Changes in fertility and microbial respiration in acid sandy soil amended with uncharred and charred poultry litter

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Abstract

Poultry litter application is an option in improving soil fertility of acid sandy soils although over application may promote environmental problems. Pot and laboratory experiments using uncharred (UPL) and charred poultry litter (CPL) at 4 levels (10, 20, 30, and 40 g kg^{-1} soil) were carried out to evaluate their direct and residual effects on the fertility and microbial respiration in acid sandy soil. Peanut was used as the test plant. At 10 and 20 days of incubation (DOI), a linear trend on the direct effects of levels regardless of the type of poultry litter was noted on soil pH_{H2O}, organic C (OC), total N, and extractable P. Exchangeable Al and acidity on the other hand, significantly decreased with increasing rates of either UPL or CPL poultry litter. Interaction of types and levels of poultry litter also resulted in a significant change on soil pH_{CaCl2}, exchangeable acidity, OC, and total N at 10 DOI but at 20 DOI, significant change was only noted on soil pH_{CaCl2} and OC. The residual liming benefit of CPL was superior to UPL. In general, the direct effects of application of uncharred or charred poultry litter resulted in better plant growth, nodulation, biomass, and N and P uptake than the control plants. The direct effects of UPL application resulted in a greater amount of CO_2 evolved than CP. The above results indicate that converting raw poultry litter into char may play an important role in reducing C emissions associated with organic matter enhancement practices and increasing C stocks in acid sandy soils.
Keywords: uncharred poultry litter, charred poultry litter, acid sandy soil, soil fertility, microbial respiration.

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1 Introduction

Inappropriate land use often leads to declining soil quality and productivity. Without appropriate soil management, continuous use of agricultural land hastens breakdown of soil organic matter (SOM). This important soil component, SOM, plays a major role in soil fertility [1] since it controls many chemical, physical, and biological properties that affect the ability of soil to supply nutrients. Intensive cultivation of soils with low organic matter such as acidic sandy soils often results in rapid soil fertility decline.

Sandy soils are coarse textured and often have low organic matter content which may lead to low nutrient holding capacity and nutrient deficiencies [2]. To make sandy soils fertile, high levels of external inputs are needed. However, this has environmental implications especially in areas under high rainfall or in irrigated agriculture. Due to its considerable amount of organic matter, poultry litter can be a valuable source of plant nutrients and amendment for sandy soils. Poultry litter is rich in nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and micronutrients [3]. In the Philippines, broiler litter is estimated to reach 1.18 million metric tons yearly [4]. Such amount of supply for use as soil ameliorant is promising as it simultaneously addresses the problem of waste disposal and the issues of rising costs of inorganic fertilizer.

Poultry litter, due to its low nutrient content, has to be applied in very large quantities. Hence, its application is time-consuming and may create odor problems. Also, poultry manure in unmodified form may contain contaminants such as residual hormones, antibiotics, pesticides, and pathogens [5]. These problems associated with the application of raw manure may be overcome by converting it to biochar [6, 7].

Biochar is the solid carbon-rich product obtained when biomass is heated at high temperatures (350–700°C) under limited supply of oxygen in a process called pyrolysis. Through charring, the volume, weight, and bad smell of the material can be significantly reduced which is very important in managing farm and livestock waste [8]. There is increasing evidence that application of charred materials improved soil fertility and microbial activity due to added organic matter [9–11].

While biochar additions are able to improve soil fertility, soil strength and water-holding capacity of sandy soil [12], little is known about the effects of poultry litter char on microbial respiration and chemical properties of acid sandy soils. Relatively little information is available on the comparison of the agricultural and ecological value of uncharred and charred broiler litter. The general objective of this study was to compare the effects of uncharred and charred poultry litter on chemical and biological fertility of acid sandy loam soil through pot and laboratory experiments. Specifically, this study compared the effects of application of varied levels of uncharred and charred poultry litter on the changes in physico-chemical properties and microbial respiration of acid sandy soil as well as nodulation, nutrient uptake and growth of peanut. Proper level of these organic materials is also very crucial in its application to plants. It is hypothesized that charred broiler litter is a better alternative in enhancing the fertility status of acidic sandy soils.

