Abstract

This paper describes the investigation on the physical properties, heat absorption and preservation, weekly variations of biodegradability, and effects on rice morphology and yield to study the mulching cultivation system for early season culture rice by using biodegradable film (referred to as BF) for keeping the environment clean.

BF had weaker transversal tensile force and tear resistance than polyethylene film (referred to as PF). Heat retention and reflectance of BF were 0.3-0.8°C less and 2-5% more than that of PF, respectively. However, the effect of BF mulching on hastening the growth of rice was similar to that of PF. On the other hand, biodegradation was slow during the important growing stage of rice and accelerated after three months. Therefore, as mulching material for early season culture rice, the effective use of BF was confirmed.

[Keywords] mulching cultivation system, early season culture rice, biodegradable film, clean environment

I Introduction

Mulching cultivation system using PF in upland fields is widely practiced for vegetable production in Japan. PF is laid mechanically on ridges before or during planting to increase soil heat absorption and preservation.

The authors reported on the use of PF in the mulching cultivation system to speed up the growth of seedlings and shorten the heading period and maturity duration of rice varieties for early season production\(^1\). Also, the authors developed a mechanical transplanter that lays PF and creates slits before transplanting the seedlings through them\(^2-4\). The system was effective in increasing soil temperature by 5°C, controlling weeds, shortening maturity duration by one week, and increasing harvest by 10%. However, the main problems are drudgery of removing the film after the maximum tillering stage or before the heading stage and disposal of used film.

The BF mulching cultivation system was thereby envisioned to solve these problems through the use of mulching material that mixes with the soil and decomposes itself during the cropping period. It should not affect plant growth and yield nor pose environmental hazard. Thus, the burdensome field activity of removing PF before the heading stage is naturally eliminated.

In 1997, initial trials in the field conducted by

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*1 JSAM Member, Faculty of Agriculture, Miyazaki University, 1-1 Gakuen Kibanadai-Nishi, Miyazaki City, 889-2192, Japan

*2 JSAM Member, Testing and Evaluation Department, Bio-Oriented Technology Research and Advancement Institution (BRAIN), Omiya City, Saitama, 331-8537 Japan
the Laboratory revealed that there was no need to remove BF before the heading stage because it was completely degraded during the cropping period. Thus after harvest, a tractor can proceed to cultivate the soil without getting entangled with the remaining mulched film.

Part 1 was conducted to compare the physical characteristics of BF and PF. The evaluation guided the development of BF mulching cultivation system.

II Materials and Methods

1. Biodegradable film

A wide range of biodegradable materials is commercially available\(^5\). Presently, they are classified as to how they are produced such as from microorganisms, natural resources and chemical syntheses\(^6\). In this study, BF produced from natural resources (Topy Green Co., Ltd.: Kiemaru) was used. It is composed of cornstarch and polyvinyl alcohol that decompose into water and carbon dioxide, thus having no harmful effects on soil and crops. It is milk-white with 0.02mm thickness, 1,200 mm width, and 200,000mm length. BF was compared to PF (Mitsumori Co.: Taikyunopori), which is transparent with 0.02 mm thickness, 1,500mm width, and 200,000mm length.

2. Testing methods for physical properties

(1) Tensile force and elongation property

JIS K7127\(^7\) was used to measure tensile strength and elongation of BF and PF. Thirty-five pieces of each film were cut longitudinally and transversally according to the specified shape shown in Fig. 1 (a). They were kept at 23°C and 70% RH for 88 hours before the test. The Universal Testing Machine (Orientech: STA-1150) shown in Fig. 2 was used to measure force and elongation. This machine recorded the tensile force in Newton N and elongation in mm until the test piece of film was cut at the speed of 500mm/min. It was linked to a personal computer loaded with a software (AND Corporation: Data Management System for General Purpose

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Testing Machine, Basic Application) that recorded the force and elongation data and showed them graphically on the screen. Data were analyzed using Student's t-test.

(2) Tear resistance

Trouser tear method in JIS K7128\(^7\) was used to measure tear resistance of films. Thirty pieces of each film shaped according to specifications shown in Fig. 1 (b) were kept at 20\(^\circ\)C and 55% RH for 88 hours before the test. The Universal Testing Machine recorded the data similarly as in JIS K7127 at the speed of 200 mm/min. For PF, the maximum tear resistance was taken. Since BF exhibited several peaks of maximum tear resistance, the average tear resistance of five peaks of equal intervals was computed. Data processing was done similarly as in JIS K7127.

