Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lcss20

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Published online: 24 Jun 2011.

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
Vol. 34, Nos. 1 & 2, pp. 41–54, 2003

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ABSTRACT

Quantitative information on the decomposition rates and patterns of organic residues is fundamental for a better understanding of organic matter dynamics and nutrient cycling in soils. A laboratory incubation experiment was conducted under constant temperature (30°C) for 3 years to study changes in total carbon (C), total nitrogen (N), and C/N ratio of crop residues (rice, corn, alfalfa) and animal feces (pig, cattle) decomposing with and without soil. On average, rice, corn, and alfalfa residues lost a larger proportion of their original organic C than cattle and pig feces (82 vs. 70%). The presence of soil did not affect the total amount of organic C lost, with the exception of corn residues in which it increased it from 79 to 84%. Alfalfa residues, pig feces, and cattle feces lost a larger proportion of their total N than rice residues (38 vs. 15%). Both rice

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DOI: 10.1081/CSS-120017414 0010-3624 (Print); 1532-2416 (Online)

and corn residues showed an initial increase in total N, which may have been due to N immobilization from the soil and/or N fixation. Rice residues started losing total N after 15 months, whereas corn residues still showed an increase in total N after three years. The presence of soil decreased the loss of total N in alfalfa residue (32 vs. 48%) and pig feces (38 vs. 51%). The C/N ratios of all materials decreased during the decomposition and, with the exception of pig feces were similar to that of the soil by the end of the study (11:1 to 12:1). These results provide quantitative information that could be used to improve the management of residues and feces.

Key Words: Decomposition; Carbon; Nitrogen; C/N ratio.

INTRODUCTION

Quantitative information on the decomposition rates and patterns of organic residues is fundamental for a better understanding of organic matter dynamics and nutrient cycling in soils. Because organic materials added to soils may contain a wide range of C compounds, the biological breakdown of the added organic material will depend on the rate of degradation of each of the C-containing materials present in the sample.[1,2] Variation in environmental factors may also change decomposition rates in soil. Of these factors, O_2, moisture content, temperature, pH, substrate specificity, and available minerals have been reported to be most important.[3–6] A comparison of the decline of organic ^{14}C in soils from England, Nigeria and four South Australian field sites, suggested that the decomposition pattern was very similar in all soils, except that the net decomposition rates doubled approximately for an 8 to 9°C rise in mean annual air temperature.[7–9]

Knowledge of N mineralization and immobilization of different organic sources added to soil (crop residues, manures, slurry) is a key factor in understanding soil fertility dynamics and in developing efficient predictions of the need for N fertilization. Much research has been conducted on the relationship between N mineralization and chemical characteristics (or quality) of crop residues and manures. Significant correlations are reported between percent N mineralization of crop residues and N-content, C-to-N ratio, lignin content or lignin-C, polyphenol content, or combinations of these factors.[10–13] Some studies, however, have not found significant relationships between N mineralization and N-content, lignin, polyphenols, or lignin-to-N ratio.[14,15] These conflicting results are partly caused by differences in the ranges of the chemical variables considered, in the types of residues studied, and in the methodology used.[16]

Compared with conventional tillage system, no-till or minimum tillage and fallow cropping systems leave more residue on the soil surface, resulting in reduced soil erosion, less on-farm energy, and greater water conservation.[17] Surface residues persist longer than incorporated residues because greater fluctuation in water and temperature regimes and reduced availability of soil nutrients adversely affect the microbes colonizing surface residue, thus slowing decomposition.[18,19] Although these cropping systems are increasing in use for economic and environmental reasons, the amount of research on residue decomposition under these systems is still limited. The objective of this study was to study the changes in total C, total N, and C/N ratio of different organic materials decomposing with or without soil for three years.

MATERIALS AND METHODS

Soil and Organic Materials

The silt loam soil used in the study was collected from the upper 15 cm of a long-term study at the Shenyang Experimental Station of Ecology (Chinese Academy of Sciences). A field-moist sample was brought to the laboratory, mixed, and passed through a 2-mm sieve. A subsample was oven dried (105°C, 24 h) and ground to pass through a 100-mesh sieve for analysis (Table 1).

