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# Integrating environmental parameters and economic benefits to analyze the ecological agriculture (EA) application in the mountain rice paddy system of Chongqing, China

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## Abstract

**Background:** Agrochemicals, such as pesticides and fertilizers used in the current conventional agriculture (CA), have contaminating effects on environments as well as food, which pose significant risks to non-target organisms and even human health. Under these environmental pressures, ecological agriculture (EA), using organic fertilizer for crop growth, was developed without pesticides to substitute CA gradually worldwide. However, EA has still not become popular in the Chinese mountain area. To identify the major factors that influence the application of EA, rice cultivation between EA and CA was compared by analyzing soil physical–chemical properties, and soil bacterial and plant diversity in Chongqing. Besides, in considering the economic benefits of small-scale paddy ecosystem, net present value (NPV) method was applied for quantification and evaluation between EA and CA.

**Results:** The rice yield of EA (3700 kg/ha) was significantly lower than that of CA (7500 kg/ha). Soil total nitrogen (TN,  $2.24 \pm 0.16$  g/kg) and available potassium (AK,  $70.67 \pm 9.88$  mg/kg) in CA were higher than those in EA, with amounts of  $1.45 \pm 0.18$  g/kg (TN) and  $54.00 \pm 5.89$  mg/kg (AK). Soil organic matter (SOM) of CA ( $55.6 \pm 5.8$  g/kg) was distinctly higher than that of EA ( $24.4 \pm 1.43$  g/kg), whereas pore water DOC concentration in EA ( $71.11 \pm 7.28$  mg/L) was higher than that in CA ( $61.07 \pm 6.61$  mg/L). Plant richness, bacterial diversity of ACE and Chao1 in EA were significantly higher than in CA ( $P < 0.05$ ). The net present value (NPV) of EA was 3.72 CNY/m<sup>2</sup>, which was higher than that of CA (2.98 CNY/m<sup>2</sup>).

**Conclusions:** The relative high amounts of AP, pore water DOC and bacterial diversity revealed the improvement of soil properties by EA. Limitations on N and AK may be responsible for the low yield in small-scale EA of the current study. In addition, economic benefits, plant richness and bacterial diversity suggested EA application in China as well as worldwide to facilitate the sustainable development of the agroecosystem. However, animal diversity and quantification on economic benefits of ecological services should be considered in further research to promote the sustainability development of the agroecosystem.

**Keywords:** Environmental sustainability, Ecological agriculture (EA), Paddy soil properties, Plant and soil bacterial diversity, Economic benefits

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## Background

Starvation, as one of the biggest challenges facing humanity, has puzzled people for thousands of years. To fight against worldwide starvation, the green revolution was developed in the late 1960s to increase agricultural production by adoption of new technologies [1]. Agrochemicals including chemical fertilizers and pesticides, as one of the main technology transfer initiatives in the green revolution, were combined with modernization management techniques in conventional agriculture (CA) and saved more than one billion people from starvation during this period [2]. However, with these CA initiatives there has been a focus on agrochemical pollution in recent years, with the improvement of public environmental awareness [3]. Data from Tillman et al. showed that the world pesticide consumption increased nearly three times from 1960 to 1990 [4], and the total fertilizer production in the world increased more than six times from 1961 (33.6 tons/years) to 2014 (207.98 tons/years) [5]. Utilization of such agrochemicals have contaminating effect on soil, air, surface and groundwater and food, which pose significant risks to non-target organisms ranging from microorganisms, to insects, plants, vertebrates, and even human health [6]. The US Department of Agriculture (USDA) reported that there were about 38.71 million people living in food insecure households, including more than 5 million children in 2017 [7]. Given these environmental and societal pressure, optimization or alteration of CA to reduce agrochemical contamination becomes an urgent issue for the related scientific communities, governments and publics [8].

Ecological agriculture (EA), which is farming without pesticides, was developed by using organic fertilizer to support the environmental sustainability of the farm. It is characterized by diverse products with good quality, pests and weeds controlled without environmental harmful input, improvement in soil quality and with low cost, which are of significant concern in recent years [6, 9]. Besides, due to the absence of pesticides and conventional fertilizer, the environmental, economic and health damages are intended to be minimized or avoided in EA, which increased the global demand for EA organic products robustly [10, 11]. Thus, EA has been gradually substituting for CA worldwide [6, 12], while in China which possesses about 7% of agricultural acreage of the world, EA has still not increased, in particular in the Chinese mountain area, where the farmland is usually of small scale [13].

Globally, the main challenge for EA application is the lower yields when compared to CA. Jouzi et al. reported that the crop yield is largely dependent on field management including soil nutrient content, patterns of soil microbes, plant diversity as well as nutrient–microbial

