

Original Paper

Agrochemical-Free, Direct-Sowing Culture of a Paddy with Non-woven Fabric Mulch—Timing of Puddling and Leveling and Basal Fertilizer Application—

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不織布マルチングによる水稲直播・有機栽培
一代かき時期と基肥施用時期の影響—

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1. Introduction

Puddling and leveling (P & L) improves the water management for weed suppression, crop establishment, nutrient use efficiency, crop uniformity and maturation, and grain yield in paddy field (IRRI, 2008a). P & L is synonymous with rice cultivation in Asia to reduce water and nutrient loss and to control weeds (Sharma and De Datta, 1985). P & L breaks down and disperses soil aggregates into micro-aggregates and individual particles. The degree of dispersion for a given P & L effect is dependent on the structural stability of the soil. P & L significantly increased the yield of rice, but many studies have reported that P & L is not es-

sential for rice growth and yield (Kukul and Aggarwal, 2003). Rickman (2002) mentioned that rice yield increased with the uniformity of leveling. Furuhashi *et al.* (2005) stated that normal P & L (not overly aggressive P & L) improves both seedling emergence and establishment after draining flooded water.

Organic farming promotes the recycling of organic material in agricultural ecosystems and enhances crop production with a minimal environmental load by maintaining ecological balance. The application of organic materials to the soil significantly enhances the grain and straw yields of rice (Singh *et al.*, 1999). The direct-sowing culture of a paddy with non-woven fabric mulch was developed as a means of sustainable agriculture and organic rice farming. This production system was found effective in controlling weeds (Hossain *et al.*, 2006b), saving labor, and providing better yield (Sugimoto *et al.*, 2003). Renewable cotton is used as a mulch sheet in this environment-friendly pro-

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duction system.

In wet direct-seeding rice cultivation, seeds are usually sown in the field 2–5 days after the final P & L (IRRI, 2008b). Direct-sowing culturing with non-woven fabric mulch is based on special water management (Hossain *et al.*, 2005). In this system, paddy fields are covered with mulch by machine or by hand 2 days after P & L. During 2001–2004, a considerable labor load was necessary for the mulching operation due to an abundance of moisture and heavy (muddy) soil. Though there are some studies on the effects of P & L on soil properties and rice yield, there is very little information available regarding the effect of the timing of P & L on the labor load. Considering this, we hypothesized that if we did P & L a couple of days before mulching (sowing), the soil would be less muddy and more solid, and it might be easy to cover the field with mulch. In the current experiments, we examined the mulch operator's physical stress by measuring the heartbeat rates and oxygen consumption rate and as well as rice growth, grain yield, and related factors affected by timing of the puddling and basal fertilizer application.

2. Materials and Methods

1) Plants and Growth Conditions

An experiment was conducted in the year 2005 in the paddy field at the Faculty of Agriculture, Ehime University, Matsuyama City (33°50.6'N latitude, 132°46.6'E longitude, 32 m above sea level), Japan. The total paddy field size was 700 m². The experimental paddy field was gray lowland, where soil pH was 6.24, and the electrical conductivity was 0.028 ms/cm. Rice (*Oryza sativa* L. cv. Koshihikari) seeds (non-spouted) with a sowing rate of 4 g/m² were used for the experiment.

2) Mulch Sheet, Mulching (Sowing) and Cultural Details

Non-woven (cloth) mulching material was collected from the Marusan Company, Ozu City,

Japan. Each mulch roll was 100 m long and 1.1 m wide. Seeds were placed between two pieces of the mulch cloth as if one were making a sandwich. Mulching (sowing) was done on May 27, 2005. P & L was done 2 days before mulching (P2) on May 25 and 10 days before mulching (P10) on May 17. After the P & L, irrigation was not done to the mulching period in all treatments.