Three plant residues (corn, rice, alfalfa) and two animal manures (pig, cattle) were used for the incubation. Plant materials were collected right after harvest and included leaves and stems. Animal manure samples were collected fresh. All materials were dried at 65°C for 48 hours and ground to pass through a 40-mesh sieve (Table 1).

Organic materials by themselves or mixed with soil were placed into 1-L jars. A control treatment with soil alone was also included. All treatments were replicated three times. The water content of materials and soil-material mixtures was adjusted with deionized water to 60% of water-holding capacity (WHC) and the jars were incubated at constant temperature (30 ± 1°C) for 3 years. Water loss during incubation was determined by weighing the jars periodically, and was replenished by adding deionized water. At 0, 3, 6, 12, 24, and 36 months, materials, soil, and soil-material mixtures were sampled for total C and N determination.

Table 1. C and N concentrations in organic materials and soil, ash concentration in organic materials, and ratio of material:soil used in incubations with soil.

Materials	Total C (g kg^{-1})	Total N (g kg^{-1})	C/N ratio	Ash (g kg^{-1})	Material:soil
Rice residue	381.7	6.15	62	14.0	100:98
Corn residue	445.6	6.35	70	5.8	100:93
Alfalfa	448.3	14.90	30	4.1	100:97
Pig feces	408.4	12.30	33	23.6	100:74
Cattle feces	391.0	14.00	28	20.3	100:48
Control Soil	11.5	1.16	10	—	—

Chemical Analyses

The organic C concentration in materials and soil was measured on a TOC-5000A Automatic Analyzer (Shimadzu Corp., Japan). Total N in materials and soil was determined by Kjeldahl digestion, followed by colorimetric determination with an autoanalyzer. The ash content of materials was measured gravimetrically after dry combustion at 650°C for 24 hours.

Calculations

For materials decomposing without soil, decomposition was determined by the loss of oven-dry weight between sampling dates. For materials mixed with soil, decomposition was determined by subtracting the mass of soil remaining in the control treatment with soil alone from the mass remaining in the material: soil mixture.

The C and N concentrations of materials decomposing by themselves were determined by analyzing samples taken during the incubation. The C concentration in materials mixed with soil was determined as follows:

$$\text{Organic C} = [(C_m \times W_{rt} - C_s \times W_{rs})/(W_{rt} - W_{rs})] \times 100$$

where: C_m = C concentration of the soil-material mixture (g C kg^{-1}),
W_{rt} = oven-dry mass of soil-material mixture (kg),
C_s = C concentration of control treatment with soil alone (g C kg^{-1}),
W_{rs} = oven-dry mass of soil in control treatment with soil alone (kg). The N concentration in materials mixed with soil was determined with a similar formula in which C concentration was replaced by N concentration.

Phases in total C and total N loss were determined by plotting the logarithm of the remaining C or N versus time. Based on that procedure, we identified three phases in the decomposition of each residue: a) 0 to 3 months, b) 3 to 12 months, and c) 12 to 36 months. Rate constants for each of these phases (k_1, k_2, and k_3, respectively) were determined graphically[5,20] assuming that losses followed first-order kinetics:

$$C_t = C_0 e^{-kt}$$

where C_t is C remaining at time t, C_0 is mineralizable C, and k is the first-order rate constant of decomposition (month^{-1}).

Rate differences between type of residue and between samples of the same residue incubated with and without soil were determined by Fisher's LSD.

RESULTS AND DISCUSSION

Loss of Mass

All materials showed a decomposition pattern (Fig. 1) similar to that reported by Jenkinson et al.[7] and Ladd et al.,[8] although the decomposition was slower than that observed in field experiments and some laboratory-incubations using litter bags.[5,6] One reason for the slower decomposition may be that organic acids produced during decomposition could not be leached and/or neutralized in jars with little or no soil and thus, the activity of microbes may have been restrained under acidic conditions.[20] High C-to-N ratio may be another reason for the slow decomposition.[21] In general, all plant materials decomposed faster than animal manures. The percentage of initial mass remaining after 3 yr of decomposition was about 46% for animal manures, whereas it ranged from 22 to 25% for plant materials. In the case of cattle and pig feces, the presence of soil increased the rate of mass loss (Fig 1).