2 Methods

2.1 Soil and soil analyses

Acid sandy soils (from Caiyanohan, Southern Leyte, Philippines) were collected randomly at a depth of 0–20 cm, placed in a plastic bucket, thoroughly mixed, and air-dried for five days. Samples were then passed through a 4-mm wire screen. Sub-samples of about 1 kg were subsequently taken for determination of initial chemical properties and the rest was prepared for the laboratory and pot experiments. Soils were then tested for their chemical properties. The methods and results of these analyses are summarized in Table 1.

Table 1: Initial properties of the soil.

Property	Method	Value
pH (1:2.5 soil to H_2O)	Potentiometric [13]	4.93
pH (1:2.5 soil to 0.01 M $CaCl_2$	Potentiometric [13]	4.39
Exchangeable Al (meq 100 g^{-1} soil)	Potassium chloride [14]	2.88
Exchangeable Acidity (meq 100 g^{-1} soil)	Potassium chloride [14]	3.08
Organic carbon (%)	Modified Walkley Black [15]	0.98
Total N (%)	Modified micro-Kjeldahl [16]	0.16
Extractable P (mg kg^{-1} soil)	Olsen extractant [17] and quantified by Ascorbic acid method [18]	1.53
Exchangeable bases (meq 100 g^{-1} soil)	Ammonium acetate method [19]	
K		0.25
Ca		3.57
Mg		1.38
Na		0.15
$CEC_{Effective}$ (meq 100 g^{-1} soil)	Ammonium acetate method [19]	8.43

2.2 Poultry litter and char processing

Poultry litter was air-dried for 5 days and sieved through 2-mm mesh. It was subsequently taken for moisture content determination and the rest was used for chemical analysis, char processing and laboratory and pot experiments. The sieved poultry litter was charred using Top Lit Updraft Double Barrel processing method with minor modifications. Briefly, 8 kg of air dried (11.07% moisture content) poultry litter was placed into a tin can measuring 35 cm in height × 20 cm diameter (the carbonization chamber) at about ¾ height of the can. The tightly covered carbonization chamber was placed in a drum measuring 80 cm in height × 40 cm diameter (the combustion chamber) with three holes (measuring 5 cm diameter) at its lower side. Three small cans measuring 5.8 cm in height × 5.2 cm diameter was placed under the carbonization chamber to facilitate airflow. Once the feedstock and carbonization chamber were in place, the combustion chamber was filled with rice hull and wood chips at 3:1 ratio which acted as the combustion fuel (Figure 1). The fuel was lit from the top at various points around the diameter of the combustion chamber to achieve an even burn. After a few minutes, a tin lid with a chimney (measuring 62 cm height × 8 cm diameter) at the center was placed on top of the drum to achieve a sufficient draft for a clean burn. The fuel was then left to burn to convert the feedstock to char which took about 6 hours. The temperature during the 6-hour period was monitored every 10 minutes using a thermometer attached to the external wall of the combustion. Analyses of charred poultry litter (UPL) and charred poultry litter (CPL) is shown in Table 2.

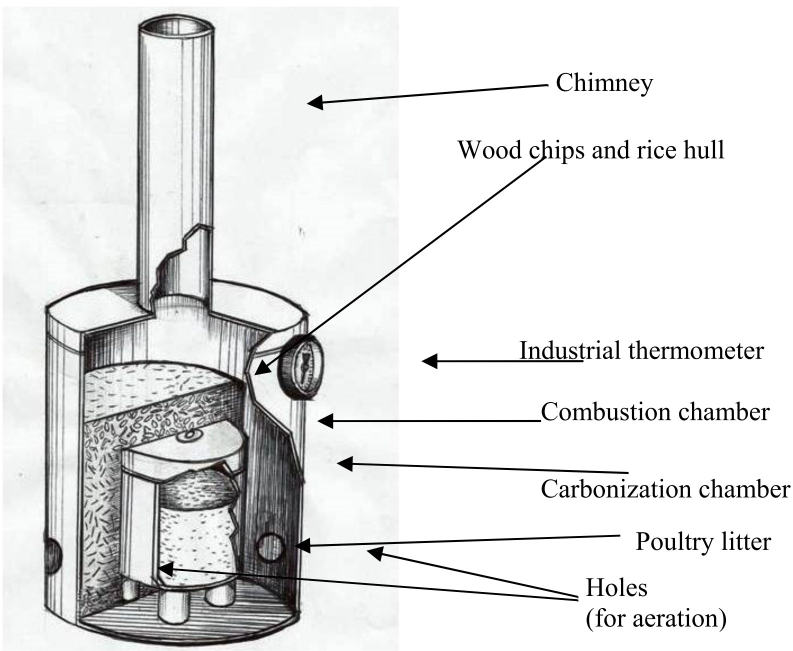

Figure 1: Pyrolyzer chamber during the charring of poultry litter.