Fertilizers were applied at the rate of 6 gN/m² (the amount of P₂O₅ was the same as N, and K₂O was 55% of N) as basal fertilizer and 3 gN/m² (the amount of P₂O₅ was 38% of N and K₂O was 19% of N) as topdressing. Rapeseed meal and poultry manure were applied together as basal fertilizer and only rapeseed meal was applied as topdressing. Basal fertilizer was applied just before P & L in P2 treatment (P2-B2). For the P10 treatment, timing of the basal fertilization was set at 14 (P10-B14, early basal fertilization) or 3 (P10-B3, late basal fertilization) days before the mulching. Just after the application of basal fertilizer, the soil surface was shallowly cultivated in the P10-B3 treatment. Before the experiment, we assumed that basal fertilization timing might have an effect on this production system, as more nitrogen might be lost due to de-nitrification in the early basal fertilization treatment. Therefore, we elected to compare the early and late basal fertilization. Topdressing was applied at 53 days after the mulching (29 days before heading) in all treatments. We also made the treatments with no fertilizer (NF) in both P & L timing P2 (P2-NF) and P10 (P10-NF).

After mulching, the field was flooded (5–10 cm in depth) under the mulch sheet, and irrigation water was drained from the field after 14 days (3.0 leaf stage). The experiment was done in Randomized Complete Block design with two replications.

3) Measurement of Heartbeat Rate and Oxygen Absorption Rate

To evaluate the labor load, we measured the

heartbeat rates, using a heartbeat rate memory instrument (Takei Co. Ltd., Japan), and the oxygen consumption rate, using the Douglas bag method (Yamashita *et al.*, 1994) in a laboratory at the same time. After that, we measured the heartbeat rates of the mulching operator in the muddy and solid paddy field and the oxygen consumption rate was estimated from the equation derived as a result of measurement in the laboratory.

4) Soil Hardness and Inorganic Nitrogen of the Soil

Soil hardness of each depth was measured on the mulching (sowing) day with a soil hardness gage (Yamanaka's standard type, Fujiwara Seisakusho, Ltd., Japan).

A surface soil sample from the 0 to 10 cm depth was collected from the paddy field. Each soil sample was collected randomly at four places in the each treatment. Total inorganic N of the soil, NH_4^+ , NO_3^- and NO_2^- , was extracted with 10% KCl, and the solution was distilled with MgO and Devarda's alloy for determination of inorganic N by titration, as described by Bremner and Keeney (1965).

5) Plant Sampling

Sampling was done 40, 58, 82 (heading), 102 and 119 (maturity) days after mulching during the growing period. For measuring the leaf area and dry weight, two portions were taken, each 1 m in length. Leaf area was measured using an automatic area meter (AAM-7, Hayashi Denko Co., Ltd., Japan). Leaves, stems (including leaf sheaths), panicles, and dead parts were separated and dried in an oven at 85°C for 72 hours to constant weight (Hossain *et al.*, 2005).

For calculating the grain yield, six portions were taken, each 1 m in length. These samples were also used for calculation of yield components. The grains were divided into filled grains and unfilled grains using salt water with a specific gravity of 1.06, and the percentage of filled grains was determined. A 1000-grain weight was

measured, and grain weight was calculated to the value at 14% moisture content. Nitrogen content in the different plant parts was analyzed using an N-C analyzer (NC-80, Sumika Chem., Japan).

6) Statistical Analysis

Data of the plant growth, yield, and other yield components were statistically analyzed using ANOVA and data means were tested at $p \leq 0.05$ according to Fisher's least significant difference test (LSD).

3. Results

1) Heartbeat Rate and Oxygen Consumption Rate

The mulch operator's heartbeat rate and oxygen consumption rate were highly positively correlated ($r = 0.975^{**}$) (Fig. 1). Covering soil with one roll of mulch in the field resulted in heartbeat rates of 107.4 beats/min in muddy field (P2-B2) and 88.5 beats/min in solid field (P10-B14). The increased percentages in muddy and solid field were 24.3% and 7.9%, respectively (Table 1).

