EFFECTS OF DEGRADABLE MULCHING FILM ON SOIL TEMPERATURE, SEED GERMINATION AND SEEDLING GROWTH OF DIRECT-SEEDED RICE (*ORYZA SATIVA* L.)

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Abstract. The effect of degradable mulching film on dry direct- seeded rice remains largely unknown. Then the aim of this research is to investigate the effects of degradable mulching film on dry direct-seeded rice. A field investigation of four treatments (CK: non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)) was conducted to evaluate the effects of degradable mulching film on the rice seed germination, seedling growth, soil temperature, and grain yield of dry direct-seeded rice. The results showed that compared to CK, mulching film treatments increased soil temperature, especially at night time, improved seed germination rate, plant height, leaf area of seedlings, and grain yield. MF1 showed good degradation performances and had the highest soil temperature at the night time of 13.65 ℃ - 14.08 ℃, grain yield at 7.938t ha^{-1}, and seedling growth with shoot dry mass at 46.73 mg $plant^{-1}$ and root dry mass at 31.34 mg $plant^{-1}$. The germination rate significantly increased by 6.99%-755.60% at MF1 as compared to CK. Overall, mulching films resulted in high yield due to the increasing soil temperature, seedling germination, and improving seedling growth, amongst MF1 performance the best.
Keywords: *hill-drop drilling, grain yield, degradation progress, leaf area, root to shoot ratio*

Introduction

Mulching film in the field provided a suitable microclimate for crop growth (Diaz-Perez et al., 2009; Namaghi et al., 2018; Zhang and Miles, 2020), enhanced the disaster resistance ability of crops and ultimately increased crop production (Bu et al., 2013; O'Loughlin et al., 2017; Deschamps et al., 2019). The use of plastic film mulching allows for an early seeding date and a shortened germination time and increases the germination rate and the emergence rate, and achieves water-saving effects (Li et al., 2013; Biswas et al., 2015; Cosic et al., 2017). Especially, dry direct-seeded rice with mulching film could improve water utilisation rate, inhibit weeds growth, and improve soil temperature after sowing, which were conducive to high and stable yield (Towa et al., 2013; Fawibe et al., 2020). Traditional mulching film is polyethylene (PE), its application has caused environmental pollution and affected the food safety (Chae et al., 2018; Boots et al., 2019;

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Hu et al., 2020). Therefore, the use of degradable mulching film is essential for the development of future agriculture.

Previous studies have reported the application of biodegradable mulching films (Brodhagen et al., 2015; Moreno et al., 2017; Cozzolino et al., 2020). For example, the effects of biodegradable films on the production of peanut (Sun et al., 2018). The effect of mulching films on the biomass and soil organic matter mineralization and the yield of tomato has been evaluated (Moreno et al., 2008). A previous study has reported that biodegradable polymers improved root growth conditions and fruit quality of tomato (Sekara et al., 2019). The biodegradable paper mulching increased the yield of tomato and improved the fruit quality due to reduced nitrate but increased vitamin C (Zhang et al., 2019a). It has been reported that degradable mulching films affect the corn production and that degradable mulching films have comparable temperature conservation and water retention effects in response to common mulching films (Yang et al., 2010). Besides, previous report has indicated that the corn yield with biodegradable mulching film was similar to that with common mulching film and the biodegradable mulching film was sufficiently degraded after crop harvest (Hu, 2015). Research has shown that there were no significant differences in yields of *Brassica chinensis* L. among the degradable films, but the yield under degradable films was increased by 80% as compared to that with the non-mulching film and by 50% compared to that of common mulching film, and the natural protein, soluble sugar, and other components in *B. chinensis* L. were adequately improved (Shi et al., 2012). The effect of biodegradable film mulching on the production test of winter oilseed rape has been investigated and results showed that no significant difference in the average yield and water use efficiency in degradable film mulching were detected, whilst degradable film mulching showed higher seed quality than PE (Gu et al., 2017). Moreover, Bilck et al. (2010) have reported the effects of biodegradable mulching film on the production and quality of strawberry. Further study about the degradable film mulching on crop growth and development is still needed.

The effect of the application of degradable mulching film on the growth and yield of many crops such as tomato, corn, strawberry has been studied. Few studies have been conducted to evaluate the effect of degradable mulching film on the rice grown and yield. In this study, a field experiment was conducted to evaluate the degradable mulching film on the rice seed germination, seedling growth, soil temperature, and grain yield of direct-seeded rice. The results of this study may provide a basis and reference for the application of degradable mulching film in the rice field.

