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Effects of Continuous Plastic Film Mulching on Soil Bacterial Diversity, Organic Matter and Rice Water Use Efficiency

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Abstract

Two field experiments were conducted to study the effects of 6-year plastic film mulching on bacterial diversity, organic matter of paddy soil and water use efficiency on different soils with great environmental variabilities in Zhejiang Province, China, under non-flooding condition. The experiment started in 2001 at two sites with one rice crop annually. Three treatments included plastic film mulching with no flooding (PM), no plastic film mulching and no flooding (UM), and traditional flooding management (TF). Soil samples were collected and analyzed for bacterial diversity by DGGE and organic matter content, and water use efficiency (WUE) was calculated. The results showed that PM treatment favored the development of a more total bacterial community compared with TF management, the total number of bands was 33.3, 31.7 at tiller stage and heading stage ($p < 0.05^*$). Hence, organic matter content was decreased by 36.7% and 51.4% under PM at two sites. PM also produced similar rice grain yield as TF at Duntou site and Dingqiao site, the average was 7924 kg·ha^{-1} and 7015 kg·ha^{-1} for PM and 8150 kg·ha^{-1} and 6990 kg·ha^{-1} for TF, respectively. Compared to TF, WUE and irrigation water use efficiency were increased significantly by 70.2% - 80.4% and 273.7% - 1300.0% for PM. It is essential to develop the water-saving agriculture.

Keywords

Rice (*Oryza sativa* L.), Water Use Efficiency, Water-Saving Agriculture, Bacterial Diversity

1. Introduction

Rice (*Oryza sativa* L.) is one of the major staple food crops in China. About 86% of the total water in China has

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been consumed in agriculture, of which 90% is consumed by rice production [1]. Owing to the pressure from large populations and water shortage for agriculture, it is urgent to develop water-saving and higher-yielding techniques for rice production. Plastic film mulching with no flooding (PM) has been adopted and developed as a new rice cultivation technique in China since the 1980s, and the total planting area under this management regime has reached 100,000 ha [2]. It is substantially different from both traditional flooded rice cultivation and rain-fed rice cultivation. PM regime plastic film is used during rice-planting stages under non-flooded conditions, and only 30 - 50 mm per irrigation is applied when soil water content falls below 80% of soil field capacities from transplanting to tiller stage. The use of this new cultivation regime has led to soil temperature and the growth of weeds has also been inhibited [3].

Soil microorganisms contribute to soil quality and regulate many ecosystem processes such as nutrient transformations and litter decomposition, as well as influence soil structural and bioremediation [4]. Both changes in soil microbial communities resulting from ecosystem management and global change can have significant impacts on ecosystem dynamics [5], and microorganisms respond sensitively to changes and environmental stress because they have intimate relations with their surroundings [6]. Therefore, interest in quantifying impacts on the biotic and abiotic component has increased with concern for the sustainability of agricultural ecosystem.

However, there is little information regarding the changes of organic matter content, bacterial community structure and water use efficiency under plastic film mulching with non-flooding conditions. In a 2-year study, Liu and Wu [7] showed the influence of PM on certain soil properties. In a rice-wheat cropping system, Liu *et al*. [8] reported the changes of nutrient uptake and nutrient balance in soil under plastic film mulching with non-flooding conditions. Hence, the objective of the present study is to investigate the effects of continuous plastic film mulching on organic matter content, bacterial community structure and water use efficiency. It is important for developing the water-saving agriculture.

2. Materials and Methods

2.1. Site Description

The field experiment was initiated in May 2001 at Duntou Town of Lanxi (29˚19'N, 119˚43'E and 72.8 m elevation above sea level) and Dingqiao township of Haining city (30˚26'N, 120˚39'E, 12.8 m elevation above sea level), which located in the Hangjiahu Plain and Jinqu Basin, Zhejiang Province, China. Average annual temperature is 17.7˚C and 15.7˚C, annual precipitation is 1399.8 mm and 1220.3 mm, cumulative temperature above 10˚C is 5532˚C and 4170˚C, annual frost-free days are 265 d and 231 d, total sunshine hours is 1981.6 h and 2021 h, respectively. The soil is referred to as Fec stagnic Anthrosols. Its properties are shown in **Table 1**.