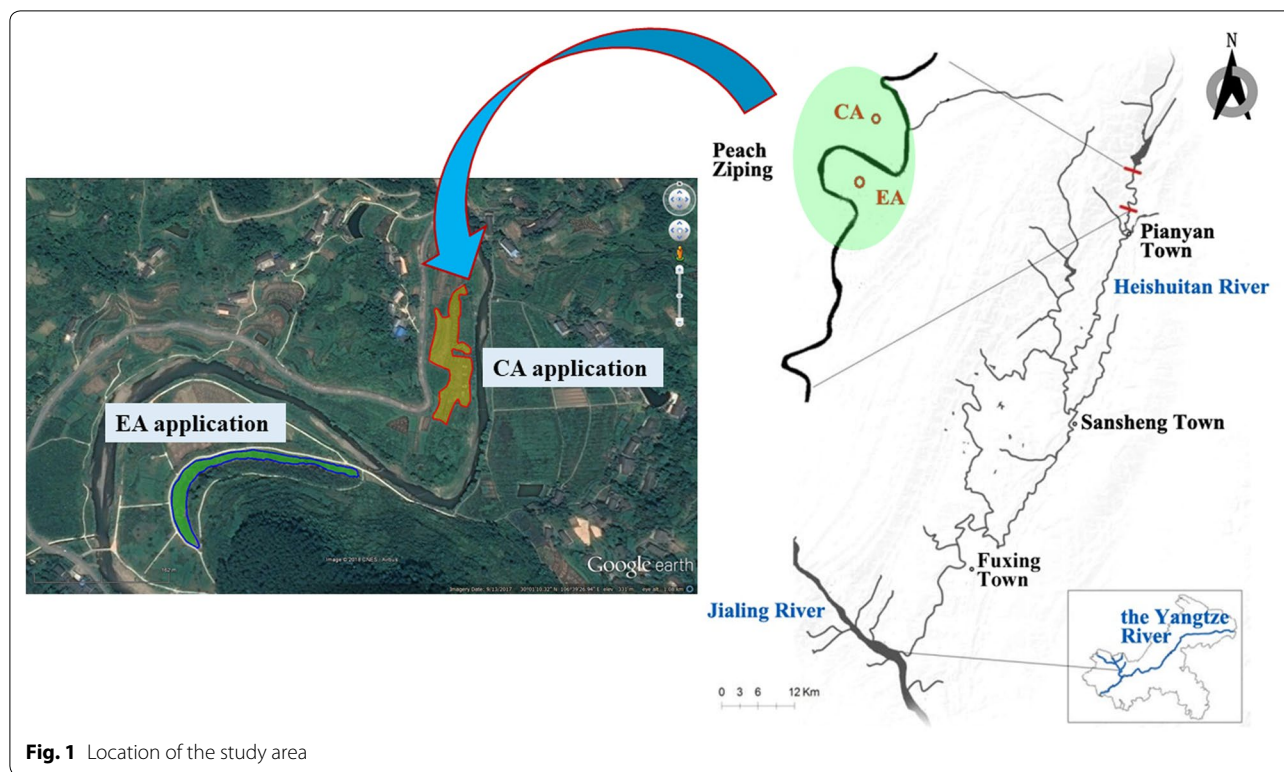
correlations [6]. Among these, soil organic matter (SOM), total nitrogen (TN), available phosphorus (AP), available potassium (AK) and slowly available potassium (SAK), as major nutrient elements for crops, play important roles during plant growth [14–16]. Nutrients dissolved in soil water are available fractions for plant uptake, and the dynamics of soil microorganism community structure and activity could affect nutrient biochemical processes and thus influence plant growth [17]. Plant diversity, such as diverse weeds in paddy ecosystem, could improve the stability of ecosystem, which facilitates the sustainable development of agriculture [18]. Besides, the economic benefit of crops, as one of the main concerns for farmers, directly influences farmers' decision on agricultural approach selection, which should be taken into consideration for analysis of the sustainability of the agriculture ecosystem [19].

To identify the major factors that influence the application of EA in China, the crop yield and economic benefits were integrated for analysis in the current study. Chongqing, as a typical mountainous area in China, was applied to compare the environmental parameters of pH, water moisture, soil physical–chemical properties, soil bacterial and plant diversity in small-scale EA and CA. Rice, as a vital crop feeding about 65% of Chinese people, was selected as a target crop [20]. Considering that economic issue is an internal motivation for crop cultivation, the economic values of farming inputs, eco-environmental benefits and rice production were quantified and evaluated using the net present value (NPV) method [21]. To our knowledge, this study is the first one integrating environmental parameters and economic benefits to analyze small-scale EA application in the mountain area of Chongqing, which promotes understanding of the co-evolution of the agroecosystem and social development for the sustainable development of agriculture.

## Methods

### Site description

The study site is in rural area and located at both sides of the river bank of the Heishuitan River, a tributary of the Jialing River in Beibei District of Chongqing, China (Fig. 1). The Heishuitan River is 65 km in length and the watershed area is 385 km<sup>2</sup>. It belongs to the subtropical monsoon region with a mean annual rainfall of 1163.3 mm and temperature of 17.5 °C. The geographic location of the study area is 30°1'6.42"N–30°1'3.51"N, 106°39'26.68"E–106°39'19.06"E for EA and 30°1'8.75"N–30°1'14.48"N, 106°39'30.85"E–106°39'32.03"E for CA, respectively. The upland area of both sites comprise non-agricultural areas. The CA site is 0.56 ha (5600 m<sup>2</sup>) and located at the right side of the riverbank, which is managed directly by the holder, and pesticide and fertilizer



**Fig. 1** Location of the study area

have been continually used for rice farming for more than 20 years. The site of EA is 0.42 ha (4200 m<sup>2</sup>), located at the left side of the riverbank and leased by Abao farm (a local environmental NGO), with 3 years of experience in ecological rice cultivation. The rice paddies distributed between the riverbank and EA are cultivated by the CA approach, where the altitude is lower than EA. The purpose of Abao farm is to demonstrate sustainable EA practice in this area and thus to guide farmers in altering the rice cultivation method to reduce environmental pollution and protect the ecosystems along the Heishuitan River watershed. The EA in the current study was practiced as rice-duck system [22, 23], and rapeseed meal was used as organic amendment.