Materials and methods

Description of study field

The experimental site is located at Wudaohezi Village, Haolibao Town, Jalaid Banner, Hinggan League, Inner Mongolia Autonomous Region, P.R. China (46°35'43"N, 123°04'36"E; 174 m in altitude). It has a temperate continental monsoon climate. There is a large temperature difference between day and night. The average annual temperature is 4.4 °C; the average annual precipitation is 430 mm, with the precipitation is primarily concentrated from June to August. The average frost-free period is 130 d. The site has a meadow soil type with deep and thick layers, and upon tillage, it is finely broken with a flat surface. The mass fraction of organic matter in the plough layer was 22.36 g/kg, and the pH of the topsoil was 5.89.

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Mulching film performance

In this study, three types of mulching film, MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China), MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China), and MF3: a common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China), were used. The performance measurements of each mulching film were repeated three times. The transmittance is an important index of optical performance that determined the amount of solar energy absorbed by the soil. In this study, transmittance/fog tester is used (Brand: Shanghai Shenguang Instrument & Meter Co., LTD.; Model Number: WGT-S; Division value: 0.01%). The light transmittance was in trend of MF1>MF3>MF2. Microcomputer controlled electronic universal material testing machine (Brand: Shanghai Hengyi Precision Instrument Co., LTD.; Model No.: Hy-0580; Maximum load: 500 N; Precision grade: 0.5 magnitudes) was used to detect the film tensile strength, elongation, and elastic modulus. The tensile strength and modulus of elasticity in MF2 and MF3 are better than that of MF1. The elongation of MF1 and MF3 was superior to that of MF2. (as shown in *Table 1*).

Table 1. *The properties of Mulching film*

Mulch	Transmittance (%)	Tensile Strength (Mpa)	Elongation (%)	Elastic Modulus (Mpa)
MF1	6.48A	9.51B	278.45B	148.80B
MF2	0.58C	10.51AB	93.64 C	297.39A
MF3	4.50B	11.90A	469.28A	263.27A

Different uppercase letters followed by the same column among the treatments means significant differences ($p<0.01$) according to LSD. MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)

Experiment design

Three mulching film treatments (MF1, MF2, and MF3) were carried in this experiment, and the non-mulching treatment was taken as control (CK). The three types of mulching film are black, with 0.01 mm in thick, and 1550 mm in wide. The planting pattern of "one film, two drip irrigation belts, and eight rows" (as shown in *Fig. 1*) was adopted, and all the field work was completed by a multi-functional machine that integrated film laying, seed sowing, and soil covering.

Figure 1. *Planting pattern diagram*

In the experiment, the length of each treatment was 50 m, and each treatment was repeated 3 times, and the total plot area was 1250 m^2 (50×25 m). The distance between treatments was 600 mm which was increased that the external influences and interactions between the treatments were reduced. During planting, wide and narrow row spacing was

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used in an alternating manner, with the narrow row spacing being 120 mm and the wide row spacing being 250 mm. One drip irrigation belt was set in the middle of the wide row, which was shared by four rows.

The same water and fertilizer management were used in the four treatments, which was consistent with local field management. The pump station was used to supply water and fertilizer in equal amounts through drip irrigation belts, and the time of water and fertilizer application was recorded. On April 10, 2019, base fertilizer was applied, and the fertilizer was mixed fertilizer (N:P:k=12:18:15) of 150 $kgha^{-1}$ and biological fungus fertilizer of 150 kg ha^{-1}. Topdressing twice during the growth cycle: June 5 (urea: 37.5 kg ha^{-1}, liquid fertilizer (high nitrogen type): 22.5 kg ha^{-1}) and June 20 (liquid fertilizer (high potassium type): 22.5 kg ha^{-1}). According to the growth stage of rice and weather conditions to determine the time and amount of water supply. In the mulching treatments, manual weeding was used, while the combination of mechanical and herbicide weeding was applied in the non-mulching treatment.

The tested rice variety was Suijing 18, which covers the largest local cultivation area. It has a growth period of 135 d. The technique of seeding in dry soil and drip irrigation for emergence was adopted. The seeds were sown on April 29, 2019, and 15±3 seeds were sown per hill with a hill spacing of 120 mm; and the plants were harvested on September 25-28, 2019. The degradation progress of mulching film was observed until the next sowing season (April 15, 2020).

Sampling and measurement

Soil temperature

The soil temperature at different soil depths for each treatment was measured by a set of sensors (Manufacturer: Sonbest Company of Shanghai; Model Number: KM3002B; Configuration: three probes), which were installed in the soil at 5, 10, and 15 cm below the ground surface. The system collected and storaged data automaticly at intervals of 30 min.

