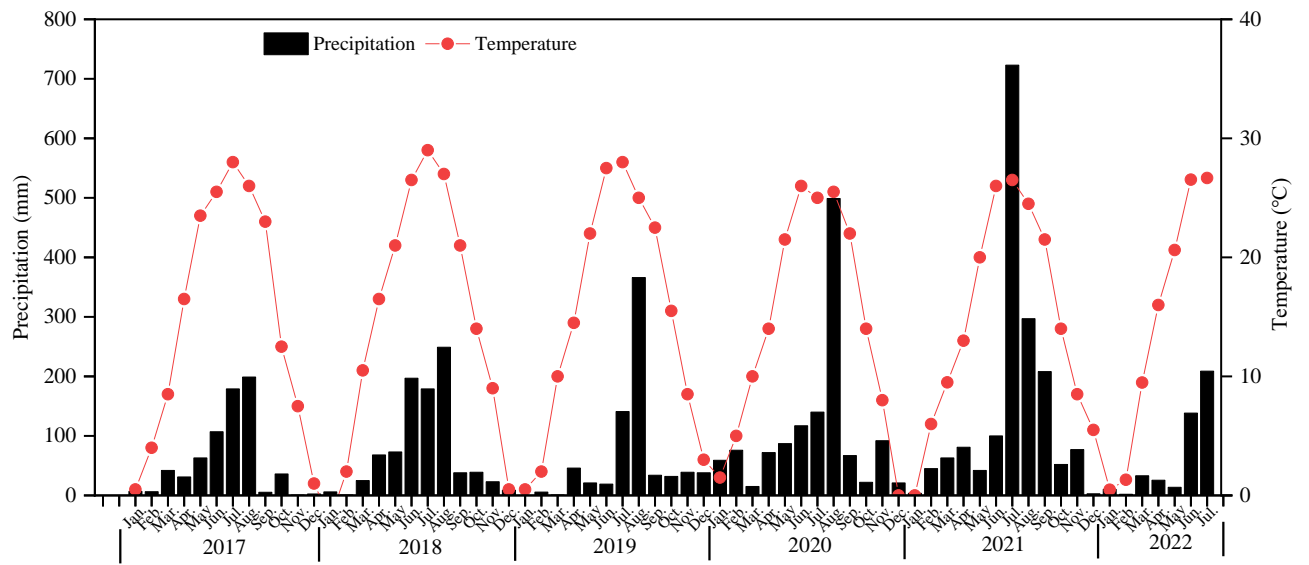
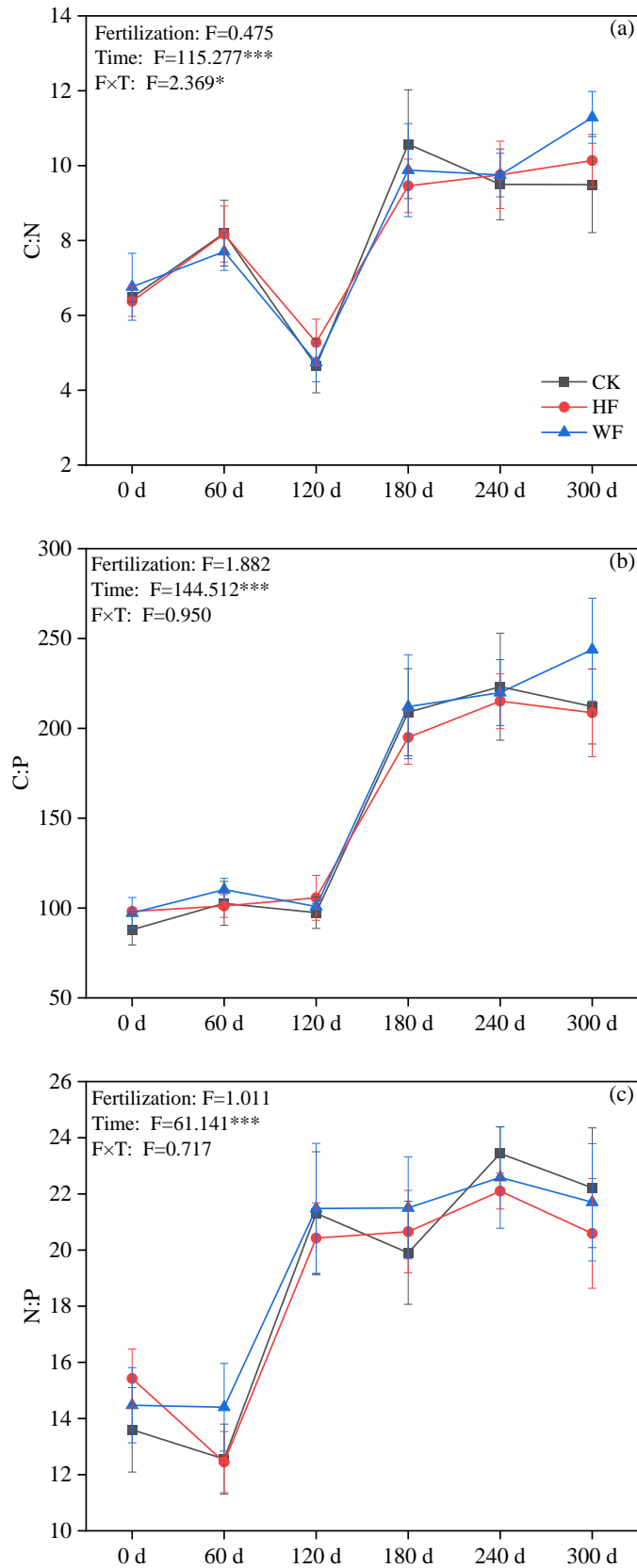


