Supplementary Materials

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As the Fig. S1 shown, the outer surface of the rice straw sample in BK was flat and its structure was intact, dense, and has neatly arranged waxy crystals before degradation (Fig. S1A1). The inner surface is smooth and has a dense structure with compactly arranged cell walls (Fig. S1B1). It serves as a primary barrier against water evaporation and pathogens such as bacteria and fungi, that is also the primary target of degradation (Jenks et al., 1994). The straw's clean, dense, and thick long tube structure may be seen in the cross-section (Fig. S1C1). After the 90-d degradation, the surface of the rice straw CK and TG samples was broken partially (Figs. S1A2 and S1A3). The outer parenchyma tissue of the rice straw disappeared partially and the crystalline particles began to fall off and degrade with the appearance of some pores, becoming rough and uneven with a few microorganisms adhered to the straw surface. The inner parenchyma tissue below was exposed (Figs. S1B2 and S1B3), and the structure began to loosen, with some of the internal tissue already detached from the original tissue and in a fragmented state. And the long tube structure in the cross-section gradually became looser in arrangement (Figs. S1C2 and S1C3), with the tube wriggling around.

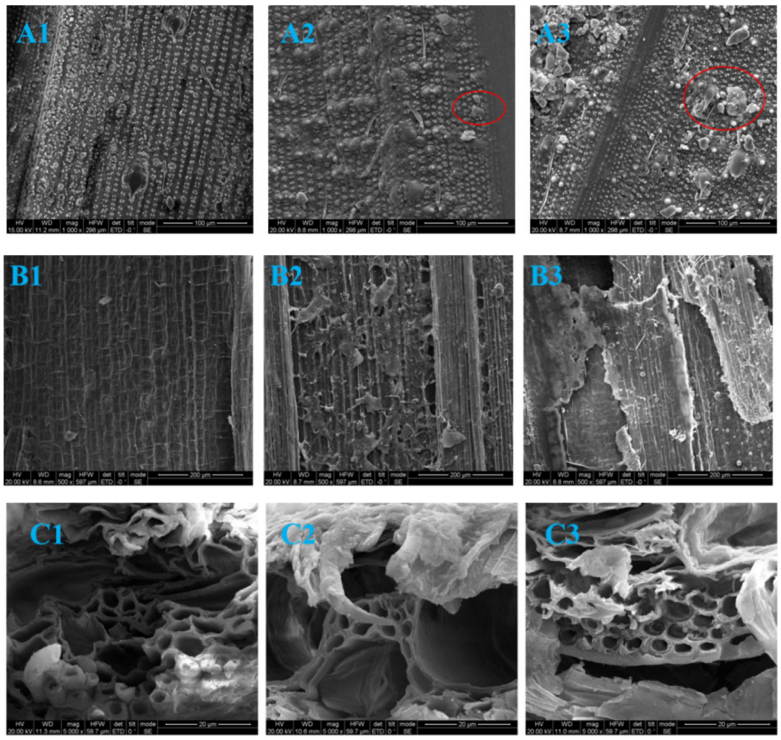

Fig. S1 Scanning electron micrographs of rice straw before degradation, natural degradation, and inoculated rumen fluid degradation (1: Before degradation for the BK sample; 2: Natural degradation for the CK sample; 3: Inoculated rumen fluid degradation for the TG sample). (a) The outer surface of the rice straw, scale bar: 0.1 mm. (b) The inner surface of the rice straw, scale bar: 0.2 mm. (c) The cross-section of the rice straw, scale bar: 0.02 mm. BK: the group of straw samples that were not returned to the field; CK: the blank control group receiving 40 mL of ultrapure water; TG: the treatment group receiving 40 mL of rumen fluid.

It was observed that the integral structure of the rice straw inoculated with rumen fluid became looser at this stage. The basic organization of TG changed more significantly with a large number of microorganisms adhering to the outer surface of the straw, promoting the dissolution of the wax-silica layer. It could confirm that RM adhesion to the fibers is critical for the subsequent degradation of lignocellulosic biomass.

As the Fig. S2a shown, both of them are in the same position which indicates that the crystalline shape of the cellulose did not change during the decomposition. Moreover, it can be found that the diffraction peak at18° is more wide and round for rice straw of TG sample compared to the control; interestingly, the straw sample both of BK and CK were sharper and narrower than TG samples at 22°. The intensity of the diffraction peaks for the straw samples (CK, TG) was reduced during decomposition. However, the intensity of TG sample diffraction peak was significantly reduced in both the non-cellulose crystalline and the cellulose crystalline, this reveals that the removal rate of most of the lignin and hemicellulose in the rice straw of TG was higher than the control. And, it is also indicating that the relative crystallinity of TG straw sample had a greater change than the control during decomposition. As refers by FTIR described that the cellulose in the straw is also greatly decomposed. Therefore, the relative crystallinity showed a decreasing trend. The researcher found that the hydrogen bonds between cellulose molecules are arranged in a regular system, resulting in an ordered system, which suggests that cellulose is the more difficult component to break down compared with the other lignocellulosic of the rice straw. The result by XRD demonstrates that RMs could break down the tough components of the rice straw, which caused the straw to become a lower structural density and a higher porosity, allowing for more microbial adhesion spots.