Germination rate

The germination rate is an important basis for guaranteeing that a crop has full germination with a single sowing, and it can reflect the effects of different treatments on germination. After the first water supply, the rice seeds would readily have the appropriate germination conditions. After 5 d of water treatment, the germination condition was closely monitored. For each treatment, 10 hills of plants were selected to determine the germination rate, which was recorded once a day until the germination rate of the all treatments was stable; the germination rate for each treatment was rendered as the final germinate rate.

$$\text{Germination rate (\%)} = \text{number of buds} / \text{number of seeds} \times 100\% \qquad \text{(Eq.1)}$$

Plant height and leaf area

The plant height and leaf area are the most commonly used indicators for measuring the growth of rice seedlings at the seedling stage. At the three-leaf stage, 10 rice plants with uniform growth were selected for each treatment; their plant heights were measured using a steel ruler, and the leaf area of each plant was calculated using an LA-S series

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plant image analyser (Manufacturer: Wseen Ltd., Hangzhou, China; Model Number: LA-S Series).

Biomass

The root and shoot biomass of rice plants were measured at the three-leaf stage. for each treatment, 10 rice seedlings with uniform growth were selected and excavated as a whole. They were washed and rinsed with water, air-dried, and then cut with scissors at the top of the root system. The plants were separately placed in a drying container, which was in turn placed in an electric thermostatic drying oven (Manufacturer: Shanghai Heheng Instrument & Equipment Co., Ltd.; Model Number: DHG-9050A) at 105 °C for fixation (30 min); next, the temperature was adjusted to 80 °C to dry the materials to a constant weight. The samples were weighed using a high-precision electronic balance (Model: Hengji Electronic Analytical Weighing Scale FA1204; Precision level: level 1; Range: 120 g; Division value: 0.1 mg).

The degradation progress of mulching film

Mulching film cannot degrade prematurely to affect the growth of rice seedlings, meanwhile, the degradation cycle cannot be too long to affect the planting of the next crop season. In this study, the degradation process was recorded and measured by visual assessment and picture comparison. The induction period, cracking period, major cracking period, fragmentation period, residue film entrainment at harvest, and the degradation of residue film under conventional tillage were recorded.

Grain yield

The grain yield was randomly harvested from three points (1 m^2) for each treatment. After artificial threshing, electronic scale is used to weigh the rice grains, and then the average value of the three points is calculated, which is the grain yield under this treatment.

Statistical analysis

Data processing (the analysis of variance (ANOVA) and correlation coefficients) were performed using Microsoft Excel and Design Expert software. The differences amongst means separated by using the least significant difference (LSD) test at 5% significance level.

Results

Soil temperature

MF1 showed higher in the soil temperature at the 5 cm depth as compared to CK. A higher in the soil temperature at the 5 cm depth from 7:00-22:00 was detected at MF2 when compared to CK. MF3 showed lower in the soil temperature at the 5 cm depth from 7:00-16:00 but higher in the soil temperature at the 5 cm depth from 16:00-7:00. Compared with CK, MF1 and MF2 showed higher in the soil temperature at the 10 and 15 cm depth. MF3 showed lower in the soil temperature from 7:00-16:00 and 8:00-17:00 at 10 and 15 cm depth than CK, respectively. Compared with CK, higher in the soil

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temperature from 16:00-7:00 and 17:00-8:00 at 10 and 15 cm depth was detected for MF3 (*Figure 2*).