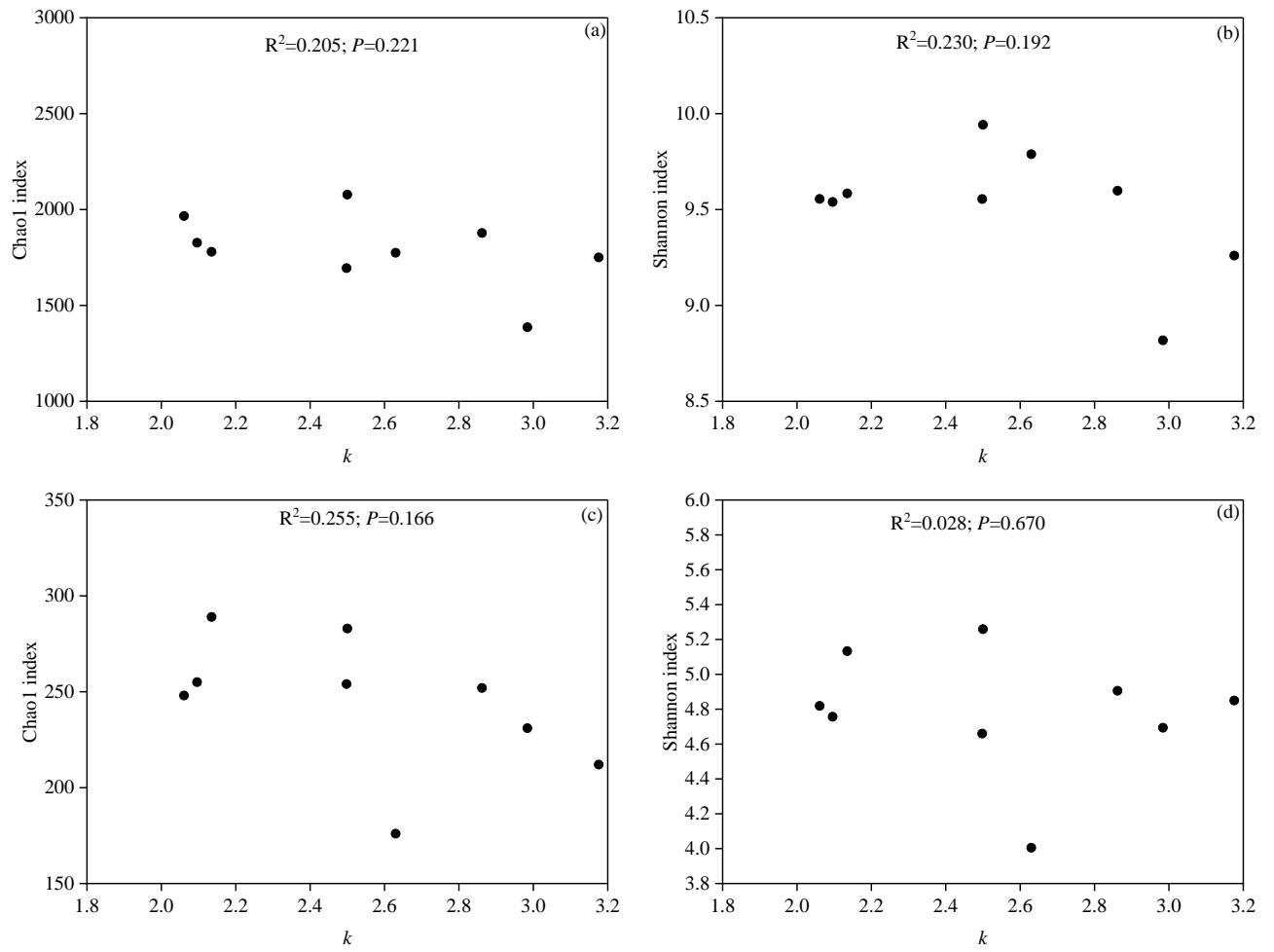
**Figure S1.** Plot diagrams and arrangement of litter plots.



