Effects of Mulching Mode on Canopy Physiological, Ecological Characteristics and Yield of Upland Rice

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Abstract: The effects of mulching mode on population physiology and ecology of rice were studied using a combination P88S/1128 as the material under three mulching cultivation modes including plastic film mulching, straw mulching and liquid film mulching, as well as bare cultivation (control). The results indicated that mulching mode had significant effects on micro-meteorological factors and individual growth of rice, as shown by a significant reduction in the rice canopy temperature, especially during high-temperature periods, an increase of relative humidity, a better internal micro-meteorological environment of rice population. The rice under mulching cultivation conditions displayed a stronger transpiration and lower temperature of leaves, thereby improving the ability of anti-high temperature stress and markedly increasing the photosynthetic rate. Furthermore, the yield components of rice were significantly optimized under mulching cultivation, of which with plastic film mulching displayed the highest grain number per panicle and seed-setting rate and a yield increase of 16.81% compared with the control; and with straw mulching displayed an increase of effective panicle number and a 9.59% increase of total yield compared to the control.

Key words: upland rice; mulching; yield; photosynthesis; microclimate

Drought is one of the major disasters in agricultural production. The arid land area is about 1/3 of the total land area, and the reduction of world agricultural production due to drought is over the cut sum reduction caused by other factors. Chinese agriculture afflicted by drought displays an obviously increasing tendency, and drought poses a more prominent threat on agricultural production and food security (Wang et al, 2001; Zhang et al, 2008). Home and abroad studies showed that global temperature will rise 1.4–5.8°C to the end of 21st century, plantation will face the challenge of high-temperature, and thermal injury will become one of the major disastrous climate to rice production (Houghton et al, 2001; Peng et al, 2004).

The relationships among the population ecology, rice growth and the yield formation were extensively studied (Yan et al, 2007; Ke et al, 2008; Lu et al, 2008; Xu et al, 2008; Zhu et al, 2008). By studying the features of crop canopy, canopy temperature and the relationship between them, it was currently thought that the level of canopy temperature can be more reasonable to reflect the status of soil moisture, the deficit of crop water and the degree of heat stress (Liu et al, 2004; Fan et al, 2007; Shi et al, 2007). Mackill et al (1983) found that under the same temperature conditions, the lower of the rice panicle temperature was, the smaller of the harm degree was; similar study indicated that the lower rice canopy temperature was, the stronger its heat resistance was (Xu et al, 1999). Furthermore, Prasad et al (2006) thought that various rice groups displayed the difference in the canopy temperature. By studying the relationships among water stress, canopy temperature, leaf rolling index and growth, Tumer et al (1986) found that with the decline of soil moisture, the difference of canopy-atmosphere temperature (the difference between the canopy and atmosphere temperature) and the degree of leaf curl increased, and the dry matter accumulation reversely decreased. However, in China fewer studies have been done on the relationship between the micro-climate factors of rice population and mulching cultivation, thereby lacking direct evidences in this field. To provide a theoretical basis for upland rice, different mulching treatments were set in this study, the leaf photosynthesis in the reproductive growth period and the micro-meteorological factors of them

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were examined, the effects of different mulching methods on rice canopy photosynthetic characteristics, temperature, humidity and yield components were investigated.