2.2. Field Experiment Design and Management

The experiment was a randomized complete block design with three treatments and three replications. The three treatments were plastic film mulching with no flooding (PM), no plastic film mulching and no flooding (UM), and the traditional flooding management (TF). The plot size was 15 m^2. The TF plots were isolated from the PM and UM plots by a 2 m wide alley with plastic film vertically buried to a depth of 60 cm. The other plots were separated by 0.5 m wide irrigation furrows with two 0.3 m wide levees at two sides of the furrows. For the TF

Table 1. Soil physical and chemical characteristics.

Parameters	Duntou	Dingqiao
pH	5.10 ± 0.15	6.08 ± 0.02
OM ($g \cdot kg^{-1}$)	23.79 ± 1.42	23.11 ± 1.42
Total N ($g \cdot kg^{-1}$)	2.28 ± 0.20	1.90 ± 0.35
Total P ($g \cdot kg^{-1}$)	1.58 ± 0.03	1.08 ± 0.08
Available N ($mg \cdot kg^{-1}$)	142.53 ± 5.14	165.28 ± 5.06
Available P ($mg \cdot kg^{-1}$)	88.46 ± 3.00	11.54 ± 0.61
Available K ($mg \cdot kg^{-1}$)	212.94 ± 3.29	103.74 ± 2.37

treatment, the plots were flood-irrigated every 3 - 5 days to maintain a 3 cm water depth until 2 weeks before rice harvest. For the PM and UM treatments, no permanent water depth on soil surface was maintained during the rice growing season. From transplanting (early May) to tilling stage (early June), limited irrigation (30 - 50 mm per irrigation) was applied on PM and UM when soil water content fell below 80% of soil field capacities. The irrigation amounts and rainfall for the treatments were measured and recorded during rice growing seasons.

Fertilizer rates were 135 kg N ha^{-1} N as urea, 90 kg P_2O_5 ha^{-1} as calcium phosphate, and 90 kg K_2O ha^{-1} as potassium chloride. Prior to rice transplanting, fertilizers were broadcasted and incorporated into the top 15 cm soil by plowing. The rice variety was Liangyoupeijiu for Duntou and Bing 0209 for Dingqiao. The rice seedlings were transplanted at a spacing of 20 cm × 28 cm with two seedlings per hill. Plastic film, 0.005 mm thick and 1.7 m wide, was used to cover the soil in the PM treatment.

2.3. Soil Sampling and Analyses

Soil samples were collected from 0 to 15 cm layer at harvest stage and air-dried and through 0.149 mm sieve for determining organic matter in every year. Organic matter was tested by Walkley-Black. And fresh soil samples at Duntou were also collected at 5 August, 7 September 2006, which were the tilling and heading stages for the rice. Five random cores were taken from the plow layer (0 - 15 cm) of each plot with a 5 cm diameter tube auger. The samples of PM and UM treatments were mixed thoroughly and sieved (2 mm mesh) to remove visible plant roots, respectively. For the TF treatment, plant roots were removed by hand. The soil for the molecular analysis was kept immediately at −20˚C.

2.4. Molecular Biology Analyses

The bacterial community structure was also studied by a polymerase chain reaction-denaturing gradient gel electrophoresis (PCR-DGGE) approach [9]. Whole-community total DNA was extracted and PCR were performed according to M. Y. Wu *et al*. [10].

2.5. Water Use Efficiency (WUE) Analysis

WUE was calculated as the amount of grain yield per unit of water used. Water losses due to runoff and leaching were assumed to be negligible [11].

2.6. Data Analysis

The difference between different treatments was determined using the least significant difference (LSD) test in the data processing system SAS 8.02 software.