Table 2: Chemical properties of uncharred poultry litter (UPL) and poultry litter char (CPL).

Property	UPL	CPL
pH (1:2.5 soil to H_2O)	8.00	10.89
pH (1:2.5 soil to 0.01 M $CaCl_2$)	7.17	10.84
Organic C (%)	13.26	15.78
Total N (%)	2.31	1.88
Total P (%)	2.08	2.89
Total K (%)	4.15	4.09
Total Ca (%)	3.90	10.32
Total Mg (%)	1.15	1.17
Total Na (%)	5.18	4.97
Total Cd (mg kg^{-1})	28.50	27.50
Total Pb (mg kg^{-1})	550.00	540.00

2.3 Experiment 1: effects of uncharred and charred poultry litter and its residuals on some chemical properties and on the growth, nodulation and yield of peanut in acid sandy soil

Two sets of pot experiment were conducted using peanut "biotest" to compare the effects of uncharred and charred poultry litter on soil chemical and biological fertility. The changes in soil fertility were measured as function of changes in physico-chemical properties soil after application of poultry litter (before and after planting), nodulation, nutrient uptake and growth of peanut were used only in the first experiment while the second experiment evaluated the residual effects of the treatments on peanut. Poultry litter treatments were applied only in the first experiment while the second experiment evaluated the residual effects of the treatments on peanut by repeating the experiment without application of amendments and inoculation. Peanut plants in the first pot experiment were harvested 45 days after planting, while the second pot experiment were harvested 95 days after planting.

During the incubations, soil pH (both H_2O and $CaCl_2$ diluents), exchangeable acidity and aluminium, organic C, total N, and extractable P at 10 days after application of amendments were analyzed. At 20 days, in addition to the above mentioned soil chemical properties, exchangeable Ca, Mg, K and Na were determined. Plant tissue at first pot experiment were analyzed for total N and P.

A 2 × 4 factorial experiment was carried out in a protective-house with UV-treated plastic film roofing of Department of Horticulture, Visayas State University, Baybay, Leyte Philippines. The factors were two types of poultry litter (uncharred and poultry litter) and four levels of amendment (10, 20, 30 and 40 g kg^{-1} soil). A control treatment (without an amendment) was included. The treatments were replicated four times and laid out in Randomized Complete Block Design. The sieved poultry litter (<2-mm) was applied at levels specified in the treatment on an oven-dried weight basis to air dried sieved soil (equivalent to 8 kg soil on oven dry weight basis). Three peanut seeds (UPL-Pn 10) inoculated with

Rhizobium spp were sown into previously made hole with 5 g of Mycovam (mixture of soil and spores of fungi belonging to Genus *Glomus*) in each potted soil. Blanket application of 15 mg each of N, P_2O_5 and K_2O kg^{-1} soil using urea, solophos and muriate of potash was done as starter fertilizer.

2.4 Effects of uncharred and charred poultry litter and its residuals on microbial respiration of acid sandy soils

To investigate the effect of uncharred and charred poultry litter on microbial respiration, two laboratory incubation experiments were carried out. The measurement of soil CO_2 respiration is a means to gauge biological soil fertility. The first incubation experiment used the same air-dried samples in the first pot experiment while the second experiment used the post-harvest soil samples from second pot experiment.

A 2 × 4 factorial experiment was carried out in the Soil Microbiology laboratory of the Department of Agronomy and Soil Science, Visayas State University, Visca, Baybay City, Leyte, Philippines. The factors were two types of poultry litter (uncharred and charred) and four levels of amendment (10, 20, 30, and 40 g kg^{-1} soil). A control treatment (without an amendment) was included. The treatments were replicated three times and laid out in Randomized Complete Block Design.