**MATERIAL AND METHODS**

**Experimental design**

Super hybrid rice combination P88S/1128 was provided by Hunan Hybrid Rice Research Center (HHRRC), Hunan Province, China. Experiments were conducted at the field of HHRRC, sowing on 15 May, harvesting on 6 October, 2009, the whole growth duration was 145 d. A total of 500 kg compound fertilizer (N: P: K=12:5:8), 500 kg cake-shaped rape seed dregs (as fertilizer), 100 kg urea were applied for each 1 hm² area. Naturally dried soil was crushed by mechanical methods and used. Mulching modes include plastic film mulching (T1), straw mulching (T2) and liquid film mulching (T3), as well as the control of bare cultivation (CK). For plastic film mulching, pave the field before transplant. For straw mulching, straw was uniformly laid on the surface with a density of unseen soil as the standard before the tillering stage. For liquid film mulching, the liquid film was diluted with water at the ratio of 1:1 and evenly sprayed onto the surface with an amount of 200 kg/hm² after the tillering stage. Each treatment was repeated four times with a plot area of 24 m², a planting density of 19.8 cm × 26.4 cm and 2 to 3 seedlings per hole. Irrigation management was respectively conducted at the returning green stage (5 June to 12 June) and at the heading stage (6 August to 18 August), a 3–5 cm water layer of the field was maintained during the irrigation management. The remaining cultivation and management was implemented as the conventional one.

**Measurement methods**

**Determination of yield and its components**

Five samples randomly selected from each plot were analyzed for the yield components including grain number per panicle, unfilled grain number per panicle, seed setting rate and 1000-grain weight. In addition, grains from 200 poles/plot were respectively harvested, weighting after drying, converting to the final yield in accordance with the rice standard.

**Physiological analysis of rice canopy leaves**

Photosynthetic rate and transpiration rate of the flag leaf, the second and third leaves from the top were determined by using a LI-6400 portable photosynthesis system analyzer (LI-COR company USA). The measurement was conducted at 9:00–11:00 a.m. of a sunny day at the heading, milky ripeness and waxy ripeness stages, respectively, with five duplications for each treatment. The light intensity and gas flow rate were respectively set as 1000 μmol/(m²·s) and 600 μmol/s.

**Determination of canopy ecological factors**

Data of field temperature and relative humidity for five consecutively sunny days at the heading and milky ripeness stages, were collected with the EM50/R system produced by the United States (DECAGON company). Briefly, the EM50/R data acquisition system was connected to the computer and the data acquisition parameters were set with the software indoors, and then placed in the field with the probes fixed to the height of 80 cm above the ground. The temperature and relative humidity in the canopy and in the atmosphere were recorded by the probes respectively exposed to them, the difference between them was calculated.

**Data analysis**

Statistical analysis was performed using the Excel 2003 software, one way ANOVA and LSD were used for variance analysis and multiple comparisons respectively (SPSS3.0).

**RESULTS**

**Effects of mulching cultivation on leaf photosynthetic characteristics**

Rice leaves are the most important photosynthetic apparatus and the yield formation is essentially the accumulation and distribution process of photosynthetic products (Xia et al, 2008). The present study showed that different mulching modes significantly affected
the net photosynthetic rate of the uppermost three leaves of upland rice (Table 1). At the whole growth period, the leaf net photosynthetic rates of the mulching treatments were higher than the CK. The highest rate was at the milky ripeness stage, followed by the full heading stage. At the waxy ripeness stage, a slightly decreased photosynthetic rate was observed due to leaf senescence. Further analysis indicated that from the flag to the third leaves from the top, the net photosynthetic rate successively decreased. Of note, the net photosynthetic rates of flag leaves with mulching cultivation were significantly higher than the CK during the whole late growth stage. The highest rate of the second leaf from the top was observed in the T1 treatment with a significant difference compared with CK ($P < 0.05$), while there was no significant difference between T2, T3 and CK at the milky ripeness stage and wax ripeness stages. Similarly, no significant difference was seen in the photosynthetic rates of the third leaf from the top in the four treatments at the milky ripeness and waxy ripeness stages. These results showed that the mulching cultivation has effectively improved the net photosynthetic rate of rice during the reproductive stage. Additionally, the plastic film mulching mode could improve the leaf photosynthetic capacity and extend the duration of strong photosynthesis, making them have photosynthetic capacity even at the waxy ripeness stage.