We calculated the oxygen consumption rate using the equation shown in Fig. 1. The oxygen consumption rate was 772.0 ml/min in muddy field and 350.6 ml/min in solid field. The Mets value (metabolic ratio of working period to rest period) was 2.54 and 1.71 for muddy and

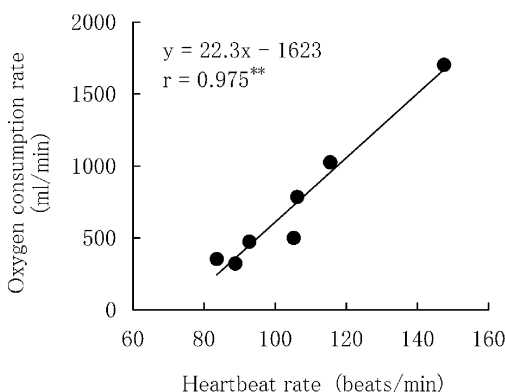


Fig. 1 Correlation between heartbeat rate and oxygen consumption rate
** : Significant at 1%.

solid field, respectively (Table 2).

2) Soil Hardness

Figure 2 shows soil hardness of each depth

Table 1 Heartbeat rate

Field condition	Heartbeat (beats/min)		Ratio (%)
	Before mulchig	After mulching	
Muddy	86.4	107.4	124.3
Solid	82.0	88.5	107.9

Muddy : Puddling and leveling was done 2 days before the mulching (P2-B2).

Solid : Puddling and leveling was done 10 days before the mulching (P10-B14).

Table 2 Oxygen consumption and Mets

Field condition	Oxygen consumption (ml/min)		Mets
	Before mulchig	After mulching	
Muddy	303.7	772.0	2.54
Solid	205.6	350.6	1.71

Muddy : Puddling and leveling was done 2 days before the mulching (P2-B2).

Solid : Puddling and leveling was done 10 days before the mulching (P10-B14).

Mets : Metabolic ratio of working period to rest period.

Oxygen consumption was calculated from the equation shown in Fig. 1.

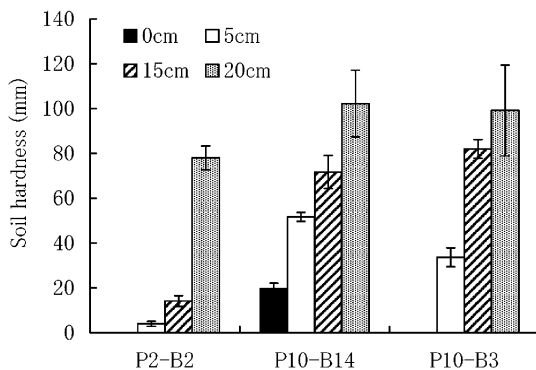


Fig. 2 Soil hardness of each depth on the mulching (sowing) day
P2, P10 : Puddling and leveling was done 2 and 10 days before the mulching.
B2, B3, B14 : Basal dressing was applied 2, 3 and 14 days before the mulching.
Vertical bars indicate standard errors.

on the mulching (sowing) day. P & L was done at 2 days before the mulching in the P2-B2 treatment and due to mud the overall soil hardness was observed very low. Again, the soil surface was shallowly plowed once again at 3 days before the mulching in the P10-B3 treatment for the basal fertilizer application and as a result, the surface (0 cm) hardness value was found almost 0 mm. On the other hand, the value was much higher (19.6 mm) in the P10-B14 treatment, because neither plow nor irrigation was done between the gap (10 days) of P & L and the mulching day. Soil hardness was almost equal in the both P10-B14 and P10-B3 treatments at 5 cm, 15 cm and 20 cm depth.

3) Inorganic Nitrogen of the Soil

On the mulching day, inorganic soil nitrogen was highest in the P2-B2 treatment, followed by the P10-B3 and P10-B14 treatment (Fig. 3). The value was very low in the no fertilizer treatments (P2-NF and P10-NF).