Air-dried 100 g soil (without amendment) were placed in a glass jar measuring 90 mm diameter and 200 mm height. The 50-ml beaker with 15 ml 1N NaOH as CO_2 trap was placed inside each jar. The jars were covered with black plastic lid to avoid CO_2 contamination from the outside atmosphere and the sides of the jar were wrapped with two layers of carbon paper to block any light from passing through the transparent glass. The samples were incubated at room temperature (27-28°C). A reference jar with only NaOH and distilled water was placed under the same conditions to take into account the initial carbonization of NaOH. For the first incubation experiment, evolved CO_2 and trapped in NaOH was measured at 0, 3, 6, 15, 20, 25, 30, 37, 44, 53, and 60 days after incorporation of poultry litter. Meanwhile, evolved CO_2 and trapped in NaOH was measured at 0, 3, 6, 15, 20, and 25 days.

At each sampling period, the alkali trap was taken out from the jar for determination of the amount of CO_2. The excess alkali was titrated with 1N HCl after precipitating the carbonate with 15% $BaCl_2$ solution in the presence of phenolphthalein. Alkali solution was replaced with a freshly prepared NaOH at every examination period. The respiration value (mg CO_2 100 g^{-1}) dry soil was computed using the formula:

$$\text{mg } CO_2 \text{ } 100 \text{ g}^{-1} \text{ dry soil} = (B\text{-}V)NE$$

where:

B = titration volume (ml) of HC in the blank (without soil)
V = titration volume (ml) of HCl in the treatments with soil
N = Normality of the acid
E = equivalent weight which is 22 for CO_2

2.5 Data analyses

Statistical analysis was conducted using CROPSTAT version 7.200. The main effects of type and level of poultry litter and their interaction were analyzed using analysis of variance (ANOVA). If found significant, the treatment means were compared using Fisher Protected Least Significant Difference (FPLSD) at a 5% level of significance.

3 Discussion

3.1 Fertility status of soil after application of uncharred and charred poultry litter at preplanting, 10 days after application of amendments

Application of either UPL or CPL increased soil pH (Table 3). The positive change on pH with application of these organic manure corroborates with the findings of [20] where they noted an increase of 0.17 pH unit with the application of 10 tons ha^{-1} raw poultry litter in a sandy loam soil in Southwestern Nigeria. According to [21], poultry litter increases soil pH because of neutralization reaction of microbial decarboxylation of calcium-organic matter complex leading to subsequent hydrolysis of calcium ions. The hydroxyl ions released in the hydrolytic reaction then reacts with both the exchangeable hydrogen and aluminum ions to form water and insoluble aluminum $Al(OH)_3$ respectively. In contrast, exchangeable acidity decreased with increasing rate of application. A linear increase in extractable P

Table 3: Means of pH_{H2O}, exchangeable acidity, and extractable P of soil at 10 days after application of amendments as affected by the types of poultry litter and their levels of application.

Treatments	pH_{H2O} *	Exchangeable acidity ($cmol^+ kg^{-1}$)	Extractable P ($mg kg^{-1}$)
Types			
UPL	6.30b	2.33	63.72b
CPL	6.42a	2.21	70.10a
LSD (5%)	0.07	ns	5.12
Levels ($g kg^{-1}$ soil)			
0 (Control)	5.42e	4.10a	1.45e
10	5.96d	2.73b	19.65d
20	6.24c	2.61b	48.02c
30	6.51b	1.87c	83.58b
40	6.72a	1.87c	116.33a
LSD (5%)	0.13	0.60	6.53

*Determined at 1:2.5 soil: diluent ratio.
UPL – uncharred poultry litter; CPL – charred poultry litter.
Means in a column at the same level of UPL and CPL application, followed by the same letter are not significantly different at 5% level of significance, using FLSD.

can be attributed to increasing amount of P added with the application of increasing levels of amendment.

3.2 Fertility status of soils at preplanting, 20 days after application of uncharred and charred poultry litter

The pattern of change in soil pH $_{CaCl2}$ after 20 DOI is similar to that of 10 DOI although there was a decline in values in former incubation period (Table 4). The observed pattern implies that time of application of these amendments is important factor to consider to maximize their liming benefit. As to the change in organic C, the trend at 10 and 20 DOI differed where at 10 DOI, application of UPL at 40g kg^{-1} resulted in higher organic C than with CPL. However, at 20DOI, the organic C values were similar at 40g kg^{-1}. This pattern implies that at higher rates UPL is as effective as CPL in raising the organic C in acid sandy soil.