As shown in Table 2, the mulching treatments increased the leaf transpiration rate to different extent. Multiple comparison analysis indicated that at the heading and milky ripeness stages, the transpiration activities of the flag and the second leaves from the top in the T1, T2 and T3 treatments were significantly higher than the CK, whereas there was no significant difference in the third leaf from the top between different groups. At the waxy ripeness stage, the transpiration rate of flag leaf in each treatment was insignificant, while those of the second and third leaves from the top displayed a markedly increase under the mulching conditions. At the reproductive growth period, the average transpiration rates of T1, T2 and T3 treatments were significantly higher than
the CK, with the largest in the T1 treatment. As the transpiration can reduce leaf temperature, making leaves have higher heat resistance and increased photosynthetic rate, this is one of the reasons for increased rice yield induced by mulching treatments.

Effects of mulching cultivation on rice canopy relative humidity (RH)

Fig. 1 shows that the canopy RH of different mulching treatments displayed a similar tendency as the sun during the heading and milky ripeness stages, as indicated by a single peak curve following the change of external environment. The atmospheric RH was almost stable at night, while it began to rapidly decline from 7:00 and reached the lowest at 13:00 to 14:00. Diurnal variation of the canopy RH in rice population was different from that of the atmosphere, as reflected by the fact that during the time of strong photosynthesis, the canopy RH fell from 8:00, it reached the lowest at about 12:00 and then rose following this time. These results confirmed that the change of the rice canopy RH lagged that of the atmosphere and the decreasing duration of the canopy RH was 4–5 h shorter than that of the atmosphere, as mainly resulted from the improvement of the canopy RH due to strong photosynthetic and transpiration capability of rice population.

As shown in Table 3, at the heading and milky ripeness stages, the RH differences between the canopy and the atmosphere in the T1, T2, T3 treatments were greater than the CK during the day time, whereas the difference trends were small during the night time. At 2:00–6:00 of the milky ripeness stage, the difference was only about 3.66%–5.74%, it gradually increased and reached the highest at 14:00–18:00. The average RHs of T1, T2 and T3 were 27.501%, 20.90% and 8.35% higher than that of CK at the heading stage respectively, and were 41.47%, 35.39% and 18.62% higher than the CK at the milky ripeness stage, respectively. These results point out

| Table 3. Effects of mulching mode on the difference between relative humidity of upland rice canopy and air. |
|---|---|---|---|---|---|---|---|
| Stage and treatment | 2:00–6:00 | 6:00–10:00 | 10:00–14:00 | 14:00–18:00 | 18:00–22:00 | 22:00–2:00 | Average |
| Straw mulching (T2) | 9.95 | 14.24 | 10.09 | 19.32 | 22.42 | 14.00 | 15.21 |
| Liquid film mulching (T3) | 9.25 | 12.80 | 8.15 | 15.50 | 20.83 | 14.02 | 13.63 |
| Bare cultivation (CK) | 9.08 | 12.65 | 6.60 | 13.10 | 18.99 | 13.81 | 12.58 |

Data followed by the same lowercase letters indicate no significant difference at the 0.05 level among treatments.
that the mulching cultivation is more effective to improve the canopy RH and provide a more favorable microenvironment for the growth and development of rice.

Effects of mulching cultivation on rice canopy temperature

Fig. 2 shows the canopy temperature dynamics of five successive days during the full heading and milky ripeness stages. The rice canopy and the atmosphere temperatures changed simultaneously. At 0:00 to 6:00, they slowly decreased due to the heat loss, from 7:00 on, they rapidly rose with the sunlight and reached the highest at 12:00–13:00, next they decreased again. During the day time, the rice canopy temperatures of the mulching treatments were lower than that of CK, displaying the case of CK>T3> T2>T1; and during the night time, the rice canopy temperatures of the mulching treatments were lower than that of the atmosphere temperature, however, there was no significant difference between different treatments.