A similar trend was observed at 49 days after the mulching. The inorganic soil nitrogen

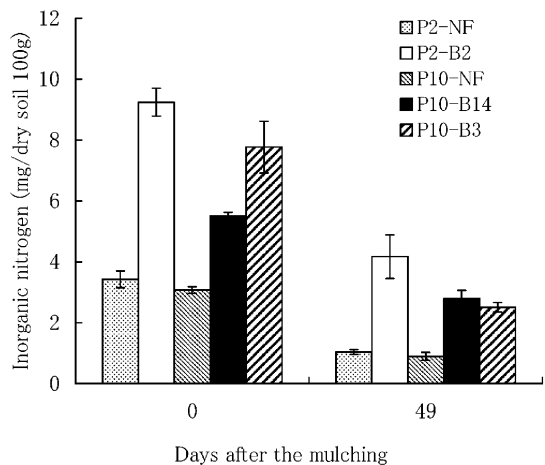


Fig. 3 Inorganic nitrogen of the soil
P2, P10 : Puddling and leveling was done 2 and 10 days before the mulching.
B2, B3, B14 : Basal dressing was applied 2, 3 and 14 days before the mulching.
NF : No fertilizer.
Vertical bars indicate standard errors.

value was quite low at this time compared to at sowing time. Inorganic soil nitrogen was highest in the P2-B2 treatment, but both the P10 treatments had almost the same amount of inorganic soil nitrogen.

4) Leaf Nitrogen

Leaf nitrogen (%) was gradually reduced as crop growth increased (Fig. 4). Fertilized treatments (P2-B2, P10-B14 and P10-B3) did not make a significant difference. Both samples that received no fertilizer (P2-NF and P10-NF) had low leaf nitrogen percentage values.

5) Dry Matter Production

The top dry weight was higher in the P2-B2 treatment at the different growth stages, and at maturity the value was 1108 g/m^2 (Fig. 5). The top dry weight was almost equal in the P10-B14 and P10-B3 treatments throughout the growth period. We noticed that the top dry weight was very low in the samples that received no fertilizer.

Figure 6 shows the changes of crop growth rate (CGR), net assimilation rate (NAR), and mean leaf area index (mean LAI). CGR was higher in the P2-B2 treatment throughout the growth period and was nearly the same in both P10 treatments (P10-B14 and P10-B3). CGR was lower in the no fertilizer treatments compared to the fertilizer treatments. Maximum CGR ($19.7 \text{ g m}^{-2} \text{ day}^{-1}$) was observed in the P2-B2 treatment. A clear difference in NAR was not found between the treatments. The mean LAI value was also higher in the P2-B2 treatment, followed by both of the P10 treatments. The difference in CGR was mostly due to the difference in mean LAI.

6) Grain Yield and Yield Components

As Table 3 shows, the grain yield was highest (508 g/m^2) in the P2-B2 treatment. Among the P10 treatments, grain yield of the P10-B14 (445 g/m^2) treatment was higher than that of the P10-B3 (428 g/m^2) treatment, though there

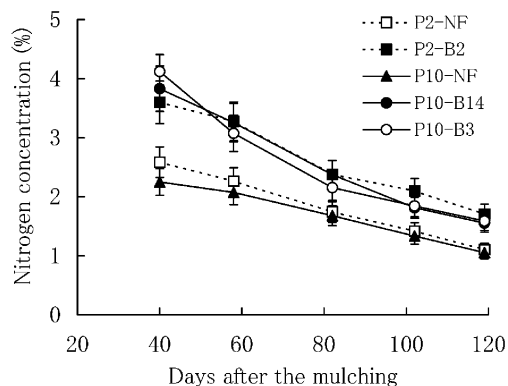


Fig. 4 Changes in leaf nitrogen concentration P2, P10 : Puddling and leveling was done 2 and 10 days before the mulching. B2, B3, B14 : Basal dressing was applied 2, 3 and 14 days before the mulching. NF : No fertilizer. Vertical bars indicate standard errors.