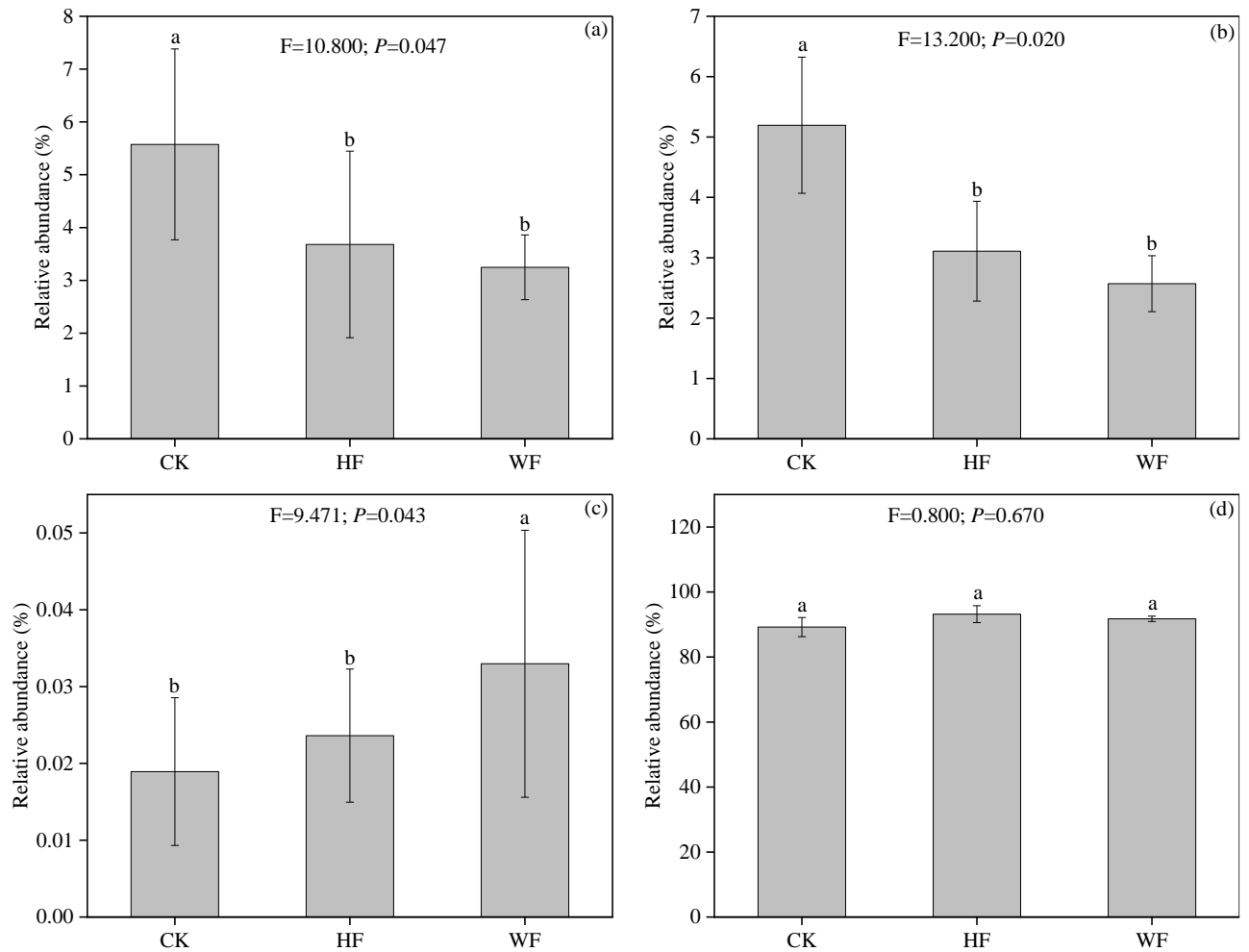
**Figure S2.** Temperature and precipitation from 2017 to 2022 in Zhangqiu District, Jinan City, China.