3. Heat absorption and preservation

(1) Experimental field layout

The experimental paddy field using soil boxes (plastic container, 360mm wide \(\times\) 540mm long \(\times\) 300mm high) is shown in Fig. 3. Film with five slits of 70mm length was fixed on a wooden frame (350mm \(\times\) 530mm). This was laid at the water level of a paddy field box. The experimental paddy field had five soil boxes representing the following treatments:

(a) Field I: BF was laid at the water level of 20mm from the soil surface (referred to as BF 20mm);

(b) Field II: BF was laid at the water level of 40mm from the soil surface (referred to as BF 40mm);

(c) Field III: film was not laid at the water level of 20mm (referred to as NF 20mm);

(d) Field IV: PF was laid at the water level of 20mm from the soil surface (referred to as PF 20mm);

(e) Field V: PF was laid at the water level of 40mm from the soil surface (referred to as PF 40mm).

These treatments were replicated three times. All sides of boxes positioned side by side were covered with styrofoam to prevent the influx of lateral heat. The rice variety was “koshihikari”. Four seedlings of koshihikari were transplanted per hill (slit) at a depth of 30mm in each soil box on March 29, 1998.

(2) Surface temperature

A thermography apparatus (Nihon Denshi Company: Thermoviewer JTG-4200S) was set up at the experimental field on May 20~21, 1998. Thermal images of the surfaces of the five paddy field boxes in front were taken every hour.

By manipulating the control panel, the thermograph profiles of images at a certain line appeared automatically. Temperature variations on all surfaces that were shown by these profiles were compared. Moreover, the average hourly temperature of areas (12 horizontal \(\times\) 12 vertical points) within the thermal images of Fields I~V were graphically presented and compared.

(3) Soil temperature

Thermo sensors were installed just below the film at the water level of 20mm or 40mm from the soil surface, and 0, 10, 30, and 80mm below the soil surface under the rice seedlings in each Field. These sensors were connected to a multi-channel digital recorder (ADVANTEST Co.: TR-2724) that printed the
temperature values every hour. Recording of data continued until the heading stage. Hourly temperature variations were graphically presented and compared. Moreover, the average hourly temperature variations of 10 days from April to June were calculated, graphically presented, and compared.

4. Weekly variations of biodegradability

(1) Experimental field layout

Fifty-four paddy field boxes with films and wooden frames as in section 3 (1) were prepared to determine the rate of biodegradation for the whole duration of the early season rice cropping period. BF and PF were laid at the water level of 20mm from the soil surface, and without film as control in each box. Seedlings were transplanted on March 29, 1998.

(2) Methods to measure reflectance, weight loss and area reduction

The reflectance of both films, and the weight loss and area reduction of BF were determined weekly. BF and PF were removed from the soil box at random to measure their weekly variations.

Reflectance

Fig. 4 shows how reflectance of new and used films, which were removed from paddy field boxes weekly for the first four weeks after transplanting, was measured under a clear sky at 1:13-1:53pm on July 24, 1998. At the center of a hole, film was hanged 150mm below the ground level. The average reflectance $\gamma$ was measured by pointing a quantum sensor (LI-COR : LI-190SA) down at 100mm above the film surface for 15 seconds. At this position, the sensor was 50mm below the ground level. This was done so that most of the unwanted reflectance coming from the surroundings such as buildings, trees, and grass, would be reduced. This unwanted reflectance could not be totally eliminated because of the presence of dry soil but its value would be negligible when the difference of reflectance of BF and PF was computed.

The average incoming radiation $J$ of full sun and sky was measured at approximately 500 mm above the film surface for 15 seconds. Hence, the percentage of reflectance $R$ was calculated based on the formula:

$$R = \frac{\gamma}{J} \times 100 \, (\%)$$

where: $\gamma$ = reflectance, $\mu$mol s$^{-1}$ m$^{-2}$

$J$ = incoming radiation, $\mu$mol s$^{-1}$ m$^{-2}$

Weight loss and area reduction

The weight loss and the area reduction were determined after cleaning BF by using an ultrasound cleaning machine (NEY Dental International : ULTRAsonic model 28B) for removing soil and weeds. The machine was operated for approximately seven minutes with the film submerged in 2% cleansing solution (KAO Corp.: Joy) in 2000ml of water. However, it was difficult to remove all the dirt and moss stains. Thus, these were removed carefully by hand. Then, an electronic balance weighed the film after air-drying for 24 hours. The percentage of weight loss $w$ was calculated and presented graphically based on the formula,
Afterward, the film was computer-scanned over a black background to convert the film area into black and white pixels as shown in Fig. 5 (a). Pure black pixels represented the degraded area as shown in Fig. 5 (b). Thus, the percentage of area reduction \( n \) was calculated and presented graphically based on the formula,

\[
\frac{W_u}{W_n} \times 100 (\%)
\]

where:  
- \( W_u \) = weight of used film, g  
- \( W_n \) = weight of new film of same area as \( W_u \), g

5. Measurements of rice morphology and yield

The experimental paddy field shown in Fig. 3 was maintained to determine the effects of mulching on weekly changes in rice morphology. Plant height was measured, leaf age was determined by counting the number of leaves that emerged, and the number of tillers was counted. The start of heading, the number of heads, and the end of heading days were recorded. After harvesting and drying the crop, the length of ears, effective and total number of ears, weight of straw, and weight of filled and unfilled grains per hill were determined. Data were analyzed using F-test and Student's t-test, and presented graphically.