As seen from Table 4, at the heading and milky ripeness stages the differences of canopy-atmosphere temperature of T1, T2, T3 treatments were higher than the CK, and the highest difference appeared at 18:00–22:00, while there was no significant difference between different treatments mainly due to the rice population self-regulatory mechanism resulting from slow internal heat loss. The canopy-atmosphere difference was the smallest at 10:00–14:00 and the average difference was only 0.98°C. Additionally, the most obvious difference of the canopy-atmosphere temperature appears at 10:00-14:00 between different treatments, as shown by a 0.71°C, 0.43°C and 0.33°C of T1, T2 and T3 higher than the CK during the full heading stage, a 0.80°C, 0.62°C and 0.33°C of T1, T2 and T3 higher than the CK during the milk stage respectively, demonstrating mulching cultivation can significantly reduce the canopy temperature especially during high temperature period.

Effects of mulching cultivation on yield and its

<table>
<thead>
<tr>
<th>Stage and treatment</th>
<th>2:00–6:00</th>
<th>6:00–10:00</th>
<th>10:00–14:00</th>
<th>14:00–18:00</th>
<th>18:00–22:00</th>
<th>22:00–2:00</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic film mulching (T1)</td>
<td>1.76</td>
<td>2.35</td>
<td>1.33</td>
<td>2.58</td>
<td>4.45</td>
<td>3.53</td>
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<tr>
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<td>1.70</td>
<td>2.27</td>
<td>1.05</td>
<td>2.11</td>
<td>4.37</td>
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<td>2.32</td>
<td>0.95</td>
<td>1.66</td>
<td>4.27</td>
<td>3.30</td>
<td>2.37 bc</td>
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<tr>
<td>Bare cultivation (CK)</td>
<td>1.55</td>
<td>1.96</td>
<td>0.62</td>
<td>1.26</td>
<td>4.19</td>
<td>3.27</td>
<td>2.14 c</td>
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<tr>
<td>Average</td>
<td>1.68</td>
<td>2.23</td>
<td>0.98</td>
<td>1.90</td>
<td>4.32</td>
<td>3.36</td>
<td>2.41</td>
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<tr>
<th>Milky ripeness stage</th>
<th>2:00–6:00</th>
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<th>10:00–14:00</th>
<th>14:00–18:00</th>
<th>18:00–22:00</th>
<th>22:00–2:00</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic film mulching (T1)</td>
<td>1.76</td>
<td>2.35</td>
<td>1.51</td>
<td>2.90</td>
<td>4.10</td>
<td>2.40</td>
<td>2.57 a</td>
</tr>
<tr>
<td>Straw mulching (T2)</td>
<td>1.70</td>
<td>2.27</td>
<td>1.33</td>
<td>2.68</td>
<td>4.03</td>
<td>2.35</td>
<td>2.50 a</td>
</tr>
<tr>
<td>Liquid film mulching (T3)</td>
<td>1.69</td>
<td>2.32</td>
<td>1.04</td>
<td>2.27</td>
<td>3.93</td>
<td>2.27</td>
<td>2.32 b</td>
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<tr>
<td>Bare cultivation (CK)</td>
<td>1.55</td>
<td>1.96</td>
<td>0.71</td>
<td>1.94</td>
<td>3.75</td>
<td>2.22</td>
<td>2.14 c</td>
</tr>
<tr>
<td>Average</td>
<td>1.68</td>
<td>2.23</td>
<td>1.14</td>
<td>2.45</td>
<td>3.95</td>
<td>2.31</td>
<td>2.40</td>
</tr>
</tbody>
</table>

Data followed by the same lowercase letters indicate no significant difference at the 0.05 level among treatments.
components

Mulching cultivation is conducive to the nutrient accumulation in the different organs of rice, in turn, it lays the material foundation for the formation of high yield. As shown in Table 5, the yields of rice in the T1 and T2 treatments were significantly higher than the CK ($F<0.05$). The rice plants in the T1 treatment performed the highest number of grains per panicle, seed setting rate and the total spikelet number. Sequentially, the yield of rice in the T1 treatment was significantly higher than the other treatments. The yield of rice in the T2 treatment was still significantly higher than the CK, mainly resulting from a substantial increase of the numbers of effective panicle and total spikelet; and the yield of rice in the T3 treatment was slightly higher than the CK, but the difference was not significant. The results confirmed that the mulching cultivation helps to improve the output of upland rice, with the most obvious effects observed in the film mulching, which yielded a 16.81% increase.