Table 4: Means for soil pH $_{CaCl2}$, organic C and exchangeable Na at 20 days after poultry litter application as affected by interaction effects of the types of poultry litter and their levels of application.

Treatments		pH $_{CaCl2}$*	Organic C (%)	Exchangeable Na (cmol$^+$ kg^{-1})
Types of poultry litter	Levels (g kg^{-1} soil)			
Control (no amendment)	0	4.71	1.00	0.21
UPL	10	4.84b	1.64a	0.26a
CPL	10	5.22a	1.60a	0.28a
UPL	20	5.45b	1.73b	0.33b
CPL	20	5.94a	1.80a	0.40a
UPL	30	5.92b	1.99b	0.45b
CPL	30	6.16a	2.03a	0.53a
UPL	40	6.10b	2.14a	0.60a
CPL	40	6.50a	2.11a	0.61a
LSD (5%)		0.05	0.04	0.04

*Determined at 1:2.5 soil: diluent ratio.
UPL – uncharred poultry litter; CPL – charred poultry litter.
Means in a column at the same level of UPL and CPL application, followed by the same letter are not significantly different at 5% level of significance, using FLSD.

3.3 Total N and P concentration and uptake of peanut

Type of poultry litter did not significantly affect both plant N and P concentration and uptake of peanut. However, level of application significantly affected plant N and P concentration and uptake. Figures 2 and 3 show the nitrogen and phosphorus uptake of peanut plant. The highest N uptake of peanut plant is at level 20 g kg^{-1} soil (Figure 2). A similar trend is also observed in the uptake of P wherein an increasing trend was observed from 0 to 10 g kg^{-1} and goes down at 30 g kg^{-1} soil (Figure 3).

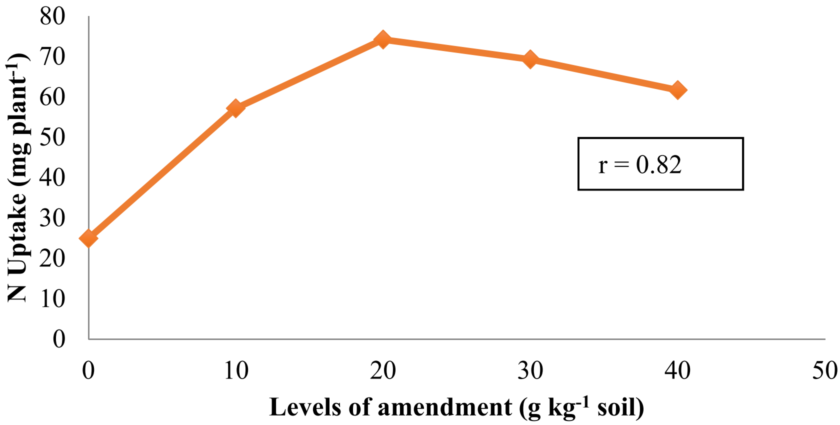

Figure 2: Nitrogen uptake (g $plant^{-1}$) of peanut as affected by the levels of UPL and CPL.

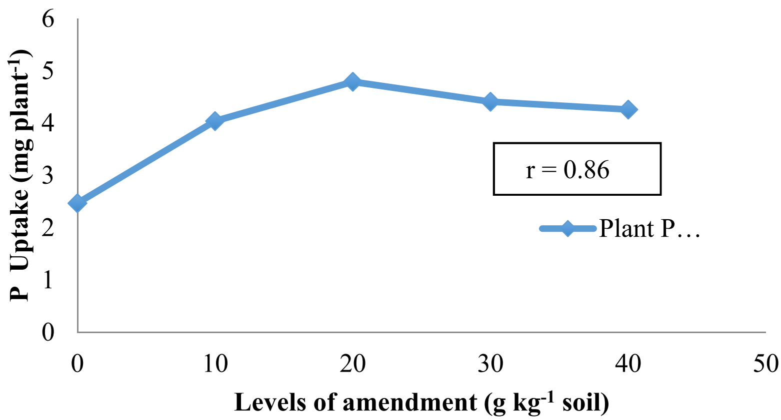

Figure 3: Phosphorus uptake (g $plant^{-1}$) of peanut as affected by the levels of UPL and CPL.