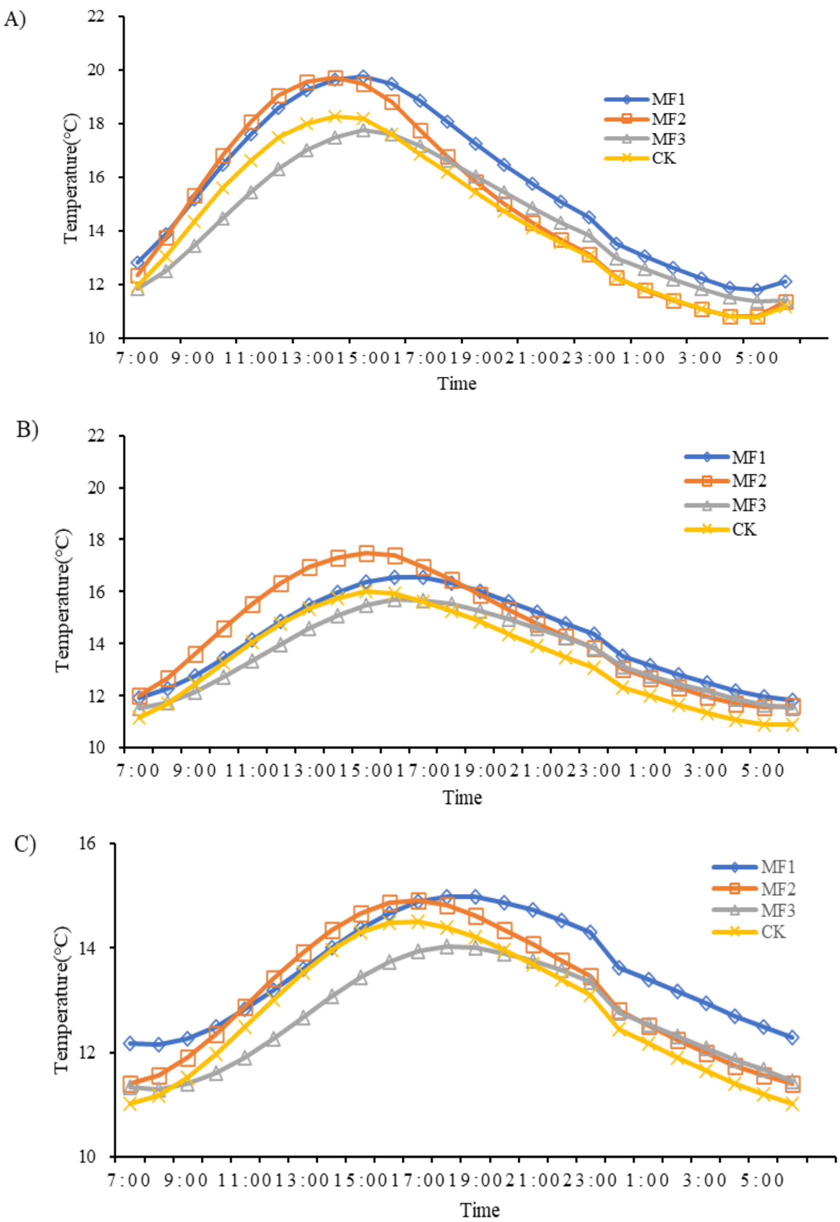

Figure 2. *Changes of the daily soil temperature in soil depth of 5 cm (A), 10 cm (B), and 15 cm (C). CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

From 8:00-18:00, compared with CK, MF1, and MF2 significantly increased the average soil temperature at 5cm depth by 7.63% and 7.42%, respectively. The average soil temperature at 10 cm depth significantly increased by 9.58% at MF2 as compared to CK. No significant difference was detected in the average soil temperature at 15 cm depth among the treatments (*Table 2*).

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Table 2. *The average soil temperature under different treatments*

Treatment	Temperature (℃) during 8:00-18:00			Temperature (℃) during 18:00-8:00		
	5 cm	10 cm	15 cm	5 cm	10 cm	15 cm
MF1	17.862a	14.84b	13.451a	14.077a	13.732a	13.653a
MF2	17.826a	15.882a	13.482a	12.894bc	13.387a	12.911b
MF3	15.912b	14.036c	12.534b	13.34b	13.249a	12.755b
CK	16.596b	14.493bc	13.096ab	12.738c	12.595b	12.54b

Different lowercase letters followed by the same column among the treatments means significant differences ($p<0.05$) according to LSD. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)

From 18:00-8:00, the average temperature in the soil at 5 cm depth significantly increased by 10.51% and 4.73% at MF1 and MF3 as compared to CK, respectively. Compared with CK, MF1, MF2, and MF3 significantly increased the average temperature in the soil at 10 cm depth by 9.03%, 6.29%, and 5.19%, respectively. The average temperature in the soil at 15 cm depth significantly increased by 8.86% at MF1 as compared with CK (*Table 2*).

Germination rate

Compared with CK, significantly increased germination rate by 213.02% was detected at MF1 on 10 May. On 12 May, the germination rate significantly increased by 755.60%, 450.71%, and 621.54% at MF1, MF2, and MF3, respectively as compared to CK. Significantly increased in the germination rate at MF1, MF2, and MF3 were detected on 13 May (increased by 331.26%- 378.49%), 14 May (increased by 20.97%-22.13%), 15 May (up to 8.63%), and 16 May (up to 6.99%) (*Figure 3*).