**Field investigation and economic benefit calculation**

A survey including the fertilizer and pesticide usage, the input of labor for the rice cultivation management between EA and CA was investigated according the International Organization for Standardization (ISO) code for Yuan Renminbi (CNY) [24]. In the current study, we selected food production and biodiversity conservation as the focused ecosystem services, which were calculated into economic values [25]. The net present value (NPV) method was performed [21], given the (period, cash flow) pairs (*t*, *R<sub>t</sub>*) where *N* is the total number of

periods, and the time-discrete formula of the NPV is estimated as follows:

$$NPV(i, N) = \sum_{t=0}^N \frac{R_t}{(1+i)^t}$$

where *t* is the time of the cash flow, *i* is the discount rate, i.e., the return that could be earned per unit of time on an investment with similar risk, and *R<sub>t</sub>* is the net cash flow, i.e., cash inflow–cash outflow, at time *t*. The rice is grown as an annual plant in the study area, the value of *t* is set as 1, and that for *i* is set as 10% [26]. Therefore, the NPV can be calculated as NPV = PV (Benefits) – PV (Costs), where PV (Benefits) are sum of rice production benefits and biodiversity conservation function benefits, while PV (Costs) are sum of cost of fertilizer and pesticide usage, labor cost and land use cost.

Field investigation was carried out on 20 August 2017 at both the CA and EA areas. As weed control in paddy fields were performed by herbicide application or in ecological ways, plant species richness and diversity were determined at the paddy bund as replacement. Plots (1 × 1 m) of two types of paddies were randomly selected with six replicates each, and Patrick richness index (*S*) [27], Simpson heterogeneity index (*D*) [28] and Shannon–Weiner index (*H'*) [29] were used to assess the vegetation community. Soil samples were, respectively, collected by

a stainless steel columnar soil sampler (diameter = 7 cm, length = 20 cm) from CA and EA at 0–20 cm depth with three replicates each. Each replicate was obtained from a combination of triplicate sub-samples.

#### Soil and pore water physical–chemical properties determination

Half of the samples were prepared for soil physical–chemical characteristics analysis, and the rest of each replicate was homogeneously mixed and immediately transported under 0 °C and stored in an ultralow temperature freezer (DW-86L338, Haier, China) before microbial diversity analysis. Soil moisture was immediately determined by drying at 105 °C for 48 h after samples were transported to the laboratory. Prior to determining other physical–chemical parameters, the samples were air-dried, ground and sieved through a 2-mm mesh. Soil pH, SOM, TN, AP, AK and SAK were analyzed according to the national standards. Soil pore water (PW) was obtained via centrifugation with 6000 rpm for 10 min (Sigma 3K15, Germany). The pH was measured by a pH-meter (Mettler Toledo FE20, Shanghai, China), and the concentrations of dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) were detected by a TOC analyzer (Shimadzu TOC-L, Japan). The concentrations of  $\text{NO}_2^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  in pore water were measured via an ion chromatography unit (ICS-600, Thermo Scientific, USA). The concentrations of  $\text{NH}_4^+$  and total phosphorus (TP) were measured by Nessler's reagent spectrophotometry (National Environmental Protection standards of the People's Republic of China, HJ535-2009) and ammonium molybdate spectrophotometry (National Environmental Protection standards of the People's Republic of China, HJ670-2013), respectively.

#### Microbial diversity measurement

Regarding soil microorganism determination, the microbial genome DNA was extracted from the soil samples (0.5 g each) using PowerSoil® DNA Isolation Kit according to the manufacturer's protocol. The V3 + V4 sequenced regions of the bacterial 16s ribosomal RNA genes were amplified by PCR using primers 5'-ACTCCTACGGGAGGCAGCA-3' and 5'-GGACTACHVGGGTWTCTAAT-3'. The PCR conditions were: 95 °C for 5 min, followed by 95 °C for 1 min, 50 °C for 1 min, 72 °C for 1 min, with 15 cycles of repetition, and 72 °C for 7 min. The PCR reactions were performed in triplicate and subsequent Illumina high-throughput sequencing were conducted (Illumina HiSeq 2500). The raw tags were obtained by merging the PE reads via FLASH version 1.2.7, clean tags were achieved by filtering the raw tags through Trimmomatic version 0.33 and finally the effective tags were obtained by removing the chimera

sequence using UCHIME version 4.2. Operational taxonomic units (OTUs) were clustered at the 97% similarity level using QIIME version 1.8.0 and the taxonomy was noted according to Silva (Release 128, <http://www.arb-silva.de>).

#### Data analysis

Statistical analysis of OTUs richness was conducted via Good's coverage (>99%). ACE, Chao1, Simpson and Shannon's indexes were obtained with Mothur (version 1.3). Canonical correlation analysis (CCA) was applied to determine environmental variables best explaining the assemblage's variability via Canoco (version 4.5 for Windows); forward selection was based on Monte Carlo permutation tests (permutations = 999). The ordination in the *x*- and *y*-axes and the length of the corresponding arrows indicated the importance of each physicochemical factor in explaining the taxon distribution across communities. Analysis of variance (ANOVA) was used to test the significance of results by IBM SPSS 20.0 at  $P < 0.05$  level.