It can be seen from the Fig. S2b that the FTIR spectra of BK, CK, and TG were compared in the spectral region was 500–4000cm^{-1}, which revealed that the straw was rich in functional groups (Xu et al., 2016). However, the intensity of some peaks decreases or disappears by the treated rice straw, which indicates that most of the cellulose, hemicelluloses, and lignin had been removed from the rice straw by TG. For example, the stretching vibration of O–H hydroxyl groups causes the 3000–3500 cm^{-1} broad absorption peaks. CK and TG have decreased the intensity of absorption peaks compared to BK, which is due to the phenolic or alcoholic hydroxyl groups contained in the straw being reduced after decomposition, and the TG absorption peak almost vanishes. Moreover, the asymmetric and symmetric C–H stretching vibration peak of the aliphatic H–C–H absorption peak at 2900 cm^{-1} decreases and disappears indicating that carbohydrate and aliphatic molecules in the straw are degraded, resulting in partial degradation of methyl and methylene groups. The TG shows again that was damaged to an obvious greater extent. And, it can be clearly observed that the peak at 1630 cm^{-1} is attributed to the strong contact between cellulose and water molecules that causes the absorption peak of water. A substantial number of cellulose and water molecules have been structurally destructed by RMs, resulting in the weakening of the absorption peak. The peaks in the 1520–1450 cm^{-1} range of the rice straw indicated vibrations in bound lignin. And the intensity of the

absorption peak at 1520 cm^{-1} has diminished slightly, indicating that the N-H link in the amide has been broken after straw treated by RMs. The decrease in the intensity of this peak at 1450 cm^{-1} which is the aromatic C=C stretch of aromatic, and it attributed to the partial removal of hemicelluloses. The absorbance peaks at 1400 cm^{-1} originate from C–H and C–O stretching vibrations and the intensity of the absorption peak is weakened due to partial acetylation of hydroxyl groups in both polysaccharides and residual lignin. Clearly, the aliphatic chemicals, carbohydrates, and lignin of the rice straw was being degraded. However, there was no substantial change in the absorption peaks at 800 cm^{-1} in CK or TG straw samples, which corresponds to the vibrational absorption of the inorganic components Si–O–Si. To sum it, RMs decreased the FTIR peaks at 1400–3500 cm^{-1} as well as XRD peaks at 2θ of 22° and 18° of straw. These results indicate RMs could effectively degrade cellulose, hemicellulose, and lignin to expose crystalline cellulose (i.e., cellulose I) and then facilitate its transformation to an amorphous structure (i.e., cellulose II). Above all, RMs significantly altered the surface morphology, chemical composition, and crystallinity of straw.

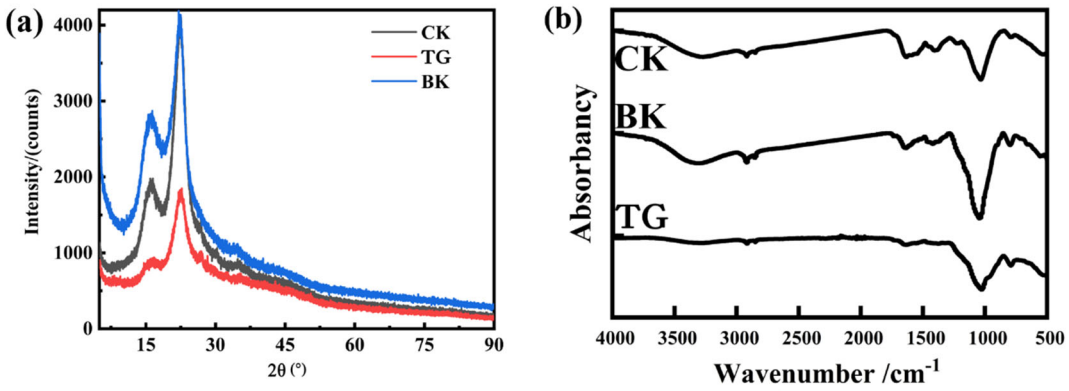

Fig. S2 Straw structure analysis. (a) The XRD diffraction spectrum. (b) The FTIR absorption spectrum.