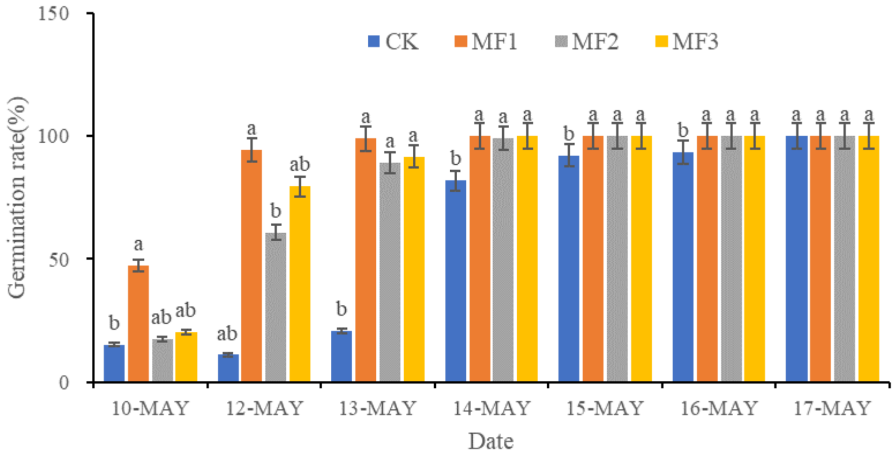

Figure 3. *The germination rate under different treatment. Different lowercase letters above bars indicated that there were significant differences ($p <0.05$) according to LSD. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

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Seedling growth

The plant heights significantly increased by 46.88%, 57.29%, and 41.67% at MF1, MF2, and MF3 as compared to CK, respectively (*Figure 4*). The leaf areas significantly increased by 26.12%, 25.64%, and 30.64% at MF1, MF2, and MF3 as compared to CK, respectively (*Figure 5*). MF1 had the highest dry mass in the shoot (46.73 mg plant^{-1}) and root (31.34 mg plant^{-1}), whilst no significant difference in shoot biomass, root biomass, and root to shoot ratio was detected (*Figures 6-8*).

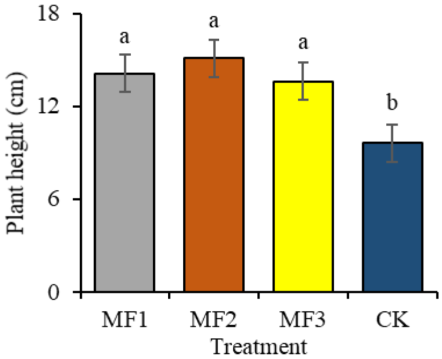

Figure 4. *The plant height of seedling under different treatments. Different lowercase letters above bars indicated that there were significant differences (p<0.05) according to LSD. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

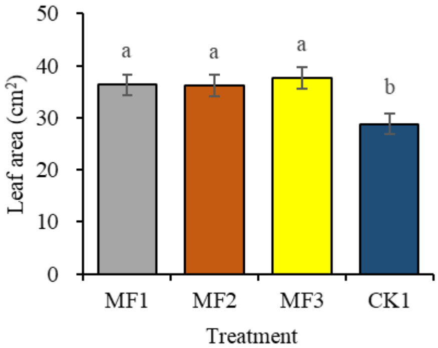

Figure 5. *The leaf area of seedling under different treatments. Different lowercase letters above bars indicated that there were significant differences (p<0.05) according to LSD. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

Grain yield

The highest grain yield was detected at MF1 (7.938 t ha^{-1}). The grain yield was increased by 11.83%, 4.82%, and 5.73% at MF1, MF2, and MF3 as compared to CK, respectively (*Figure 9*).

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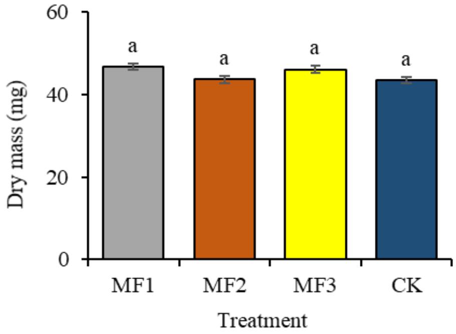

Figure 6. *The aboveground dry mass of seedling under different treatments. Different lowercase letters above bars indicated that there were significant differences (p<0.05) according to LSD. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

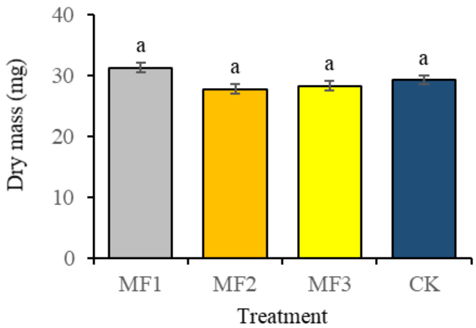

Figure 7. *The root dry mass of seedling under different treatments**.** Different lowercase letters above bars indicated that there were significant differences (p<0.05) according to LSD. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