**Figure S3.** Stoichiometric ratios of the leaf litter treated through three fertilization regimes. a, C:N; b, C:P; c, N:P; CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer. \*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; \*\*\*,  $P < 0.001$ .



**Figure S4.** Linear fitting of bacterial (a–b) and fungal (c–d) diversity to decomposition constants.



**Figure S5.** FUN-Guild analysis for predicting fungal functions in three fertilization regimes. a: pathotroph; b: saprotroph; c: symbiotroph; d: others. CK: no fertilization; HF: hole fertilization; WF: integration of water and fertilizer.

#### Supplementary Material—Tables

**Table S1.** Chemical properties of topsoil (0-20 cm) treated through three fertilization regimes.

Soil properties	CK	HF	WF	F	P
pH	7.640±0.423	7.500±0.299	7.745±0.269	0.797	0.469
SOM (g/kg)	16.916±2.343	18.312±2.481	16.266±1.093	1.533	0.248
SOC (g/kg)	9.812±1.359	10.622±1.439	9.835±0.634	1.533	0.248
TN (g/kg)	0.978±0.079	1.014±0.053	0.961±0.021	1.378	0.282
TP (g/kg)	0.516±0.021	0.538±0.018	0.530±0.049	0.743	0.492
TK (g/kg)	17.132±0.843	17.496±0.425	17.637±0.806	0.792	0.471
AN (mg/kg)	61.380±7.130	59.392±1.388	57.404±2.944	1.158	0.341
AP (mg/kg)	16.315±4.637	17.098±5.387	15.438±5.666	0.150	0.862
AK (mg/kg)	180.129±13.503	193.418±23.135	175.032±4.707	2.193	0.146

Note: Mean±SD values are shown. SOM, soil organic matter; SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; TK, total potassium; AN, alkaline hydrolyzed nitrogen; AP, available

phosphorus; AK, available potassium; CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer; F and P value originated from the Kruskal–Wallis test.

**Table S2.** Total mass and carbon content of leaf litter in 2021.

Fertilization	Total mass (kg)	Total C content (kg)
CK	2470.26±44.58 a	1052.85±19.32 a
HF	2842.81±34.11 a	1224.87±21.66 a
WF	2607.58±22.68 a	1113.75±15.48 a

Note: Mean±SD values are shown. Different lowercase letters in each column indicate significant differences between fertilization regimes ( $P < 0.05$ , Tukey's HSD). CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer.

**Table S3.** Decomposition constant ( $k$ ) and the duration for leaf litter to decompose by 50% ( $t_{50\%}$ ) or 95% ( $t_{95\%}$ ) in three fertilization regimes.

Fertilization	$k$	$t_{50\%}$ (a)	$t_{95\%}$ (a)
CK	3.007±0.158 a	0.231±0.012 b	0.998±0.052 b
HF	2.543±0.076 b	0.273±0.008 ab	1.179±0.034 ab
WF	2.097±0.037 c	0.331±0.006 a	1.429±0.026 a

Note: Different lowercase letters in each column indicate significant differences between fertilization regimes ( $P < 0.05$ , Tukey's HSD). CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer.

