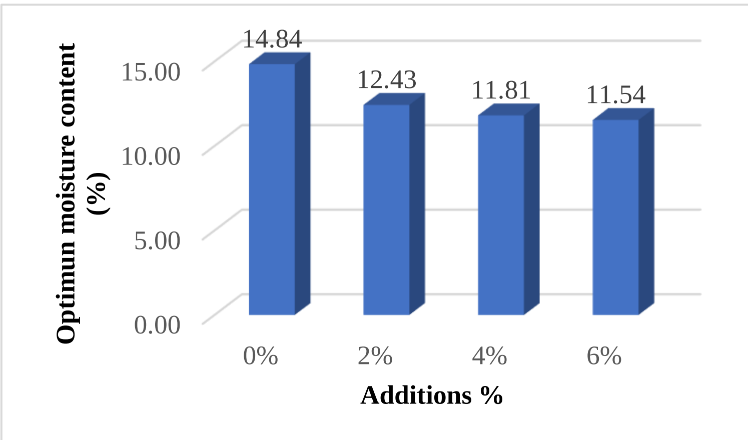

Figure 5: Optimum Moisture Content Results in Percentage.

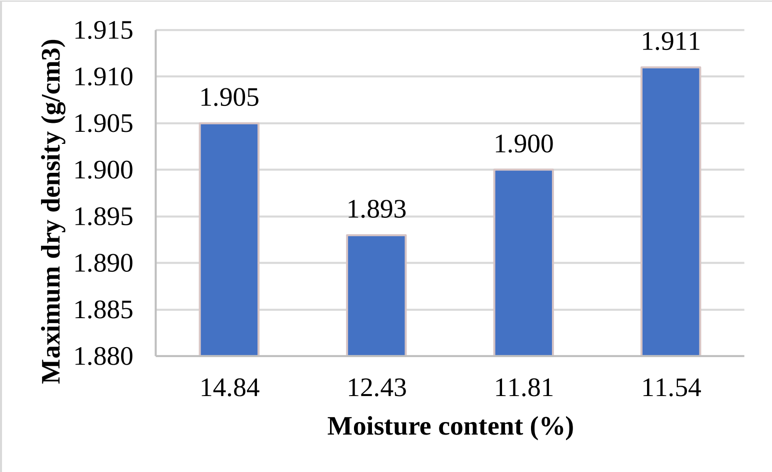

Figure 6: Results of maximum dry density

Figure 7: Results indicating that the inclusion of chicken manure ash and Portland cement type I significantly improves the bearing capacity of a clayey soil, with an increase of up to 25.5% in this capacity. The obtained bearing capacities classify the soil as Very Good Subgrade (CBR ≥ 20% to CBR < 30%) and even as Excel-lent Subgrade (CBR ≥ 30%) from an Insufficient Subgrade (CBR ≥ 3% to CBR < 6%) according to the highway manual.

The combination that showed the highest bearing capacity at 95% at 0.1" was the one with a 4% addition, reaching a value of 31.15%. Therefore, it can be stated that this percentage of addition is the best in terms of bearing capacity.