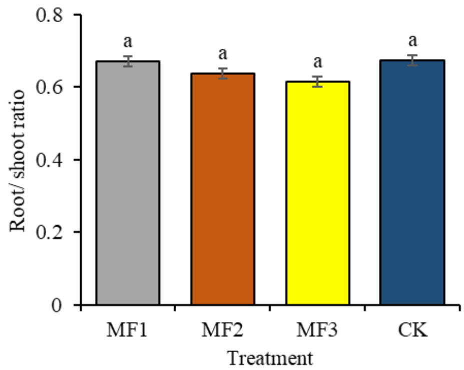

Figure 8. *The root/shoot ratio of seedling under different treatments**.** Different lowercase letters above bars indicated that there were significant differences (p<0.05) according to LSD. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

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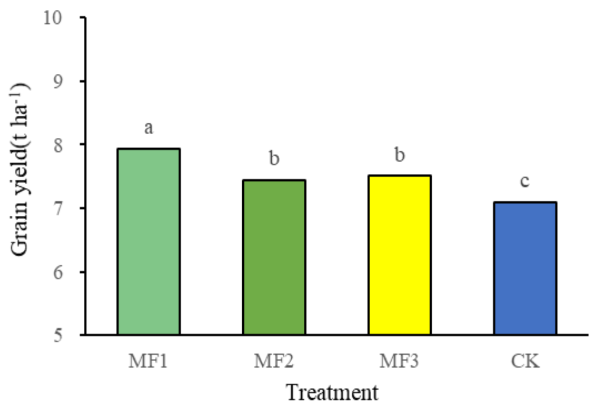

Figure 9. *The grain yield under different treatments. CK: Non-mulching; MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: Common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)*

The degradation progress of mulching film

The induction period for MF1 and MF2 was 19-June and 28-June, respectively. The cracking period for MF1 and MF2 was 28-June and 7-July, respectively. A similar major cracking period and fragmentation period were detected for MF1 and MF2. Both MF1 and MF2 showed good degradation performances. MF3 showed no degradation (*Table 3*).

Table 3. *The degradation progress of mulching film in field*

Period	MF1	MF2	MF3
Induction period	June 19	June 28	-
Cracking period	June 28	July 7	-
Major cracking period	September 7	September 7	-
Fragmentation period	September 17	September 17	-
Residue film entrainment at harvest	No entrainment	No entrainment	No entrainment
Degradation of residue film under conventional tillage	Good degradation	Good degradation	No degradation

MF1: a degradable film (Shanghai Hongrui Biotech, Shanghai, China); MF2: a degradable film (Xifeng Plastic Corp. Ltd., Baishan, China); MF3: common agricultural mulching film (Jialiming New Material Corp Ltd., Hinggan League, China)

Correlation analysis

The germination rate on 10 May was significantly positively related to the mean temperature at 5 cm depth in the soil from 18:00-8:00 and the mean temperature at 15 cm depth in the soil from 18:00-8:00. The plant height is highly related to the germination rate on 14-May, 15-May, and 16-May. The leaf area is highly related to the germination rate on 13-May 14-May, 15-May, and 16-May (*Table 4*).

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Table 4. *Correlation analysis between the investigated parameters*

Index	V001	V002	V003	V004	V005	V006	V007	V008	V009	V010	V011	V012	V013	V014	V015	V016
V002	0.7059															
V003	0.5390	**0.9598***														
V004	0.4664	0.9414	**0.9962****													
V005	0.4410	0.9254	**0.9935****	**0.9987****												
V006	0.4410	0.9254	**0.9935****	**0.9987****	**1.0000****											
V007	0.7859	0.8488	0.6709	0.6388	0.6000	0.6000										
V008	0.8700	0.2894	0.0574	-0.0247	-0.0560	-0.0560	0.5767									
V009	0.3809	-0.3781	-0.5129	-0.5846	-0.5906	-0.5906	-0.1456	0.7240								
V010	0.3622	0.8250	0.9476	**0.9526***	**0.9661***	**0.9661***	0.4019	-0.1390	-0.5282							
V011	0.3862	0.9230	**0.9770***	**0.9903****	**0.9869***	**0.9869***	0.6441	-0.1009	-0.6788	0.9195						
V012	0.5101	0.2720	0.3444	0.2911	0.3147	0.3147	-0.0407	0.3462	0.4302	0.4867	0.1581					
V013	-0.0204	0.0254	0.2358	0.2275	0.2715	0.2715	-0.4502	-0.2249	0.0842	0.5091	0.1320	0.8321				
V014	0.3836	0.0255	0.0957	0.0412	0.0677	0.0677	-0.2346	0.3369	0.5854	0.2649	-0.0941	**0.9674***	0.8273			
V015	**0.9551***	0.8403	0.6701	0.6139	0.5824	0.5824	0.9309	0.7564	0.1237	0.4489	0.5681	0.3041	-0.1870	0.1303		
V016	0.7559	0.9407	0.9406	0.9084	0.9044	0.9044	0.6890	0.3372	-0.1919	0.8837	0.8473	0.5810	0.3298	0.3594	0.8000	
V017	**0.9628***	0.7655	0.6667	0.5994	0.5858	0.5858	0.6962	0.7381	0.2907	0.5603	0.5046	0.6817	0.2284	0.5342	0.9043	0.8732

* and ** significant at 0.05 and 0.01 level, respectively.