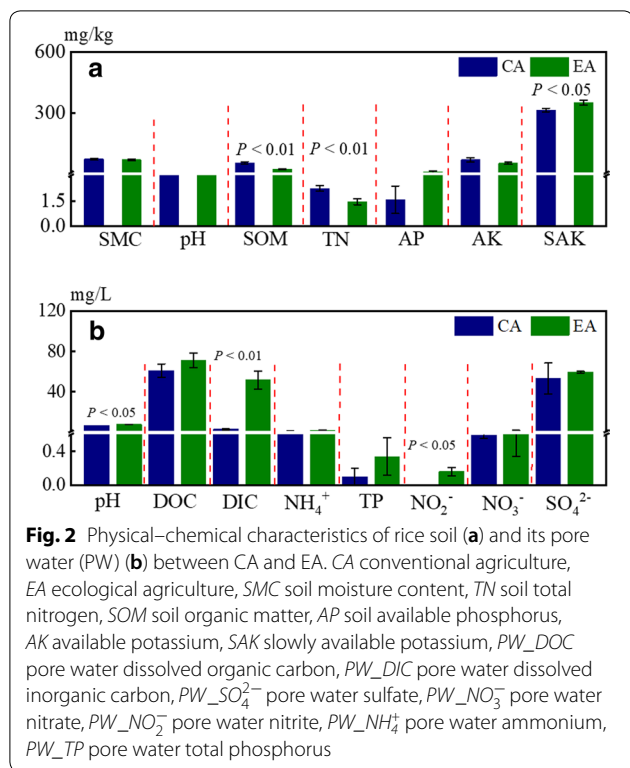
## Results

#### Paddy soil and pore water physical–chemical characteristics

As shown in Fig. 2, soil moisture was similar between CA ( $73.96\% \pm 5.05\%$ ) and EA ( $71.20\% \pm 4.01\%$ ). The pH value of CA was  $5.90 \pm 0.49$ , which is slightly lower than that of EA ( $7.00 \pm 0.45$ ), while the SOM of CA was approximately two times greater than that of EA, amounting to  $55.6 \pm 5.8$  g/kg in CA and  $24.4 \pm 1.43$  g/kg in EA, respectively. Additionally, both TN and AK of CA ( $2.24 \pm 0.16$  g/kg and  $70.67 \pm 9.88$  mg/kg, respectively) were higher than that of EA ( $1.45 \pm 0.18$  g/kg and  $54.00 \pm 5.89$  mg/kg, respectively), and soil SAK in CA ( $315.67 \pm 8.73$  mg/kg) was also higher than in EA ( $350.67 \pm 11.84$  mg/kg). However, AP of EA ( $10.17 \pm 5.37$  mg/kg) was significantly higher than that of CA ( $1.57 \pm 0.81$  mg/kg). Regarding soil pore water (PW), the pH values of both PW were higher than those of the corresponding soils, amounting to  $6.96 \pm 0.32$  and  $7.77 \pm 0.06$  for CA and EA, respectively. DOC concentration of EA ( $71.11 \pm 7.28$  mg/L) was higher than that of CA ( $61.07 \pm 6.61$  mg/L), implying that a relatively high amount of organic compounds was transformed from solid phase to liquid phase. However, TP of both CA ( $0.10 \pm 0.10$  mg/L) and EA ( $0.34 \pm 0.22$  mg/L) were distinctly lower than AP in the corresponding soils.

Statistical analysis showed that significant differences were found for soil SOM ( $P < 0.01$ ), TN ( $P < 0.01$ ) and AK ( $P < 0.05$ ) between CA and EA. Concerning pore water, pH ( $P < 0.05$ ), DIC ( $P < 0.01$ ) and  $\text{NO}_2^-$  ( $P < 0.05$ ) concentrations differed significantly between CA and EA.



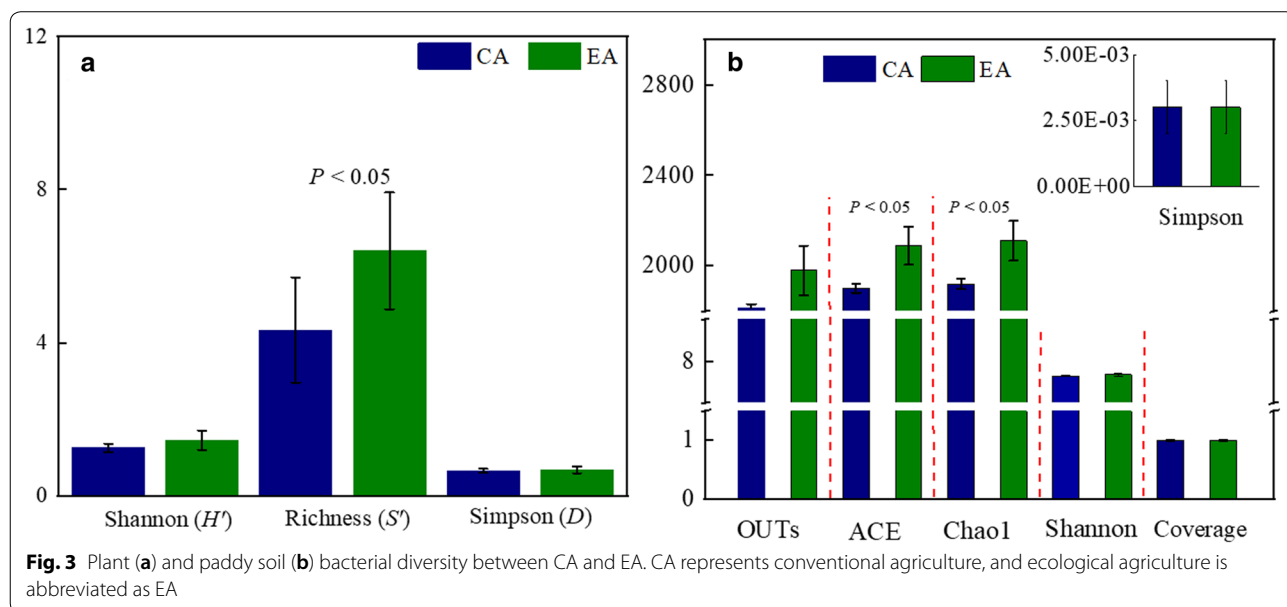


**Plant and paddy soil bacterial diversities**

Plant richness in EA bund was found higher than in CA distinctly ( $P < 0.05$ ) (Fig. 3a). Similarity, Shannon and Simpson indexes of EA bund were slightly higher than that of CA, but the variations were not significant between the sites ( $P > 0.05$  for both). However, plant alpha