Changes in Total Carbon

As in the case of mass loss, the amount of C decomposed in 3 yr was larger in crop residues than in manures (Figs. 2 and 3, Table 2). This was probably caused by the fact that the readily decomposable C fraction in animal manures had already been decomposed in the animal digestive tract. The presence of soil increased the rate of C decomposition during the first three

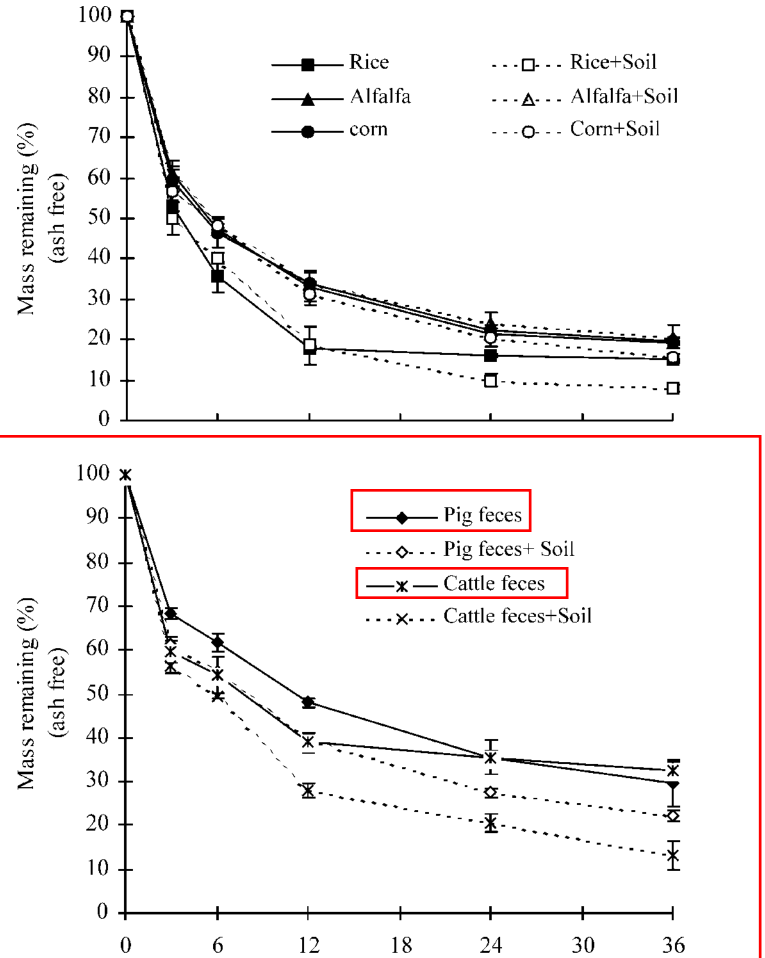

Figure 1. Ash-free mass remaining in crop residues (alfalfa, rice, corn) and animal feces (cattle, pig) incubated with and without soil at 30°C for three years. Where bars do not appear, symbols were larger than SD.

months in corn and pig feces (Table 3) and during the last two years in rice. Between 3 and 12 months, however, the presence of soil decreased the rate of C decomposition in rice. As a result, there was no overall effect of soil on the total amount of C decomposed from rice residues in three years (Table 2). A similar counteracting effect seemed to have occurred with pig feces, resulting in no net effect of soil in total C decomposition. In contrast, the enhancing