**Table S4.** Nutrient release rates of leaf litter in three fertilization regimes.

	CK	HF	WF
N release (%)	81.333±7.760 A	79.401±7.877 B	73.134±9.218 C
P release (%)	85.603±9.046 A	81.508±11.361 B	79.509±10.405 C
K release (%)	90.499±8.034 A	87.951±11.150 B	86.529±12.320 C
Ca release (%)	38.756±9.053 A	28.495±5.017 B	25.308±4.631 B
Mg release (%)	61.246±8.817 A	55.684±9.048 B	57.759±13.885 AB
C release (%)	77.147±8.886 A	73.864±8.468 B	67.831±8.000 C

Note: Different capital letters in the same row indicate significant differences between fertilization regimes ( $P < 0.05$ , Tukey's HSD). CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer.

**Table S5.** Relative abundance at the phylum level of bacteria and fungi.

Fertilization	CK	HF	WF
<b>Bacterial phylum</b>			
Proteobacteria	40.612±6.609 a	35.389±2.934 b	31.636±1.565 b
Actinobacteria	28.027±6.978 a	26.598±4.671 a	28.158±4.385 a
Bacteroidetes	9.318±1.240 a	10.584±3.270 a	11.756±2.102 a
Firmicutes	7.779±0.844 b	8.175±3.524 b	10.348±4.536 a
Acidobacteria	6.673±1.130 b	8.980±2.163 a	8.705±0.924 a
Gemmatimonadetes	2.720±0.162 b	4.172±0.800 a	2.982±0.235 b
Chloroflexi	1.673±0.698 a	1.959±0.729 a	1.655±0.250 a
Verrucomicrobia	0.772±0.245 c	1.292±0.299 b	1.868±0.334 a

**Fungal phylum**

Ascomycota	70.241±2.885 a	68.282±3.588 a	62.939±4.208 a
Mortierellomycota	15.595±4.159 a	17.304±1.292 a	15.351±2.069 a
Basidiomycota	12.339±1.607 a	11.409±3.217 a	9.552±1.987 a
Chytridiomycota	0.459±0.189 b	1.882±1.540 a	1.144±0.372 a

Note: Mean±SD values are shown (abundance ≥1%). Different lowercase letters in each row indicate significant differences between fertilization regimes ( $P < 0.05$ , Tukey's HSD). CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer.

**Table S6.** Alpha diversity of bacteria and fungi in three fertilization regimes.

	CK	HF	WF	F	P
<b>Bacteria</b>					
OTU	1657±256	1836±198	1845±97	1.156	0.561
Chao1	1671.495±255.029	1848.908±202.204	1857.631±96.981	1.422	0.491
Shannon index	9.225±0.391	9.762±0.195	9.860±0.023	2.756	0.252
Simpson's index	0.991±0.002	0.996±0.001	0.997±0.002	5.067	0.079
<b>Fungi</b>					
OTU	232±12	238±32	264±13	2.222	0.329
Chao1	231.667±11.552	237.667±31.950	264.000±12.662	2.222	0.329
Shannon index	4.816±0.110	4.841±0.627	4.903±0.202	0.622	0.733
Simpson's index	0.919±0.004	0.929±0.037	0.939±0.010	1.067	0.587

Note: Mean±SD values are shown. CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer. F and P values determined through Kruskal–Wallis test.

**Table S7.** The results of envfit function of R package indicated correlations between all parameters and microbial communities (genus level).

Parameters	Bacteria		Fungi	
	R <sup>2</sup>	P	R <sup>2</sup>	P
pH	0.568	<b>0.007</b>	0.276	0.423
SOM	0.548	<b>0.038</b>	0.231	0.496
SOC	0.548	<b>0.038</b>	0.232	0.496
TN	0.544	<b>0.044</b>	0.507	<b>0.040</b>
TP	0.332	0.380	0.510	<b>0.035</b>
TK	0.401	0.270	0.077	0.752
AN	0.328	0.386	0.513	<b>0.031</b>
AP	0.032	0.853	0.531	<b>0.002</b>
AK	0.120	0.714	0.179	0.583
N (L)	0.549	<b>0.036</b>	0.195	0.557
P (L)	0.547	<b>0.040</b>	0.185	0.573
K (L)	0.012	0.885	0.512	<b>0.032</b>
Ca (L)	0.061	0.808	0.522	<b>0.016</b>
Mg (L)	0.552	<b>0.032</b>	0.271	0.430
OC (L)	0.560	<b>0.019</b>	0.506	<b>0.042</b>
C:N (L)	0.319	0.400	0.288	0.403
C:P (L)	0.563	<b>0.014</b>	0.324	0.343
N:P (L)	0.568	<b>0.006</b>	0.299	0.384