diversity of the current study was found to be significantly higher than that in the other rice paddies and wetlands of China [30]. 16S rRNA gene libraries were established from pyrosequencing of the CA and EA communities with 61,842–65,011 effective tags (average length of 420 bp). By performing the alignment at a uniform length of 420 bp, 1791–2084 OTUs were clustered with 97% similarity using the Mothur 1.30 (Fig. 3b). The total numbers of OTUs were  $1814 \pm 18$  (CA) and  $1979 \pm 109$  (EA), which did not vary distinctly ( $P > 0.05$ ). ACE and Chao1 represent the pattern of bacterial richness, and ACE and Chao1 of EA were both higher than those of CA significantly ( $P < 0.05$ ), amounting from  $1901 \pm 20$  to  $2088 \pm 84$  for ACE and from  $1920 \pm 23$  to  $2110 \pm 87$  for Chao1, respectively. The Shannon and Simpson indexes are commonly used to evaluate the abundance and evenness of species in a community, respectively. The Shannon index of the EA ( $6.702 \pm 0.087$ ) was higher than that of CA ( $6.614 \pm 0.032$ ). The coverage of both CA and EA was higher than 0.99, revealing that most bacterial species were characterized. Overall, the bacterial diversities of EA were higher than those of CA, and ACE and Chao1 between the two tillage varied significantly at the rice mature stage ( $P < 0.05$ ).

The bacterial sequences were affiliated with 40 phyla, among which Proteobacteria, Acidobacteria, Chloroflexi, Nitrospirae and Gemmatimonadetes were the dominant phyla and accounted for 78.70–85.76% of the total OTUs, followed by a few other minor phyla with average abundance  $> 1\%$ , including Actinobacteria (3.52–4.39%), Bacteroidetes (1.83–5.39%), Ignavibacteriae (1.57–1.77%) and Latescibacteria (1.38–1.50%) (Fig. 4a). Regarding



the genus level, 217 genera species in total were identified. The dominant genera was *Anaeromyxobacter* (1.78–2.43%), *Bryobacter* (0.83–1.83%), *Candidatus Solibacter* (0.90–1.98%), *Desulfobacca* (0.99–1.06%), *Geobacter* (1.78–2.07%), *H16* (2.04–2.29%) and *Haliangium* (0.78–1.69%) (Fig. 4b). Besides, the genera with extremely minor proportion amounted to 60.68–63.18% of the total OTUs relative abundance.

CCA analysis (Fig. 5) indicated that different environmental variables may affect the bacterial distribution. Besides, some microorganisms prefer to coordinate symbiosis in rice paddy soil. The variation in bacterial composition was significantly explained by SOM, soil TN and pore water DOC, which were well correlated with the composition of the bacteria (with the longer arrow). Acidobacteria and Gemmatimonadetes were the closest to the arrow of  $PW\_SO_4^{2-}$ , Latescibacteria was the closest to the arrow of  $PW\_TP$ , and the same was true for Chloroflexi to SMC, Proteobacteria to SAK and Nitrospirae to  $PW\_NO_3^-$ , respectively. Therefore, paddy soil bacteria are more correlated with pore water chemical properties compared to the corresponding soil.

**Economic benefit assessment**

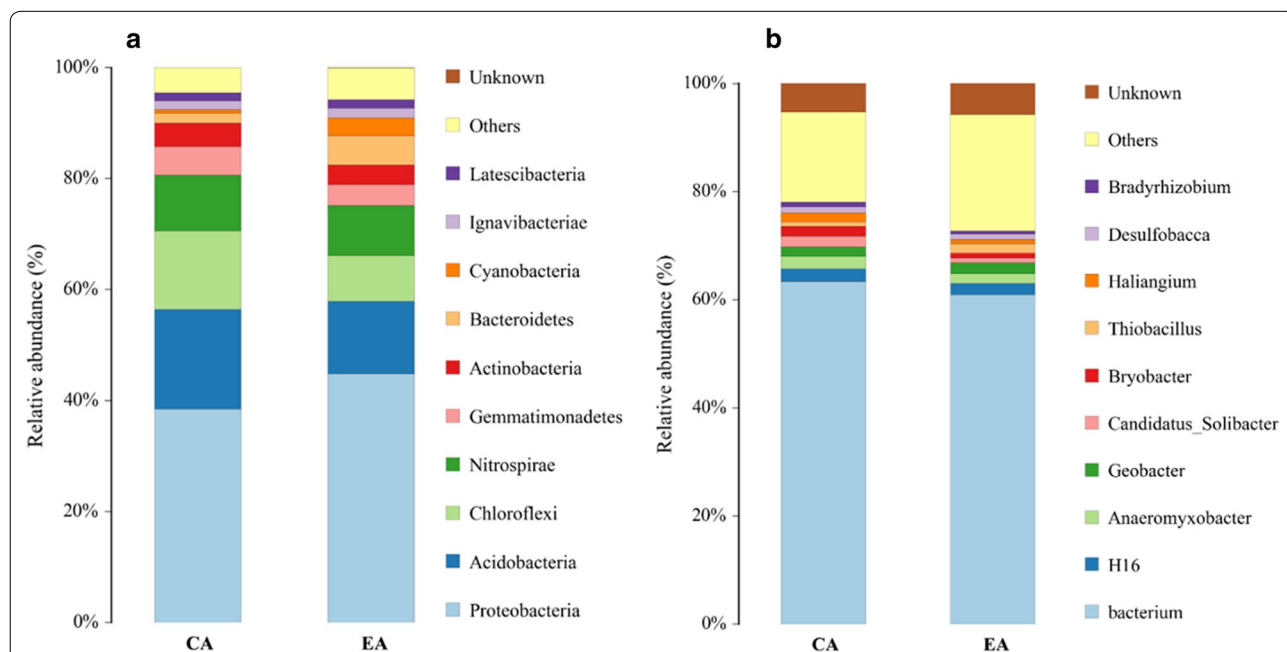
As shown in Fig. 6, the cash outflow of CA was 2608 CNY (0.47 CNY/m<sup>2</sup>), among which labor input accounted for the major proportion (69%), followed by fertilizer (21% in total) and pesticides (10%) with amounts up to 1800, 556 and 252 CNY, respectively.