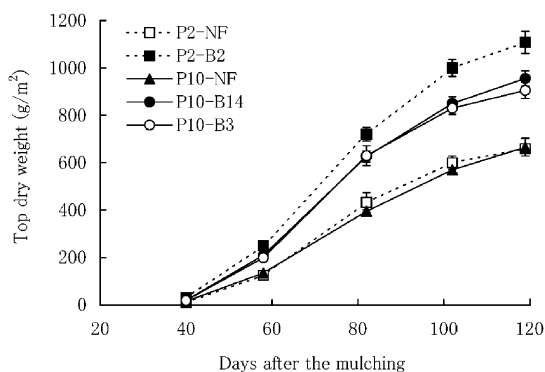


Fig. 5 Changes in top dry weight P2, P10 : Puddling and leveling was done 2 and 10 days before the mulching. B2, B3, B14 : Basal dressing was applied 2, 3 and 14 days before the mulching. NF : No fertilizer. Vertical bars indicate standard errors.

was statistically no significant difference. Among the no fertilizer treatments, the P2-NF treatment produced a higher grain yield than that of the P10-NF treatment, though there was no significant difference in grain yield. The grain yield difference between the P2-B2 and P10-B14 treatments was due to the percentage of ripened grains.

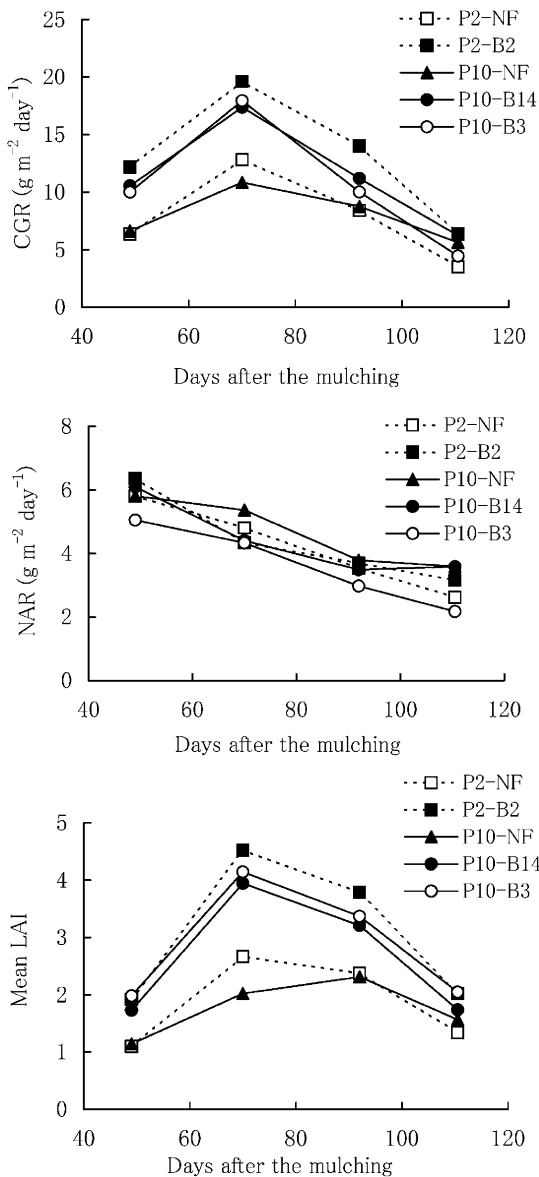


Fig. 6 Changes in crop growth rate (CGR), net assimilation rate (NAR), and mean leaf area (Mean LAI)
 P2, P10 : Puddling and leveling was done 2 and 10 days before the mulching.
 B2, B3, B14 : Basal dressing was applied 2, 3 and 14 days before the mulching.
 NF : No fertilizer.