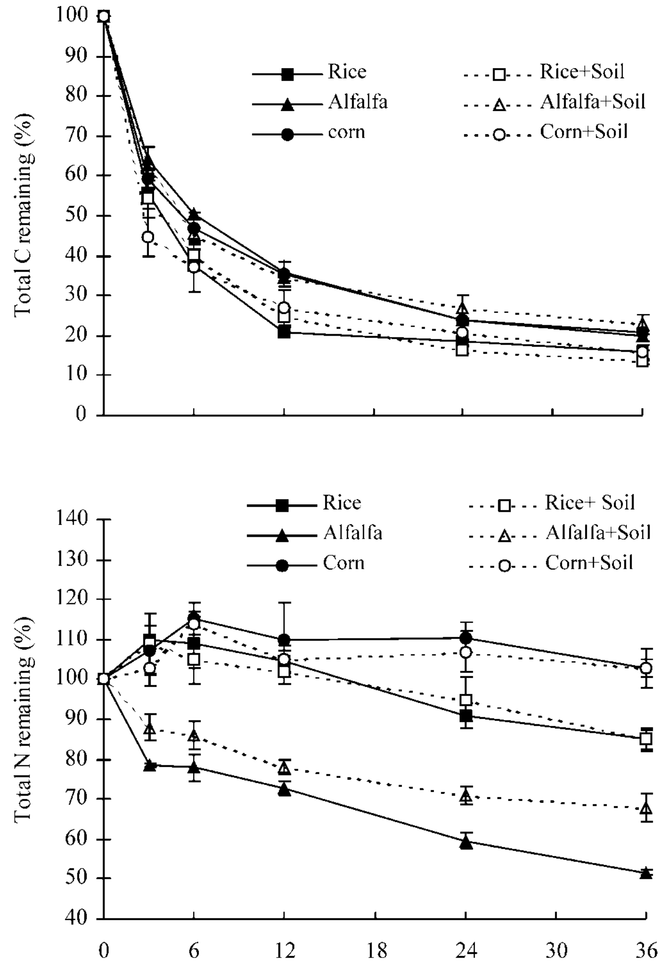

Figure 2. Total C and total N remaining in alfalfa, corn, and rice residues incubated with and without soil at 30°C for three years. Where bars do not appear, symbols were larger than SD.

effect of soil on corn residue decomposition during the first 3 months translated into a larger C decomposition by the end of the study (Table 2). The presence of soil may enhance C decomposition through the effect of organic acids on bacterial activity and may reduce organic C decomposition through the formation of organo-mineral complexes that are difficult to degrade.[22]

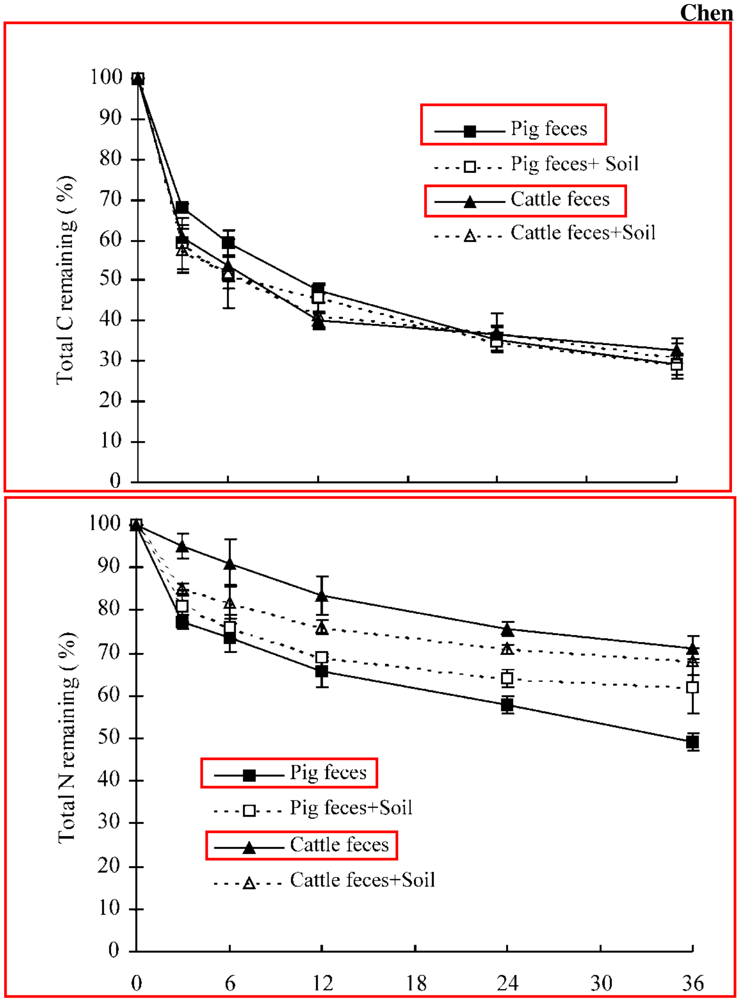

Figure 3. Total C and total N remaining in cattle and pig feces incubated with and without soil at 30°C for three years. Where bars do not appear, symbols were larger than SD.