The fertilizer application amounts were: potassium chloride (150 kg/ha), urea (180 kg/ha) and phosphate fertilizer (150 kg/ha), respectively. With EA, the cash outflow was 19,100 CNY (4.55 CNY/m<sup>2</sup>), which is approximately ten times as much as CA. This is because land rent (land use cost) took up 66% of the inputs (12,600 CNY). Besides, the proportions of labor cost and manure application were 25% (4775 CNY) and 9% (1719 CNY), respectively. Thus, it is found that the labor cost of EA is about 3.6 times that of CA. Regarding the cash inflow, the rice yield for CA was 7500 kg/ha and the average price of CA was about 5 CNY/kg for several years [31]; thus, the economic benefits of CA is 21,000 CNY (3.75 CNY/m<sup>2</sup>) with NPV amounting to 2.98 CNY/m<sup>2</sup>. The rice yield of EA was 3700 kg/ha, but the price is 26 CNY/kg, which is five times higher than CA. The food production benefit of EA is therefore 40,404 CNY (9.62 CNY/m<sup>2</sup>). Additionally, the ecosystem service of biodiversity in EA is calculated to about 0.02 CNY/m<sup>2</sup>, with reference to the work of Meng et al. [25]. Thus, the NPV of EA is 3.72 CNY/m<sup>2</sup>.

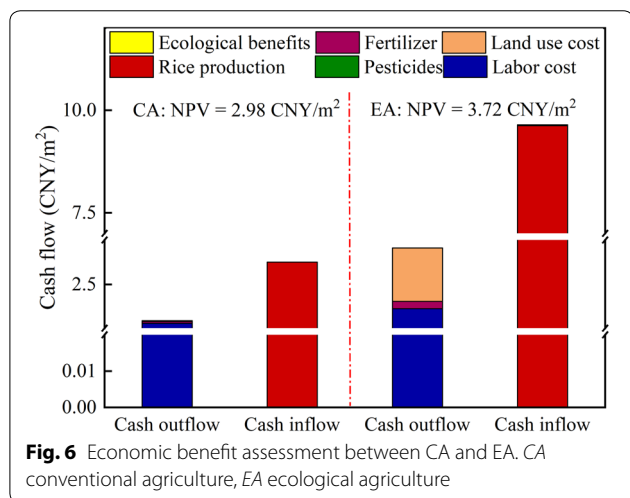
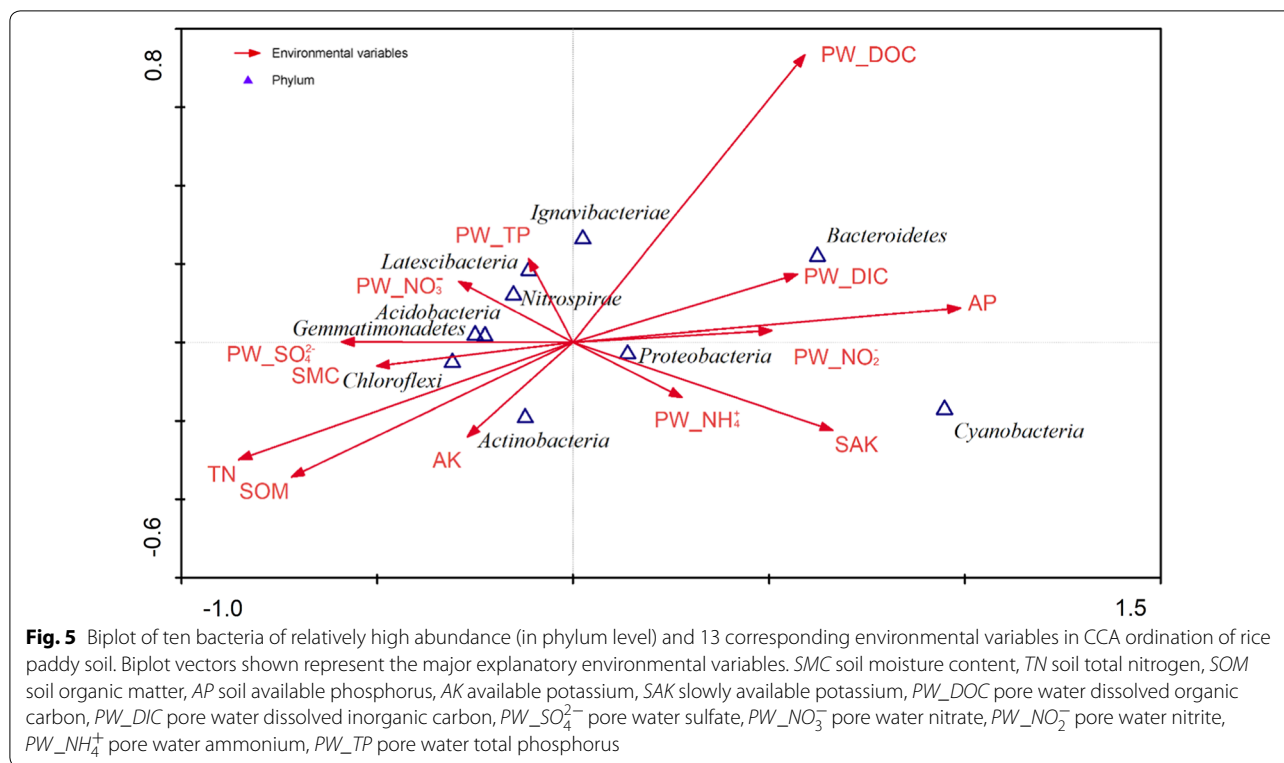
**Discussion**