4. Discussion

P & L is used to prepare soil for irrigated rice throughout Southeast Asia, creating a soft mud

often over a plow pan, which is a more favorable condition for the rice crop than for dry land crops (Ringrose-Voase *et al.*, 2000). In our previous studies, we observed that organic fertilizer (rapeseed meal combined with poultry manure) was more effective than chemical fertilizer in direct-sowing rice cultivation using non-woven fabric mulch (Hossain *et al.*, 2006a). Magdoff (1995) stated that organic systems rely upon the use of organic fertilizers and amendments that typically release nutrients (especially nitrogen) at a slower rate compared with chemical fertilizers. In the present experiment, we used rapeseed meal along with poultry manure as the nutrient source. Brye *et al.* (2004) stated that poultry manure is an organic amendment that has been used successfully as an alternative nutrient source for inorganic commercial fertilizers.

During 2001–2004, we observed that when P & L was done 2 days before the mulching (sowing), the field was muddy and mulch operation needed a considerable labor load. To study this matter, we first attempted to evaluate the operator’s physical stress by measuring the heartbeat rates in the muddy (P & L 2 days before mulching) and solid (P & L 10 days before mulching) paddy field (Fig. 2). Here, we observed that the operator’s physical stress was considerably lighter in solid field than in muddy field (Tables 1 and 2). Leblanc (1975) concluded that the Mets value from 2.0 and 3.0 indicated light work and a value from 1.5 to 2.0 indicated very light work. The Mets value in solid field was 1.71, which belongs to very light work (Table 2). We also evaluated the machine performance for mulch operation in muddy and solid field and observed that mulching by machine was much easier (in work hardness and as well as maintenance of mulch) in solid field than in muddy field (Yamashita *et al.*, 2006).

It was also revealed in the current experiment that the early basal fertilizer treatment (P10-B14) produced higher grain yield than

Table 3 Grain yield and yield components

Treatment	No. of panicles (/m ²)	No. of spiclets (/panicle)	Grain no. (/m ²)	Ripened grain (%)	Thousand grain wt (g)	Grain yield (g/m ²)
P2-NF	317 ^b	46.8 ^b	14808 ^d	78.7 ^a	23.3 ^{bc}	272 ^c
P2-B2	421 ^a	63.8 ^a	26761 ^a	79.7 ^a	23.8 ^{ab}	508 ^a
P10-NF	277 ^c	65.2 ^a	17898 ^c	58.4 ^c	22.4 ^c	231 ^c
P10-B14	422 ^a	64.4 ^a	27163 ^a	71.2 ^b	23.2 ^{bc}	445 ^b
P10-B3	405 ^a	58.1 ^a	23488 ^b	75.3 ^{ab}	24.3 ^a	428 ^b

Values within the same column and followed by the same letter do not differ significantly ($p < 0.05$).

P2, P10 : Puddling and leveling was done 2 and 10 days before the mulching.

B2, B3, B14 : Basal dressing was applied 2, 3 and 14 days before the mulching.

NF : No fertilizer.

that of the late fertilization treatment (P10-B3), but the difference was not statistically significant, which means that the timing of basal fertilization has no positive or negative impact on rice grain yield. That is, basal fertilization timing had no effect on the grain yield when P & L was done 10 days before the mulching.