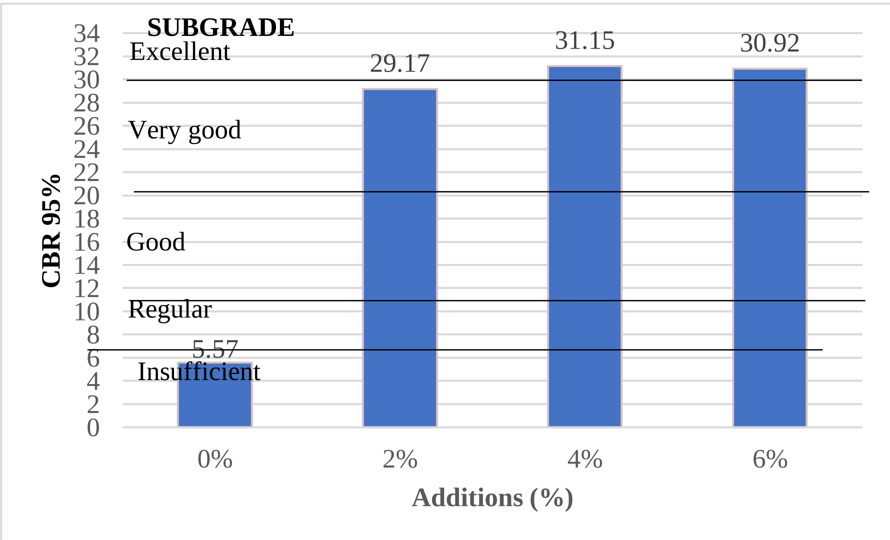

Figure 7: Results of CBR at 95% at 0.1".

The results of the physical and mechanical tests conducted on the sample without addition and the samples with additions of poultry manure ash and Portland cement type I are presented in Table 6. It can be observed the significant improvement of the mechanical properties and to some extent, the improvement of the physical properties of the clayey subgrade.

Table 6. Results of physical and mechanical tests of samples with additions of poultry manure ash and Portland cement type I.

Test	**Samples C3**			
	0%	**2%**	**4%**	**6%**
Plasticity index	14.89	16.87	14.41	13.74
Modified Proctor test				
Maximum dry density (gr/cm3)	1.905	1.893	1.900	1.911
Optimum moisture content (%)	14.84	12.43	11.81	14.54
CBR (0.1") al 95%	5.57	29.17	32.15	30.92

Conclusions

The use of poultry manure ash in combination with Portland cement has proven to be a highly effective solution for improving the quality of clay subgrades. The obtained results have been very encouraging, demonstrating that this alternative represents a significant advancement in the field of civil engineering. Moreover, the use of poultry manure ash not only contributes to improving soil quality but is also beneficial for the environment, making this technique highly valued. In summary, the utilization of poultry manure ash and Portland cement is a new alternative for improving clay substrates that deserves to be considered and further studied.

- In conclusion, the results obtained from the Differential Thermal Analysis (DTA) and Thermogravimetric Analysis (TGA) tests demonstrate that poultry manure ash has significant thermal properties that can be useful in various industrial applications. The evaluation within a temperature range of 25 to 920°C shows that poultry manure ash has a low ash percentage and a maximum temperature peak at 522.5°C, indicating its capacity to withstand high temperatures. Similarly, the chemical analysis performed using X-ray Fluorescence Spectrometry on the poultry manure ash has revealed the presence of several important elements. These tests support the potential of poultry manure ash as a suitable material for implementation in soil improvements and highlight its relevance in engineering and construction.

- It is concluded that as the dosage of poultry manure ash with Portland cement type I increases, the moisture content decreases. This is significant, as higher moisture content can result in lower load-bearing capacity due to reduced compaction energy. Therefore, the decrease in moisture content upon adding the additives is favorable for improving the soil's load-bearing capacity. It is worth noting that with a 6% addition, the moisture content decreases from 14.84% to 11.54%. These findings are relevant to the study and the field of engineering, as they demonstrate that the incorporation of poultry manure ash and Portland cement type I can have significant effects on the moisture content and maximum dry density of the soil.
- The obtained results of load-bearing capacity classify the soil as Very Good or even Excellent, which is beneficial for road construction and other infrastructure projects. Furthermore, it is concluded that the combination that showed the best load-bearing capacity was the one with a 4% addition, as analyzing the data of load-bearing capacity at 95% at 0.1" yields a value of 31.15%; suggesting that this percentage of improvement is optimal in terms of load-bearing capacity.
- Finally, it is concluded that these findings can be useful in formulating new materials for various applications, as well as in developing more efficient and environmentally-friendly technologies. Moreover, these results provide a solid foundation for further research and optimization of the admixture blends in pursuit of effective soil property enhancement.

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