III Results and Discussion

1. Physical Properties of films

(1) Relationship of tensile force and elongation

The average longitudinal tensile force of 3.8 N required to elongate and eventually cut BF was significantly greater than the transversal tensile force of 2.36 N as shown in Fig. 6. That means 61% more strength is required to overcome this longitudinal tensile force. Similarly, the average longitudinal tensile force of 3.12 N required to elongate and eventually cut PF was significantly greater than the transversal tensile force of 2.55 N. That means only 22% more strength is required to break the film.

BF was five times highly elongated longitudinally at 213.4 mm than transversally at 40.7 mm. Longitudinally, it was also significantly more elongated than PF at 142.3 mm. However, transversally, PF was more elongated at 133 mm. Tensile force applied longitudinally or transversally did not vary the elongation of PF.
(2) Tear resistance

In Fig. 7, tearing BF longitudinally by 0.6N was as easy as tearing it transversally by 0.57N but it was significantly harder to tear PF transversally by 4.42N than longitudinally by 3.1N. These values revealed that BF was five times easier to tear longitudinally and seven times easier transversally than PF. This result suggests that a cutting tool that can provide 0.6N is enough to form a slit in BF.

2. Heat absorption and preservation

(1) Surface temperature

Fig. 8 is an example of temperature variations on the surface derived from thermal image analyses. The graph shows that those temperature trends of all Fields except Field III (control) were not distinct until 15:00 because of varying global radiation and air temperature. However, between 16:00~22:00, global radiation and air temperature were decreasing uniformly. During this period, the downward trend of temperature variations of BF 20mm and BF 40mm lagged by an average of 0.4°C and 1.0°C compared to the trend of temperature variations of PF 20mm and PF 40mm, respectively. However, these values were significantly smaller than 1.6°C and 2.7°C of NF 20mm.

This result revealed that heat preservation at the surface of BF 20mm was four times greater than that of NF 20mm.

(2) Soil temperature

Examples of daily temperature variations in the soil profile are shown in Figs. 9 and 10. In Fig. 9, at 6:00, the trend of temperature variations in the soil (from the soil surface to a depth of 80mm) of BF 20mm and BF 40mm lagged by 0.3°C and 0.1°C compared to that of PF 20mm and PF 40mm, respectively. Then, the soil temperature differences became indistinguishable from 12:00~15:00 except that the soil temperature of PF 40mm continued to increase. At 18:00, temperature variations (from the soil surface to a depth of 30mm) decreased significantly but the temperature variations in the soil of BF 20mm and BF 40mm lagged by only an average of 0.3°C and 0.8°C from that of PF 20mm and PF 40mm, respectively. NF 20mm lagged by 2.4°C compared to that of PF 20mm.

This trend revealed that the 24-hour cycle of temperature variations in the soil (from the soil surface to a depth of 30mm), with respect to PF 20mm and PF 40mm, were 0.1~0.4°C and 0.1~0.8°C for that of BF 20mm and BF 40mm, respectively. That of NF 20mm were 0.5~2.4°C and 0.4~5.0°C compared to BF 20mm and PF 20mm, respectively. Therefore, based on daily temperature variation, BF 20mm could
preserve soil heat five to six times better than NF 20mm.

Fig. 10 shows an example of soil temperature variations, for soil depths of 0mm and 30 mm, calculated based on the average of 10 days. In this graph, only temperature variations at the water level of 20mm from the soil surface are presented. PF 20mm retained heat more than BF 20mm and NF 20mm. However, temperature variations in the soil (0~30mm depth) of BF 20mm lagged by only 0.7°C compared to that of PF 20mm from 13:00 to 23:00. On the other hand, temperature variations in the soil of NF 20mm lagged significantly by more than an average of 1.8°C. Therefore, based on 10-day average temperature variation, BF 20mm could preserve soil heat more than twice that of NF 20mm.

3. Weekly variations of biodegradability

(1) Percentage of reflectance
The percentages of reflectance $R$ of new BF and PF were 17% and 15%, respectively. For the first four weeks after transplanting, the average percentage of reflectance $R$ of used BF was 20% and the average percentage of reflectance $R$ of used PF was the same as that of new PF. The difference of 2~5% might have caused the 0.4°C lag on the surface of BF 20mm compared to that of PF 20mm. However, this difference would not hinder the growth and yield of rice as explained in section 4 (3).