3.4 Microbial respiration of acid sandy soil as affected by uncharred poultry litter (UPL) and charred poultry litter (CPL)

This C content in the soil is vulnerable to management systems employed. One of the major ways for a carbon to be lost from the soil to the atmosphere is through microbial respiration mainly produced by oxidizing organic matter by microorganisms. Measuring the rate of CO_2 is a commonly done to estimate microbial respiration. . Cumulative evaluation of microbial respiration is a useful tool in determining the total CO_2 evolution of a treatment.

The results revealed that CPL may serve as a good habitat for microorganism but not as food. Similar results in a laboratory experiment conducted by [22] wherein biochar amended soil initially reduced microbial activity in laboratory conditions. The results, however, contradicts with that of Steiner *et al.* [24] wherein higher microbial respiration was observed after the addition of charcoal in a highly weathered Ferralsol soils in Amazon. It was observed that there is a greater difference on the levels of uncharred and charred poultry litter applied. Similar effect was revealed in the study of Lehmann *et al.* [12], where microbial respiration significantly decreased with increase in the level of fly ash in a sandy loam.

It was observed that with the increasing rate of application, the greater is the difference of the microbial respiration rate between UPL and CPL (Figures 3 and 5).

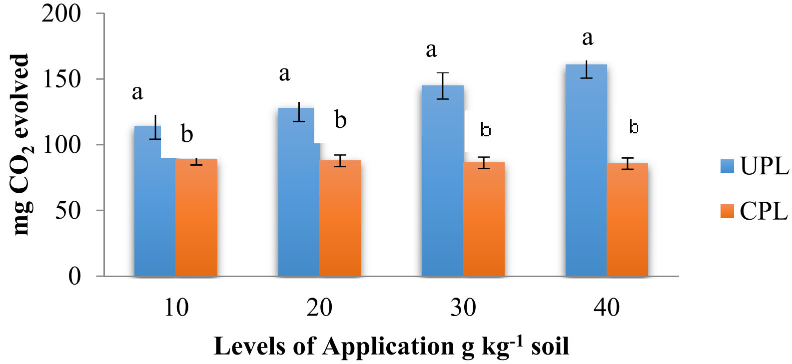

Figure 4: Interaction effects of the type of poultry litter and levels of application on the cumulative CO_2 evolved (mg 100 g^{-1} soil) during the 1st incubation period.

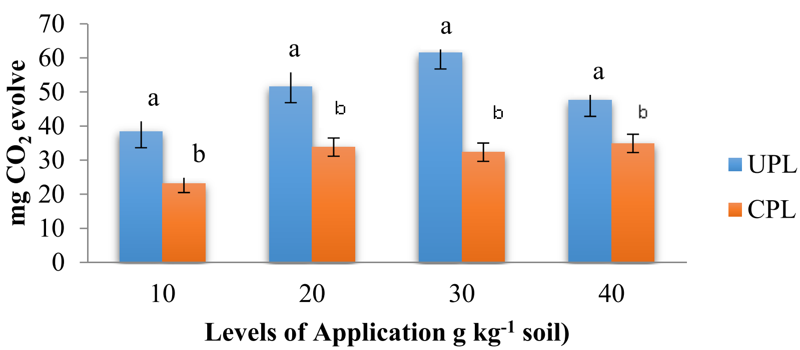

Figure 5: Interaction effects of the type of poultry litter and levels of application on the cumulative CO_2 evolved (mg 100 g^{-1} soil) during the 2nd incubation period (residual).

4 Conclusion

Based on the results of the study, the following conclusions could be drawn:

1. Both UPL and PLC can change the chemical properties of acidic sandy soil.
2. Both microbial activity and nodulation have interaction effect on the mode of processing and level of amendment. Higher level of application of uncharred treatments increases microbial activity while application of PLC does not vary with increasing level. UPL-treated treatments have more nodules but PLC-treated treatments have heavier nodules.
3. UPL and PLC levels at 20−30 g kg 1 did perform best among the levels.

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