Note: The bold numbers in the table indicate significant effects ( $P < 0.05$ ). SOM—Soil organic matter; SOC—Soil organic carbon; TN—Total nitrogen; TP—Total phosphorus; TK—Total potassium; AN—

Alkaline hydrolyzed nitrogen; AP—Available phosphorus; AK—Available potassium; N(L)—N content of leaf litter; P(L)—P content of leaf litter; K(L)—K content of leaf litter; Ca(L)—Ca content of leaf litter; Mg(L)—Mg content of leaf litter; OC(L)—organic carbon content of leaf litter; C:N(L)—C:N ratio of leaf litter; C:P(L)—C:P ratio of leaf litter; N:P(L)—N:P ratio of leaf litter.

**Table S8.** Number of lines in network analysis for bacteria and fungi.

Fertilization	Bacteria				Fungi			
	Collaborate (positive)	Antagonistic (negative)	C:A ratio	Total	Collaborate (positive)	Antagonistic (negative)	C:A ratio	Total
CK	216	234	0.92	450	218	232	0.94	450
HF	168	282	0.60	450	196	254	0.77	450
WF	166	284	0.58	450	188	240	0.78	428

Note: CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer; C:A ratio, Collaborate:Antagonistic.

**Table S9.** Relative abundance of saprophytes at genus level in three fertilization regimes.

CK		HF		WF	
Fungi genus	Relative abundance (%)	Fungi genus	Relative abundance (%)	Fungi genus	Relative abundance (%)
<i>Filobasidium</i>	<b>1.336</b>	<i>Neocosmospora</i>	<b>0.743</b>	<i>Neocosmospora</i>	<b>0.624</b>
<i>Coprinopsis</i>	<b>1.116</b>	<i>Filobasidium</i>	0.551	<i>Filobasidium</i>	0.515
<i>Neocosmospora</i>	0.794	<i>Trichocladium</i>	0.356	<i>Trichocladium</i>	0.296
<i>Trichocladium</i>	0.353	<i>Monocillium</i>	0.176	<i>Monocillium</i>	0.206
<i>Monocillium</i>	0.306	<i>Tetracladium</i>	0.169	<i>Acrocalymma</i>	0.187
<i>Cystofilobasidium</i>	0.294	<i>Cystofilobasidium</i>	0.152	<i>Keissleriella</i>	0.178
<i>Coprinellus</i>	0.163	<i>Acrocalymma</i>	0.140	<i>Talaromyces</i>	0.152
<i>Preussia</i>	0.105	<i>Talaromyces</i>	0.122	<i>Cystofilobasidium</i>	0.104

Note: The relative abundances of saprophytes are shown ( $\geq 0.1\%$ ). CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer.

**Table S10.** Relative abundance of decomposing bacteria at genus level in three fertilization regimes.

CK		HF		WF	
Bacteria genus	Relative abundance (%)	Bacteria genus	Relative abundance (%)	Bacteria genus	Relative abundance (%)
<i>Arthrobacter</i>	<b>8.063</b>	<i>Arthrobacter</i>	<b>6.152</b>	<i>Arthrobacter</i>	<b>5.871</b>



<i>Pseudomonas</i>	2.913	<i>Lactobacillus</i>	3.435	<i>Lactobacillus</i>	1.905
<i>Lactobacillus</i>	1.249	<i>Pseudomonas</i>	1.140	<i>Pseudomonas</i>	1.285
<i>Massilia</i>	1.139			<i>Bacillus</i>	1.230
<i>Bacillus</i>	1.112				
<i>Shinella</i>	1.098				

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Note: Relative abundance values  $\geq 1\%$  are shown. CK, no fertilization; HF, hole fertilization; WF, integration of water and fertilizer.