V001: germination rate on 10-May; V002: germination rate on 12-May; V003: germination rate on 13-May; V004: germination rate on 14-May; V005: germination rate on 15-May; V006: germination rate on 16-May; V007: aboveground dry mass; V008: root dry mass; V009: root/shoot ratio; V010: plant height; V011: leaf area; V012: mean temperature at 5 cm depth in soil during 8:00-18:00; V013: mean temperature at 10 cm depth in soil during 8:00-18:00; V014: mean temperature at 15 cm depth in soil during 8:00-18:00; V015: mean temperature at 5 cm depth in soil during 18:00-8:00; V016: mean temperature at 10 cm depth in soil during 18:00-8:00; V017: mean temperature at 15 cm depth in soil during 18:00-8:00

Discussion

The effect of degradable and traditional mulching films on soil temperature has been widely documented. Generally, the degradable mulching film and PE mulching film have similar effects of increasing soil temperature at crop early growth stages. For example, Shen et al. (2012, 2019) reported that in the early period of maize growth, the degradable films had good warming effects on soil, which were similar with the plastic film. The degradable films fulfilled successfully all the functions of the plastic film, thus they were recommended as viable option to the plastic film due to their good degradability. Zhang et al. (2020) reported that biodegradable plastic film mulching increased the soil temperature at soil depths of 5 cm, 15 cm, and 25 cm, over the maize's entire growth period, by 3.1 °C-3.2 °C in 2017 and 1.2 °C-2.1 °C in 2018 compared with the non-mulched treatment. This study shows that biodegradable plastic film could be used as a substitute for common plastic film (Zhang et al., 2020). But, previous study reported that the soil temperature under degradable mulch was higher than that of PE mulch (Subrahmaniyan et al., 2008), which was maybe related to the transmittance of mulch. The amount of heat exchange and radiation at night was related to the mulch materials, as the description of previous studies (Sekara, 2019). Therefore, in the present study showed that MF1 degradable film and the PE plastic film had good warming effects on soil in the early period of rice growth, but the increased temperature performance of degradable mulching films at the 5 cm, 10 cm, and 15 cm soil depths outperformed that of PE mulching film and the non-mulching treatment (*Table 2, Figure 2)*. Both degradable mulching film and PE mulching film had the effect of raising soil temperature, especially the thermal insulation effect at night promoted the germination of rice seeds and affected the growth of seedlings. Previous study reported that degradable mulch could significantly improve the temperature of soil tillage layer and promote plant growth and development. The grain yields for degradable films No.2, No.1, and No.3 which had different degradation cycles were significantly improved, and with no significant difference between degradable films and the plastic film (Shen et al., 2019). Previous study found that the night temperature of biodegradable mulch was higher than that of ordinary mulch, promoting the growth of crops (Zhang et al., 2016). Yin et al. (2012) described that biodegradable film mulching could significantly improve the temperature of soil tillage layer, with better thermal insulation performance, and was conducive to the growth and development of crops in the early stage. Alamro et al. (2019) reported that the current results showed that all mulching plot had significantly higher soil temperature than bare soil. The improvement of tomato plant growth was noticed mainly in leaf area, fresh and dry weight of shoot under biodegradable mulch treatment. Based on the results, the using of biodegradable mulch could perform similar and/or better than polyethylene mulch in term of tomato growth and yield, which could be adopted as a sustainable alternative to polyethylene mulch. Lopez-Tolentino et al. (2017) found that different plastic mulches impact positively on the yield of cucumber crop. The benefit in yield by the different plastic mulches in the conditions of this study was due to their soil warming ability that results in improved soil temperature, leaf area, and plant dry weight (Lopez-Tolentino et al., 2017). In the present study, degradable mulching film showed better warming effect, which was due to its higher light transmittance. Meanwhile, MF1 had the highest soil temperature at the night time of 13.65 ℃ - 14.08 ℃ (*Table 2*, *Figure 2*), which effectively extended the growth time of crops, and promoted rice germination and plant growth. The results of the present study were consistent with those of previous studies.

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MF1 degradable mulching film could be used as an alternative to PE mulching film due to the its similar properties in temperature.