**Soil physical–chemical characteristics and nutrient status**

SOM, as a major nutrient in paddy ecosystem, is mainly dependent on natural organic composition and chemical fertilizer [32]. The bioavailability of SOM is actually decided by the factions that is dissolved in the soil water [33], in particular pore water. Although SOM in



**Fig. 4** The relative abundance (%) of bacteria identified by Illumina high-throughput sequencing at the phylum (a) and genus (b) levels. CA represents conventional agriculture, and ecological agriculture is abbreviated as EA



CA was significantly higher than in EA, a higher amount of pore water DOC ( $71.11 \pm 7.28$  mg/L) found in EA implied that SOM was not the limit factor of low yield in the current study. Simultaneously, soil properties and fertility improvement by EA application has been recorded. Contrary to SOM, an extremely low amount of AP ( $1.57 \pm 0.81$  mg/kg) was observed in CA, which is more than one-fifth of that in EA ( $10.17 \pm 5.37$  mg/kg), showing a better condition for rice growth. Our results

are similar to the study by Irshad et al., in which rapeseed meal was applied to soil resulting in accumulation of phosphorus fractions up to 4.6-fold [34]. The possible reason for this phenomenon could be that rapeseed meal was used as organic amendments in this study, since the decomposition of organic amendments usually experiences longer time, while fertilizers are accumulated by plants and microorganisms rapidly or transported to the water body in the vicinity via runoff [35]. A relatively high amounts of AP and pore water DOC were observed from EA, revealing that organic amendments can extend the sustainability of paddy ecosystem and improve paddy soil properties [36]. Soil moisture content did not vary significantly between EA and CA, both of which are favorable for rice growth. Soil pH at neutral level is suitable for crop growth. The pH in EA was  $7.00 \pm 0.45$ , which is higher than that in CA ( $5.90 \pm 0.49$ ), indicating better pH condition of EA than CA.

Hu illustrated that AK ranges at 50–100 mg/kg and simultaneously SAK amount is approximate or higher than 350 mg/kg are the optimal condition for rice growing [37]. Thus, soil AK (54.00 mg/kg for EA and 70.67 mg/kg for CA) and SAK (315.67 mg/kg for CA and 350.67 mg/kg for EA) in both fields facilitated rice cultivation in the current study area. Soil TN is rich in both fields, but the available fractions for plant accumulation (N-pore water fraction in the current study, i.e.,

PW\_NH<sub>4</sub><sup>+</sup>, PW\_NO<sub>2</sub><sup>-</sup> and PW\_NO<sub>3</sub><sup>-</sup>) were the extreme limit. However, TN and AK in EA were both lower than that in CA, indicating that limitations on N and AK may be the major reasons for the low yield in EA. Overall, EA practice fosters biotic and abiotic interactions in the soil and enhance nutrient cycling, and thus significantly improve the soil fertility, while long-term experience of CA leads to soil quality degradation [38].

### Biodiversity and ecological service functions

We found that the plant richness in EA was significantly higher than in CA, implying that higher stability of paddy ecosystem in EA is expected, which promotes the sustainability of agriculture development. Although weeds have generally been considered as a main factor limiting grain yield due to the strong competition with rice plants for nutrient uptake [39], multiple ecological benefits can be obtained through optimization on weeds diversity, for instance biodiversity conservation, pest control, greenhouse effect mitigation and nutrient and soil properties' improvement [22, 23]. The rice-duck cultivation, as one of the effective ecological approaches to control weeds and pest, contributed remarkably to the sustainability of paddy ecosystem in EA.

According to the CCA results, SOM, soil TN and pore water DOC were highly responsible to the patterns of bacterial diversity. Although the amounts of SOM and soil TN were higher in CA than in EA, pore water DOC of EA was contrarily higher than that of CA. Bacterial diversity in EA were higher than that in CA, in particular for ACE and Chao1 ( $P < 0.05$ ). Thus, in the current study, pore water DOC could be the main reason of increasing bacterial diversity in EA, suggesting that with 3 years experience of EA, the soil properties were improved. Our results are also consistent with those of other studies that the use of biochar or straw as organic amendments can promote soil microbial diversity [40–42].