**DISCUSSION**

Mulching cultivation can increase soil temperature, preserve moisture, promote the decomposition and release of soil nutrients, increase dry matter accumulation and high yield formation of rice (Wang et al, 2002). The current study demonstrated that the mulching cultivation had a significant effect on micrometeorological factors and the individual growth of upland rice, the three different mulching modes increased the yield of rice to a different extent, among which the plastic film mulching displayed a 16.81% increase of the yield compared with the CK, as consistent with Shen’s report (Shen et al, 1997). It was also reported that rice yield slightly decreased under mulching cultivation (Sheng et al, 2004). These results reflected that rice yield is determined not only by planting patterns, but also by ecological environment, soil fertility and management measures, as well as other factors.

Extensive studies on crop canopy characteristics, canopy temperature and the relation between them have been conducted to reveal the ecological mechanism of preventing and avoiding heat, and to confirm the effects of mulching in optimizing the crop population environment and increasing rice yield (Shen et al, 1997). It was indicated that the canopy-atmosphere difference at noon could reflect the status of rice water deficit (Zhang et al, 2007); the heat stress on the canopy temperature and the seed setting rate was significantly and negatively correlated (Garrity et al, 1995); the rice canopy temperature increased with the decline of soil moisture and it might increased by 3–4°C under heavy stress, and the canopy temperature at the flowering stage was negatively related with grain yield and seed setting rate (Chauham et al, 1999). The present results indicated that the canopy temperature decreased in the mulching cultivation, while the seed setting rate and yield increased, as consistent with the above findings. It should be noted that there have no effective methods to resolve the large number of white pollution resulted from mulching with plastic film at present. An alternative mulching by using biodegradable liquid film made of crop straw was investigated in our study. The results indicated that it could also reduce the canopy temperature, increase the canopy humidity, promote photosynthetic rate and transpiration, but its effects were lower than the plastic film and close to that of rice straw. Therefore, further investigations are needed in the replacement of chemical film with liquid film in the application of upland rice.

### Table 5. Rice yield and its components under different mulching cultivations.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Effective panicle number ($\times 10^8$/hm²)</th>
<th>Filled grain number per panicle</th>
<th>Total spikelet number ($\times 10^6$/hm²)</th>
<th>Seed setting rate (%)</th>
<th>1000-grain weight (g)</th>
<th>Yield (kg/hm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic film mulching (T1)</td>
<td>227.27 ab</td>
<td>228.84 a</td>
<td>564.43 a</td>
<td>91.73 a</td>
<td>27.97 a</td>
<td>12507.84 a</td>
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<tr>
<td>Straw mulching (T2)</td>
<td>236.36 a</td>
<td>186.13 b</td>
<td>502.38 b</td>
<td>87.11 a</td>
<td>27.42 a</td>
<td>11735.19 b</td>
</tr>
<tr>
<td>Liquid film mulching (T3)</td>
<td>216.67 b</td>
<td>183.73 b</td>
<td>450.09 c</td>
<td>87.17 a</td>
<td>27.23 a</td>
<td>11098.89 c</td>
</tr>
<tr>
<td>Bare cultivation (CK)</td>
<td>210.61 b</td>
<td>182.57 b</td>
<td>442.87 c</td>
<td>86.80 a</td>
<td>27.18 a</td>
<td>10708.02 c</td>
</tr>
</tbody>
</table>

Within a column, data followed by the same lowercase letters mean no significant difference at 0.05 level.
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REFERENCES