As is known to all, temperature is an important factor affecting the germination of seeds. Mulching films increases the soil temperature and creates good conditions for seed germination. In this study, compared with CK, mulching film treatments increased soil temperature, especially at night time, which promoted the germination of seeds. Adamczewska-Sowinska and Sowinski (2020) reported that low soil and air temperatures hinder the germination of sweet maize seeds and their early growth. Similarly, previous study showed that degradable mulch has the same effect as PE plastic film, which promotes the germination and emergence of seeds and speeds up the growth process (Zhang, 2010). All of the researches were the same as the present study, in the present research both degradable mulching films and PE mulching film promoted the germination progress of rice seeds, and MF1 was 4 d earlier than that under the non-mulching treatment, and these effects may be due to the insulation and water retention of mulching films.

In the present study, the plant height, and leaf area of rice in the different mulching film treatments were higher than those in the bare soil, with no significant differences detected among the three mulching films. In this study, the positive effect of MF1 degradable mulching film on rice plant height, and leaf area in this region was comparable to that of the PE plastic film (*Figures 4-8*). These results are similar to previous studies, which have described that no significant differences were recorded in leaf area of seedling between degradable mulching films and common mulching film, whereas leaf area was lowest under the not mulched control. Moreover, degradable black mulching film N8 and common mulching film had the highest fruit yield, 77.8 t/ha on average, the not mulched control had the worst performance, 68.8 t/ha (Sekara et al., 2019). Zhang et al. (2019b) reported that the average plant height had no significant difference across all mulched treatments, but was greater than no mulch control. Furtherly, total fruit yield was greater across mulched treatments than the bare ground control. Zhang (2010) found that degradable mulch increased plant height and dry matter accumulation of crops, with no significant difference from normal mulching film. And the analysis of yield characteristic indicated that covered by normal mulching film and degradable film had great significance with bare land, but the influence of liquid film was not significant. Deng et al. (2019) found that both the biodegradable mulch film and the polyethylene plastic film significantly increased various physiological parameters, such as crop height, stalk diameter, and leaf area. And all the mulch film treatments significantly increased the yield of maize and cotton, but there was no significant difference among the three mulch film treatments. In this research, these mulching film treatments increased rice grain yield by 4.82-11.83% as compared to CK, due to mulching film treatments to promote the growth and health of plants, it was associated with the increase in rice grain yield. So, the present study was in agreement with previous studies.

The degradability of degradable mulching film is an important factor to be adopted. A lot of studies have been carried out on the degradation of degradable mulching film. Sintim et al. (2020) studied the degradation of different biodegradable plastic film in compost and soil. The results showed that the degradation performance of degradable plastic film was mainly affected by its physical and chemical properties. Meanwhile, the degradation rate of degradable plastic film in compost was faster than that in soil, the degradation rate in summer was greater than that in winter, and the degradation rate in rainy season was better than that in dry season. Yin et al. (2019) carried out a study on

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the effects of different degradation rates of biodegradable mulching film on soil environment and maize growth. The study showed that the degradation rate of biodegradable mulching film was affected by climate and crop species. For example, high temperature increased the degradation rate of biodegradable mulching film. Previous study reported that under controlled conditions, the aerobic biodegradation of Agrobiofilm®1 had an increase of 55.8% when comparing the continuous and the batch system, for 72 days of assay (Costa et al., 2014). In a maize experiment, Zhang et al. (2020) described that at the end of the growth period the degradation rates of biodegradable film1, 2, and 3 were 35.2%, 19.7%, and 18.1% in 2018, respectively. In the current study, the two kinds of degradable mulching film showed good degradation performance (*Table 3*). There was no bulk mulching film residue during tillage and preparation, which had no effect on the tillage and the next sowing season. Meanwhile, the degradation cycles could meet the requirements of rice growth. The present results consistent with the ones achieved.

Overall, mulching film treatments affected the soil temperature, lead to changes in the germination rate, plant height and leaf area of seedlings, and ultimately affected the grain yield. MF1 showed good degradation performances and the highest soil temperature at night time, grain yield, germination rate, and seedling growth.

Conclusions

Mulching film treatments increased soil temperature at night time, germination rate, plant height and leaf area of seedlings, grain yield. MF1 showed good degradation performances and the highest soil temperature at night time, grain yield, germination rate, and seedling growth. So MF1 degradable mulching film could be considered as an alternative for the common agricultural mulching film.

Degradable mulching film has a positive effect on the growth and yield of rice. In the future, the trial area of degradable mulching film in rice cultivation should be expanded to further verify the feasibility of this technology and the adaptability to different soil conditions. Meanwhile, the influence of degradable mulching film on soil should be studied.

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