Due to higher soil hardness in the P10-B14 treatment (Fig. 2), the operator's physical stress was observed very low and the operation to cover the field with cloth mulch was easily executed. However, as shown in Table 3, the grain yield of the P10-B14 treatment was 12% lower than that of the P2-B2 treatment due to lower percentage of ripened grain. Because of the lower inorganic nitrogen of the soil (Fig. 3), the growth of leaf area was suppressed and dry matter production was lower in the P10-B14 treatment compared to the P2-B2 treatment (Fig. 5, 6), which might have resulted in lower percentage of ripened grains. In our previous study (Hossain *et al.*, 2007), leaf area and photosynthetic rate of the lower leaves increased when we applied topdressing at the rate of 6 gN/m². Higher photosynthetic rate of the lower leaves was brought about by a higher rate of nitrogen accumulation due to topdressing. Increased leaf area and higher photosynthetic rate in the lower leaves resulted in better root activity, which contributed to a better percentage of ripened grain, and finally a better rice grain yield. To increase the grain yield of the P10-B14 treatment, future research

is needed to consider the application amount and application timing of topdressing, and also to reduce the gap between P & L time and mulching (recommending the gap 5–6 days with sunny weather). Of course, water permeability status of the experimental soil needs to be considered as low permeable soil may require couple of days for drying and compaction.

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Summary

In direct-sowing rice culture using cloth mulch, puddling and leveling (P & L) is usually done 2 days before the mulching (sowing). However, the mulching is very difficult, due to the muddy condition of the soil. Comparative studies were made to observe the effects of the timing of P & L, that is, P & L 10 days before mulching (P10) vs. P & L 2 days before the mulching (P2), on the operator's physical stress, the rice growth, and grain yield. Basal fertilizer was applied 2 days before the mulching in the P2 treatment (P2-B2), and topdressing was applied at 29 days before heading in all treatments. For the P10 treatment, timing of the basal fertilization was set at 14 (P10-B14) or 3 (P10-B3) days before the

mulching.

Results revealed that the timing of basal fertilization had no significant effect on the growth and grain yield between P10-B14 and P10-B3 treatments. The operator's physical stress was very low due to higher soil hardness in the P10-B14 treatment; however the grain yield was 12% lower than that of the P2-B2 treatment due to lower percentage of ripened grain. Because of the lower inorganic nitrogen of the soil, the growth of leaf area was suppressed and dry matter production was lower in the P10-B14 treatment, which resulted in lower percentage of ripened grain. To increase the grain yield of the P10-B14 treatment, future research is needed to consider the application amount and timing of topdressing, and also to reduce the gap between P & L time and mulching.

Key Words

Dry matter production, fertilization, inorganic nitrogen in the soil, non-woven fabric mulch, *Oryza sativa*, physical stress, puddling and leveling, yield components

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要 旨

不織布を利用した布マルチ水稲直播・有機栽培では、代かきを布マルチの敷設(播種)2日前(P2)に行っていたが、土壌がぬかるみ、敷設作業時の身体的負担が著しく大きかった。そこで、これを軽減するため代かきを敷設10日前(P10)に行い、作業者の身体的負担の度合ならびに水稲の生育・収量をP2区と比較した。基肥には菜種油粕と鶏糞堆肥を用い、窒素が6g/m²(リン酸は窒素と同量、カリは窒素の55%)となるようP2区では敷設2日前(P2-B2, 代かきの直前)に、P10区では敷設14日前(P10-B14)および3日前(P10-B3)に施用した。追肥は各区とも出穂29日前に菜種油粕を用い、窒素が3g/m²(リン酸とカリは窒素のそれぞれ38%および19%)となるよう施用した。

P10-B14区とP10-B3区とで水稲の生育・収量に有意な差はなく、P10区では基肥施用時期については特に考慮する必要のないことが分かった。P10-B14区では土壌表層部の硬度が高くなり、敷設作業時の身体的負担が軽減された。しかし、同区の収量はP2-B2区より12%低かった。土壌無機態窒素が低く推移したことから、葉面積の展開が抑制されて乾物生産が不足し登熟歩合が低かったことに起因したと考えられた。作業者の身体的負担の軽減を図りながら収量を減らさないための代かき時期、追肥の量やその施用時期などの検討が今後必要である。

キーワード

乾物生産, 収量構成要素, 代かき時期, 身体的負担, 水稲, 施肥, 土壌無機態窒素, 布マルチ, 有機栽培