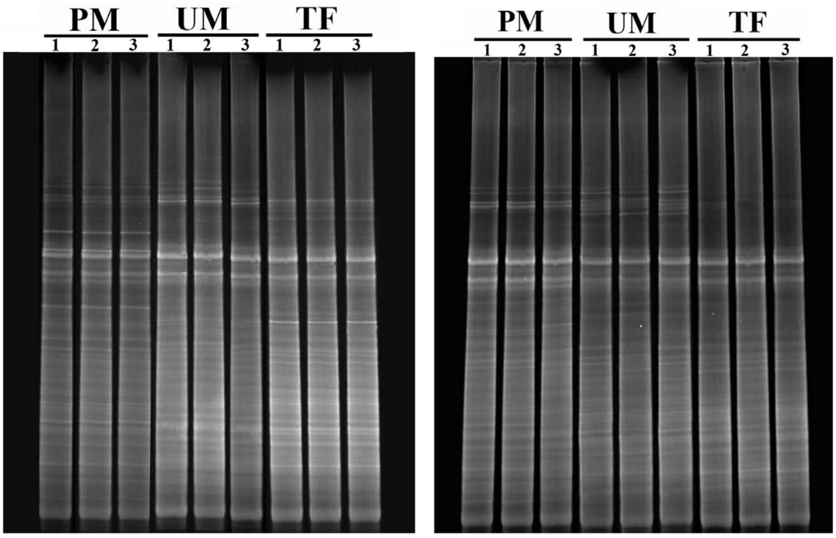
3. Results and Discussion

3.1. Bacterial Community Profile Determined by 16S rDNA Targeted DGGE

The DGGE fingerprinting of PCR-amplified 16S rDNA was shown in **Figure 1(a)** and **Figure 1(b)**, which was extracted from the soils with different treatments at tiller and heading stages. Apparently, the band patterns of three replicate samples from PM, UM, and TF were highly similar (>95% similarity). The total number of bands in DGGE profiles of different treatments is shown in **Table 2**. At tiller stage, the total number of bands was 33.3, 23.7, 27.0 for PM, TF, and UM treatment, respectively ($p < 0.05^*$). At heading stage, the total number of bands was 31.7, 20.0, 28.3 for PM, TF, and UM treatment, respectively ($p < 0.05^*$). That is, these changes in the number of bands suggest that PM treatment favored the development of a more total bacterial community compared with TF management. One dominant band showed little change among three treatments, suggesting that it may be a predominant bacterial community. It is possible that low pH in TF management could be responsible for the low numbers of dominant bacterial bands as found on DGGE, because there was an increased pH value in PM management [10] [12].

3.2. Changes of Organic Matter

The decreased trend of organic matter content was presented with continuous plastic film mulching under



(a) (b)

Figure 1. Denaturing gradient gel electrophoresis gel of bacteria 16S rDNA polymerase chain reaction products amplified from three replicate samples of PM, UM, TF treatment soil-DNA extracts. (a) Tiller stage; (b) Heading stage. PM: non-flooded plastic film mulching cultivation; TF: traditional flooding cultivation; UM: non-flooded cultivation without plastic film mulching; 1, 2, 3: three replicate samples from PM, UM, TF, respectively.

Table 2. Total number of bands in DGGE profiles from PM, TF, UM treatments.

Treatment	Tiller stage	Heading stage
PM	33.3 (±0.6) a	31.7 (±0.6) a
UM	27.0 (±1.0) b	28.3 (±0.6) b
TF	23.7 (±0.6) c	20.0 (±1.0) c

Standard error is indicated in parentheses (n = 3).

non-flooding condition. At Duntou sites, organic matter content were declined by 36.7%, 28.5% and 33.9% under PM, UM and TF, respectively, compared with the initiation (**Figure 2**). At Dingqiao sites, organic matter content under PM, UM and TF were decreased by 51.4%, 51.5% and 40.3% after 6 years, respectively (**Figure 3**). The reason for these results is that plastic film mulching increased soil temperature during the entire growing seasons, and resulted of the improving of bacterial community activities and diversities, which promoted the decomposition of organic matter. This was similar to the previous studies [13] [14].

3.3. Grain Yield and Water Use Efficiency (WUE)

No significant trend existed in rice yields among the different treatments (**Table 3**). PM produced similar rice grain yield as TF at Duntou and Dingqiao sites, the average was 7924 $kg \cdot ha^{-1}$ and 7015 $kg \cdot ha^{-1}$ for PM and 8150 $kg \cdot ha^{-1}$ and 6990 $kg \cdot ha^{-1}$ for TF. Grain yields in PM had significantly higher than UM plots for two years at two sites, 2.7%, 6.1% at Duntou and 0.8%, 8.1% at Dingqiao, respectively.