Changes in Total Nitrogen

Cattle feces, pig feces, and alfalfa residue (with C/N ratios ranging from 28 to 33) showed a net loss of N during the three years of decomposition. The presence of soil decreased the rate of N loss from alfalfa residue during the first

Table 2. Total C and total N lost from crop residues (rice, alfalfa, corn) and animal feces (pig, cattle) incubated with and without soil at 30°C for three years.

Residue	No soil	With soil	Effect of soil
Total C lost (% of initial)			
Rice	84a	86a	NS
Alfalfa	80a	77b	NS
Corn	79a	84a	*
Pig feces	72b	71c	NS
Cattle feces	67c	69c	NS
Total N lost (% of initial)			
Rice	15c	15b	NS
Alfalfa	48a	32a	**
Corn	−3d	−3c	NS
Pig feces	51a	38a	**
Cattle feces	29b	32a	NS

Within a column, means followed by the same letter are not significantly different according to Fisher's LSD at a 0.05 probability level; $*p < 0.05$, $**p < 0.01$.

three months and during the last two years (Fig. 2, Table 3). As a result, the total N loss from alfalfa residue was smaller when it was mixed with soil than when it decomposed by itself (Table 2). The presence of soil also decreased the rate of N loss from cattle feces during the first three months (Table 3), but that was not enough to translate into a smaller loss by the end of the three years (Table 2). In the case of pig feces, the presence of soil decreased the rate of N loss during the last two months, resulting in an overall smaller loss at the end of the three years (Tables 2 and 3).

Rice and corn residues (with C/N ratios of 62 and 70, respectively) showed an initial increase in total N, which in the case of residues mixed with soil was probably due to immobilization of N from the soil (Fig. 2). In the case of residues decomposing without soil, the increase in total N may have been caused by nonsymbiotic N fixers.[23] Rice residues started losing total N approximately 15 months after the initiation of the study (Fig. 2), at which time, the C/N ratio of the residues had decreased to approximately 13:1 (Fig. 4). In contrast, corn residues still showed an increase in total N by the end of the study. It is interesting to note that by the end of the study the average C/N ratio in corn residues was near 13:1. Previous results have suggested that the breakpoint C/N ratio between net N mineralization and immobilization ranges from 20,[24,25] to 30,[14,26] or 40 to 50.[11,16,27] The present results suggest that the critical C/N ratio may be smaller for materials that have large

Table 3. Rate constants for total C and total N loss from crop residues (alfalfa, corn, rice) and animal feces (cattle, pig) incubated with and without soil at 30°C for three years.

	k_1 (0–3 months)			k_2 (3–12 months)			k_3 (12–36 months)		
Residue	No soil	With soil	Soil effect	No soil	With soil	Soil effect	No soil	With soil	Soil effect
Tatal C ($month^{-1}$)									
Rice	0.203a	0.203b	NS	0.108a	0.089a	**	0.010b	0.025a	**
Alfalfa	0.147b	0.160b	NS	0.066b	0.064b	NS	0.024a	0.018ab	NS
Corn	0.173ab	0.270a	**	0.058b	0.056b	NS	0.022a	0.022a	NS
Pig feces	0.129b	0.176b	*	0.039c	0.029c	NS	0.023a	0.019ab	NS
Cattle feces	0.165ab	0.184b	NS	0.046c	0.037c	NS	0.008b	0.013b	NS
Total N ($month^{-1}$)									
Rice	−0.0317c	−0.0277c	NS	0.0056bc	0.0066bc	NS	0.0086bc	0.0080a	NS
Alfalfa	0.0803a	0.0420b	**	0.0088b	0.0132ab	NS	0.0142a	0.0058a	**
Corn	−0.0233c	−0.0083c	NS	−0.0024c	−0.0024c	NS	0.0026d	0.0007b	NS
Pig feces	0.0860a	0.0707a	NS	0.0182a	0.0169a	NS	0.0120ab	0.0047a	**
Cattle feces	0.0170b	0.0547ab	**	0.0145ab	0.0125ab	NS	0.0067c	0.0043ab	NS

Within a column, means followed by the same letter are not significantly different according to Fisher's LSD at a 0.05 probability level; $*p < 0.05$; $**p < 0.01$.