Proteobacteria, Chloroflexi and Actinobacteria are the dominant phylum in most rice paddy fields [43], which are consistent with our findings. The predominant genus belongs to Proteobacteria, except Bryobacter and Candidatus Solibacter, both of which belong to Acidobacteria in both EA and CA. With Proteobacteria, Geobacter is a dominant genus within the family of Geobacteraceae in our study, which plays an important role in metals cycling and biogeochemical cycle of nutrients and organic pollutant degradation [44]. The relatively high abundance of Anaeromyxobacter and Geobacter in the paddy field may contribute to metal reduction such as Fe(III) and As(V), and thus the higher abundance of Geobacter and Thiobacillus found in EA may alter the emission of greenhouse gases in EA [45]. The presence of Thiobacillus and Desulfobacca as predominant genera and high concentration

of SO<sub>4</sub><sup>2-</sup> in pore water could reveal fast biogeochemical cycle of sulfur in the paddy fields of the current study sites. In addition, Desulfobacca may co-contribute to the carbon transformation process with other microorganisms, for instance methane generation and oxidation [46].

### Economic benefits of the small-scale paddies in the mountain area

The economic benefits of an agricultural cultivation are evaluated from NPV; the NPV of EA in the current study is 24.8% higher than that of CA, Sharda et al. even observed that the NPV of conservation bench terrace system is 56% higher than the conventional system [26], suggesting the advantage of EA in the mountainous area. In the current study, the cash outflow was quantified by labor cost, nutrient and pesticide application. The labor cost of EA (1.14 CNY/m<sup>2</sup>) is 3.6 times more than that of CA (0.32 CNY/m<sup>2</sup>) currently, both of which will increase continually due to the labor shortage resulting from the depopulation in the mountainous rural area, implying the necessity to optimize EA practice. Although the fertilizer cost of EA (0.41 CNY/m<sup>2</sup>) is four times that in CA (0.1 CNY/m<sup>2</sup>) and accounted up to only 10% of the cash outflow, soil fertility is better maintained in EA. Thus with soil degradation in CA, chemical fertilizer usages may increase. Since the land rent in EA accounted for 66% of the cost (12,600 CNY or 3 CNY/m<sup>2</sup>), if the farmland is managed without rent fee as CA, the net economic benefits of EA will significantly increase. The cash inflow was characterized as economic benefits received and ecosystem services provided, in which the rice price is the most important factor due to the fact that Chinese consumers are price sensitive in their rice purchases [31]. Meanwhile, rice price is also highly correlated to the scale of rice cultivation and sales [31, 47].

Considering that EA and CA can hardly alternate between the years, the decision for EA practice has to be carefully assessed in advance. Ecosystem services are not merchandized at the markets, which is difficult to stimulate farmers' enthusiasm. While for sustainable agriculture, there is a necessity to balance the trade-offs among production, biodiversity conservation and other ecosystem services, as well as social awareness, as pointed out by Kirchmann and Thorvaldsson and Norton [48, 49], in addition, a rice price guarantee and the improvement on the added values for example tourism may help the farmer's decision on EA [47]. With the increase in environmental awareness and EA products demand, CA may be replaced gradually by EA and consequently ecosystem services functions will be restored in the future.

Ladha et al. reported that rotation between rice and dry season crops such as wheat or rapeseed is one of the



most important agricultural systems in the world, which facilitates soil properties [50]. Integrating rice–dry season crop rotation with EA is considered as a replacement of the current CA. With respect to the depopulation and aging in the mountainous rural area, traditional agricultural systems and countryside landscape as well as rural social systems have been consistently changing. Combining EA with modern technologies for improving productivity and achieving multi-ecological benefits is the trend [51], which can synergetically develop along with agriculture, social–economic, and eco-environment benefits in Chinese mountainous area [52], as well as in the other developing countries [53].

## Conclusion

The current study serves as a modest spur to raise concern on the major factors that influence the application of EA in China. To this end, the patterns of soil nutrients, soil bacterial diversity, plant diversity and economic benefits of the rice paddies cultivated by CA and EA were investigated. Limitations on N and AK could be the major reasons for the low yield in EA. Pore water DOC could be the main reason for bacterial diversity increase in EA. The relatively high amounts of AP, pore water DOC and bacterial diversity revealed that EA can extend the sustainability of the paddy ecosystem and improve paddy soil properties. Besides, significant economic benefits were achieved in EA, suggesting that EA application in China mountain area can facilitate the sustainable development of the agroecosystem. However, animal diversity, as the other important biota in the agroecosystem, should be considered in further research [54]. Quantification of the economic benefits of ecological services to stimulate farmers' enthusiasm and environmental awareness is necessary.

## Abbreviations

CA: conventional agriculture; EA: ecological agriculture; USDA: the U.S. Department of Agriculture; SOM: soil organic matter; TN: total nitrogen; AP: available phosphorus; AK: available potassium; SAK: slowly available potassium; S: Patrick richness index; *D*: Simpson heterogeneity index; *H'*: Shannon–Weiner index; PW: soil pore water; DOC: dissolved organic carbon; DIC: dissolved inorganic carbon; TP: total phosphorus; OTUs: operational taxonomic units; CCA: canonical correlation analysis; ANOVA: analysis of variance; NGO: non-government organization; CNY: the ISO code for Yuan Renminbi; NPV: net present value.

## Authors' contributions

YS supported data interpretation and drafted the manuscript; ZLC conducted sampling, interpreted and evaluated the data and drafted the manuscript; ZHZ provided chemical analysis data; HXY and BL contributed to supporting the writing of the manuscript. All authors read and approved the final manuscript.

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## Competing interests

The authors declare that they have no competing interests.

## Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Consent for publication

All authors agreed to publish the paper.

## Ethics approval and consent to participate

Not applicable.

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