(2) Pattern of film degradation
Fig. 11 shows how BE was degraded. Two weeks after transplanting, it had still no sign of degradation. However, at 28 days after transplanting, degradation started with small holes slowly appearing with black discoloration. Bigger and irregular-shaped holes appeared later after the heading stage 90 days after transplanting when the atmospheric temperature was high. Mulch at high temperature was no longer necessary. At that time, BF decomposed rapidly and eventually dis-
Figure 11 Pattern of film degradation in days after transplanting appeared in the soil. Hence, there was no more film 109 days after transplanting. This pattern of field degradation was favorable to farm workers because the activity of removing the film was eliminated.

Also, it was observed that slits of BF were not lengthened but widened by an average of 47mm at the middle, 42% more open than PF slits at maximum tillering stage 63 days after transplanting.

(3) Percentage of weight loss and area reduction

The weight of PF did not change throughout the cropping period. On the other hand, BF started losing weight seven days after transplanting and continued exponentially for 76 days after transplanting as shown in Fig. 12. At this time, the percentage of weigh loss was only less than 10%. Then starting at 83 days after transplanting, the percentage of weight loss increased abruptly. Although BF started losing weight early, its film area was not reduced until 28 days after transplanting. Afterward, the film area was reduced quadratically until 76 days after transplanting. However, the percentage of area reduction was only less than 10%, which was similar to the percentage of weight loss. The film area was reduced exponentially starting at 83 days after transplanting until almost 100% of BF had disappeared.

This result revealed that BF was still effective in preserving and absorbing heat during the tillering stage that lasted for 63 days after transplanting because its weight loss and area reduction was only less than 10% for 76 days after transplanting. Moreover, this fact was supported by insignificant differences in surface and soil temperature variations of PF and BF. After the tillering stage, that is, from the heading stage until harvest, BF was no longer needed.

4. Effects on morphology and yield

Examples of these effects are maximum tillers, advance in heading, and yield in weight of filled grains per hill.

(1) Rate of tiller production

Plants mulched with BF and PF produced similar number of tillers 21 days after transplanting as shown in Fig. 13. Tiller production stabilized after 35 days with plants mulched with BF producing significant number of tillers. This result occurred because BF was easily torn apart, which allowed the tillers to emerged freely.
(2) Advance in heading date
Heading dates of rice in BF 20mm and BF 40 mm were significantly advanced by five and seven days, respectively, compared to the heading date in NF 20mm as shown in Fig. 14. Heading dates were only delayed by one and two days compared to those planted in PF 20 mm and PF 40mm, respectively. However, these delays were insignificant.

This result revealed that plants grown in BF could be harvested in the same period as those in PF and the heading date could be advanced by five to seven days compared to those without film. Thus, there would be no delay in harvest that might cause detrimental consequences in post-harvest handling and marketing.

(3) Yield in weight of filled grains per hill
Plants in BF 20mm and BF 40mm produced more filled grains of 24.6 and 24.3g/hill but similar with the 23.1 and 24.1g/hill produced in PF 20mm and PF 40mm, respectively as shown in Fig. 15. Although similar, there was an 8.5% increase in yield by using BF than by not using mulch at all.

IV Summary
The physical characteristics of BF that was envisioned to replace PF as mulch in the mulching cultivation system for early season rice have been evaluated as follows:

(1) BF required 61% more strength longitudinally to overcome the tensile force compared to 22% for PF. It was six times more elongated transversally than PF.

(2) BF required 0.6N to overcome tear resistance. It was five times easier to tear than PF longitudinally and seven times easier transversally.

(3) Heat preservation at the surface of BF 20mm was similar to that of PF 20mm but four times greater than that of NF 20mm.

(4) Based on daily temperature variation, soil heat preservation in BF 20mm was similar to that of PF 20mm but five to six times greater than that of NF 20mm. On the other hand, based on the average temperature variation of 10 days, soil heat preservation in BF 20mm was still similar to that of PF 20mm but more than twice that of NF 20mm.
(5) BF reflected 2～5% more light than PF. However, this percentage difference was insignificant to slow down heat exchange at the film surface and in the soil.

(6) The percentages of weight loss and area reduction of BF were less than 10% during the first two cropping months. Also, these percentages were insignificant to influence heat exchange. After this period, the decomposition proceeded rapidly and BF eventually disappeared on the ground. Thus, removal of BF was no longer necessary.

(7) Rice heads in BF emerged at similar period with those in PF. Heading date was advanced significantly by five to seven days. Thus, harvesting period was also advanced, and the crop yielded 8.5% more filled grains per hill than that without film.

In view of these facts, BF used in the study is hereby accepted to replace PF in mechanizing the mulching cultivation system for early season culture rice.

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