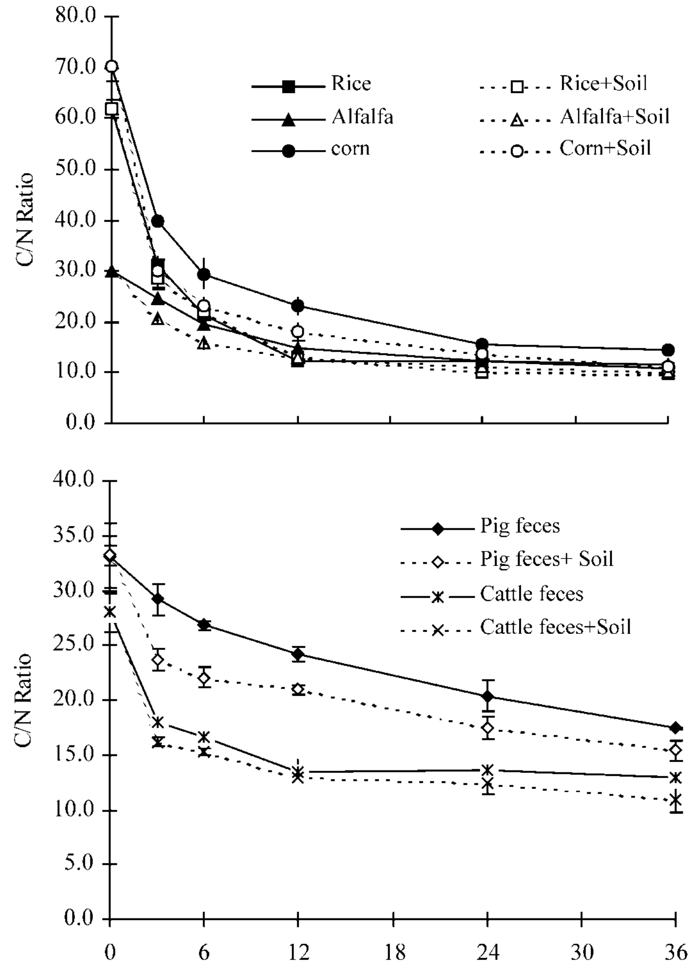

Figure 4. C/N ratios of crop residues (alfalfa, corn, and rice) and animal feces (cattle, pig) incubated with and without soil at 30°C for three years. Where bars do not appear, symbols were larger than SD.

initial C/N ratios. The presence of soil did not affect the gain or loss of total N in rice and corn residues (Table 2).

The C/N ratio of all residues decreased during decomposition because C was lost at a higher rate than N (Fig. 4). After three years of decomposition, all materials, except pig feces had C/N ratios similar to that of the soil. Pig feces still had C/N ratios around 16:1, which suggests that decomposition may not have been complete even after three years.

SUMMARY AND CONCLUSIONS

On average, rice, corn, and alfalfa residues lost a larger proportion of their original organic C than cattle and pig feces (82 vs. 70%). The presence of soil did not affect the total amount of organic C lost, with the exception of corn residues in which it increased it from 79 to 84%. Alfalfa residues, pig feces, and cattle feces lost a larger proportion of their original N than rice residues (38 vs. 15%). Both rice and corn residues showed an initial increase in total N, which may have been due to N immobilization from the soil and/or N fixation. Rice residues started losing N after 15 months, whereas corn residues still showed an increase in total N after three years. The presence of soil decreased the loss of N from alfalfa residue (32 vs. 48%) and pig feces (38 vs. 51%). The C/N ratios or all materials decreased during the decomposition and, with the exception of pig feces were similar to that of the soil by the end of the study (11:1 to 12:1). These results provide quantitative information that may be useful to improve the management of residues and feces.

ACKNOWLEDGMENTS

Financial support by NKBRSF(G1999011804—03) is gratefully acknowledged. Shenyang Experimental Station of Ecology and Terrestrial Ecological Process Laboratory, Chinese Academy of Sciences, offered constant temperature lab and instruments are highly appreciated.

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