Plastic film mulching reduced rice water consumption. During rice growing seasons in different years, the total water consumption in PM plots was 723 - 890 mm, much lower than that in TF plots, which was 1388 - 1591 mm. Irrigation water used in PM was 103 - 253 mm and in UM 196 - 310 mm, which were much lower than those in TF (718 - 947 mm). The irrigation water use reduced by 72.8% - 85.6% in PM and 66.9 - 72.8% in UM compared to TF treatment. Water use efficiency (WUE) in terms of grain yield per unit consumed water increased by 70.2% - 80.4% for PM and 47.9% - 63.8% for UM. Irrigation water use efficiency in terms of grain yield per unit irrigation water improved by 273.7% - 1300.0% for PM and 171.8% - 585.4% for UM, compared with TF respectively. PM reduced water consumption and increased WUE significantly compared to TF. These results were strongly supported by other studies conducted in the same region or elsewhere [15] [16].

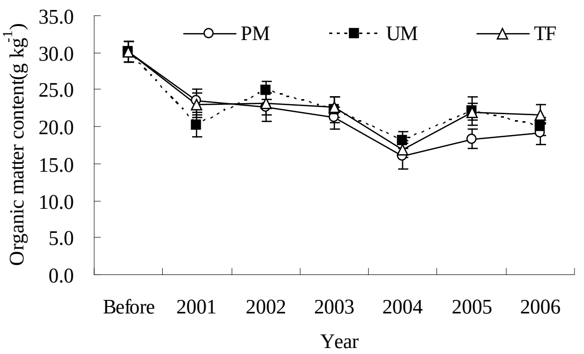


Figure 2. Dynamics of soil organic matter content in different years at Duntou site.

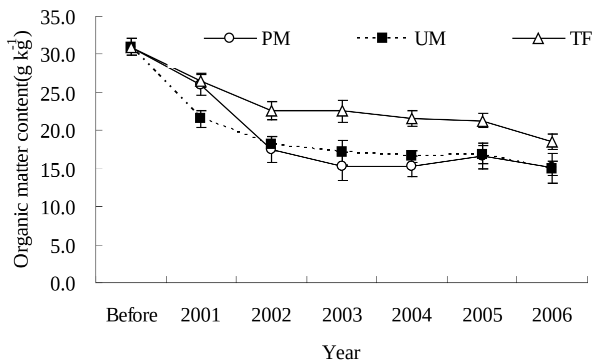


Figure 3. Dynamics of soil organic matter content in different years at Dingqiao site.

Table 3. Effect of plastic film mulching on grain yield and water use efficiency.

Site	Year	Treatment	Grain Yield ($kg·ha^{-1}$)	Irrigation (mm)	Rainfall (mm)	Water Consumption (mm)	WUE ($kg·m^{-3}$)	IWUE ($kg·m^{-3}$)
Duntou	2003	PM	8910 a	251 c	607	858 c	1.04 a	3.55 a
		UM	8670 b	310 b	607	917 b	0.95 a	2.80 b
		TF	9000 a	947 a	607	1554 a	0.58 b	0.95 c
	2006	PM	6937 a	253 c	610	873 c	0.80 a	2.74 a
		UM	6540 b	308 b	610	948 b	0.71 a	2.12 a
		TF	7300 a	931 a	610	1590 a	0.47 b	0.78 c
Dingqiao	2003	PM	7080 a	118 c	655	773 c	0.92 a	6.01 a
		UM	7020 a	201 b	655	856 b	0.82 a	3.49 b
		TF	7110 a	733 a	655	1388 a	0.51 c	0.97 c
	2006	PM	6950 a	103 c	707	890 a	0.86 a	6.72 a
		UM	6430 b	195 b	707	927 b	0.71 b	3.29 b
		TF	6870 a	718 a	707	1460 c	0.48 c	0.48 c

4. Conclusion

This study shows that 6-year PM treatment in rice field stimulated the development of total bacterial communities by DGGE, which resulted of the decreased organic matter content in two study areas, and PM also produced similar or higher rice grain yield compared to TF and improved water use efficiency.

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