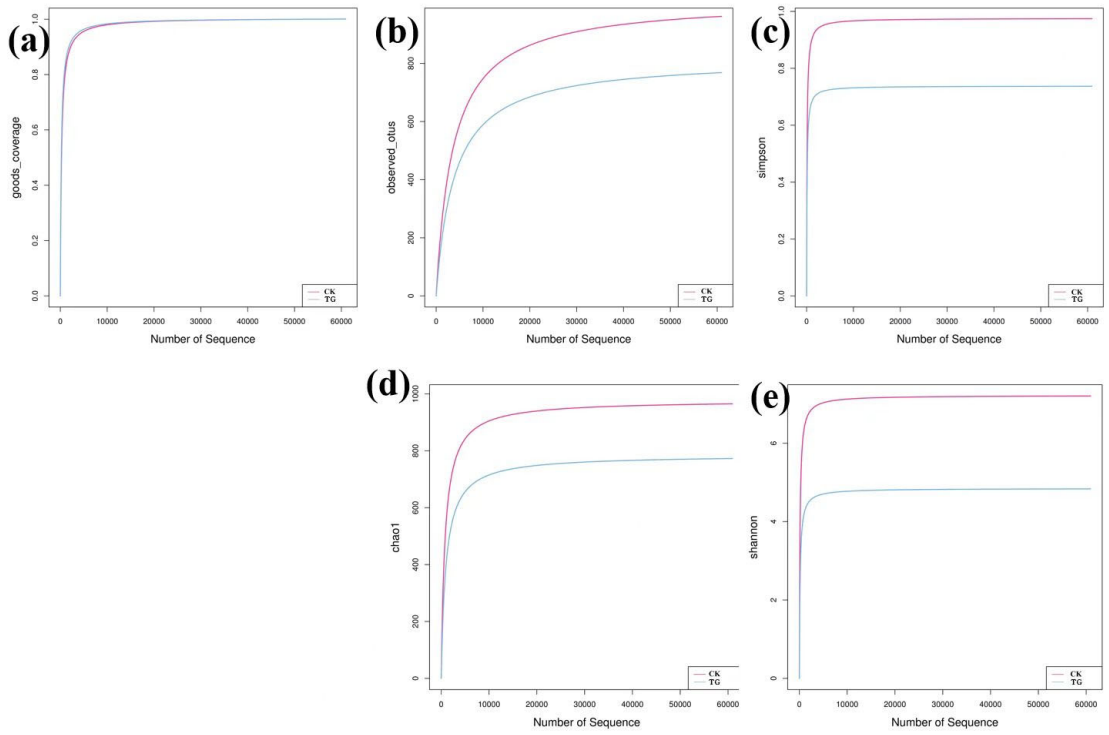

Fig. S3 Variations of soil bacterial community by alpha diversity. (a) Goods_coverage. (b) Observed_OTUs. (c) Simpson. (d) Chao 1. (e) Shannon.

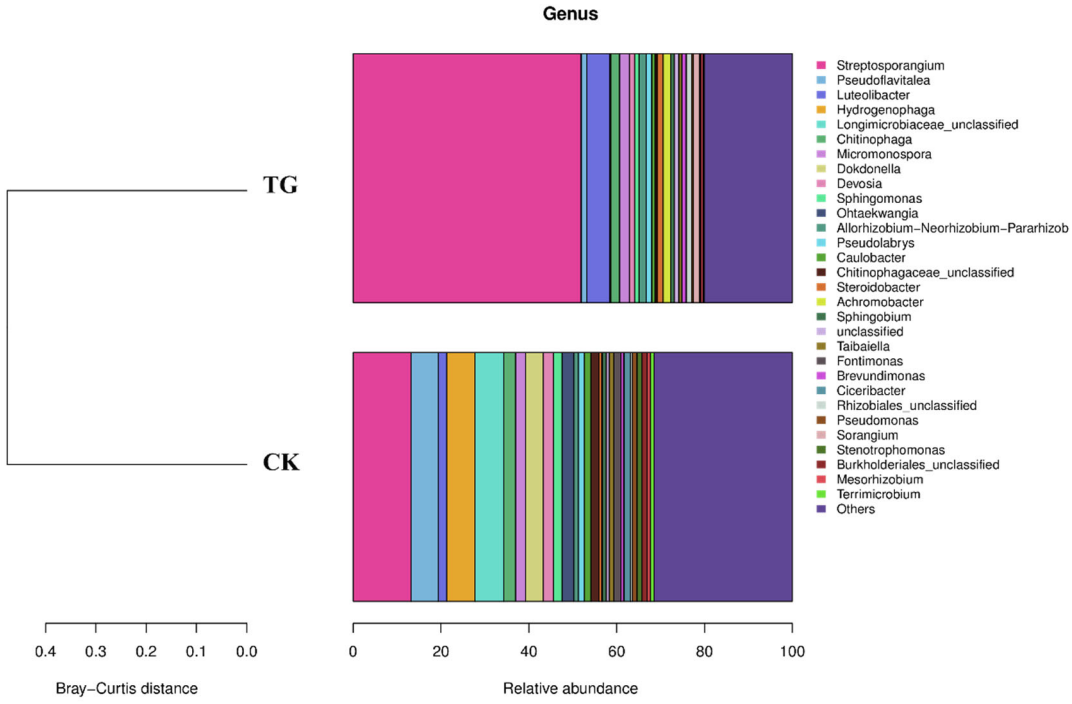

Fig. S4 Variations of soil microbial community structure (Genus).