The use of desalinated-dried jellyfish and rice bran for controlling weeds and rice yield

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Abstract

To achieve higher rice production, rice-growing countries have used great amounts of synthetic chemical compounds (chemical fertilizers and pesticides) that can have adverse effects on the environment and humans. Organic products and organic farming technologies are friendlier to the environment and more conducive to sustainable agriculture but require different inputs, knowledge and skills. Weed control is one of the major challenges in organic rice cultivation. The present study proposes and tests the use of desalinated-dried jellyfish chips in the development of sustainable rice production. Vast amounts of jellyfishes have been found in the Sea of Japan (Nomura's jellyfish, *Nemopilema nomurai* Kishinouye) and Japan inland sea areas (Water jelly, *Aurelia aurita* (Linne)), and jellyfish populationc can have a negative impact on the fishery industry. In this context, the use of jellyfish in organic agriculture has attracted attention. The present study found that the application of desalinated-dried jellyfish (small pieces of jellyfish which are desalinated and dried) mixed in soil before transplanting can effectively control weeds in rice fields and has a nutrient effect because of the high nitrogen content (12-13%). Desalinated-dried jellyfish has potential as an agricultural material that replaces herbicides and chemical fertilizers. It also contributes to environment-friendly rice production. It was found that both desalinated-dried jellyfish and rice bran effectively controlled rice weeds when mixed in the soil before the transplanting.The grain yields of desalinated-dried jellyfish treatments were consistently higher than the corresponding rice bran treatments. The rice yield from the desalinated-dried jellyfish treatments were comparable to the chemical fertilizer treatment.

Keywords: desalination, jellyfish chip, organic rice, rice bran, weed control and yield, organic agriculture, organic farming, Japan.

Introduction

Rice is highly adaptable to its environment and can be grown in widely different locations and in a variety of climatic environments. However the impacts of chemical fertilizer application on the environment and humans include water pollution, greenhouse gas emissions (N_2O), damage to human health, soil acidification and soil salinization. As a result of these effects, soil productivity, agricultural sustainability and human survivability are negatively impacted (Paull, 2007). A very high level of nitrogenous fertilizer has been applied in Japan (FAO, 2013). The use of herbicides has been accompanied by resistance to herbicides in many countries. One of the major problems with the use of herbicides is that the repeated use of the same herbicide induces the emergence of

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herbicide-tolerant weeds (Diggle *et.al.* 2003). In addition, the overuse of chemicals causes soil exhaustion and environmental pollution. These chemicals are also harmful to human health (Harris & Hill, 2007; Shimbo *et al.,* 2001).

According to the International Federation of Organic Agricultural Movements (IFOAM), the role of organic agriculture, whether in farming, processing, distribution, or consumption, is to sustain and enhance the health of ecosystems and organisms. Thailand is reported as the world's leading organic rice producer country, followed by the Philippines and Italy (Willer & Yussefi, 2007).

Rice is the main food grain in Japan, and Japanese consumers have a strong desire for organic rice grown without the use of, or with a decreased use of, farm chemicals. In Japan, research on the production of organic rice or with a decreased use of farm chemicals was begun in 1988 (Chunjiang & Guiqing, 1999). Organic rice production has been practiced using methods including integrated rice-duck farming (Furuno, 2001; Hossain *et al.* 2005; Hossain *et.al.,* 2007) and using the Japanese rotary weeder, non-woven fabric mulch (Tsuno, 1993; Hossain *et al.* 2009), rice bran, and newspaper mulch (Ueno *et al.,* 1999).

Bran is the hard outer layer of a grain and consists of a combination of aleurone and pericarp. Rice bran has mass amounts of protein, vitamins, minerals and 107 known naturally occurring antioxidants. It contains valuable components such as oil, protein, vitamins and some essential minerals as well as enzymes, microorganisms, natural toxicant constituents, and may also contain harmful contaminants and adulterants (Barber & Barber, 1980). To use rice bran in rice production, the farmer fills the field with water when the seedlings are very young and scatters rice bran on the rice field.

Jellyfish are planktonic marine members of a group of invertebrate animals composed of about 200 described species of the class *Scyphozoa* within the phylum Cnidaria or class Cubozoa. They can be found in every ocean in the world. Jellyfish are an important foodstuff in Asia, especially in China and Japan. The average annual catch of jellyfish between 1988 and 1999 in Southeast Asia was estimated to be about 169,000 metric tons in wet weight, and the worldwide annual catch is approximately 321,000 metric tons (Omori & Nakano, 2001). The jellyfish are reported to have a negative effect on the Japanese fishing industry (http://asiapundit.com/2006/06/12/three-gorges-and-giant-jellyfish/). Nomura's jellyfish, typically found in Japan, measure up to one meter in diameter and can weigh as much as 200 kilograms (http://pinktentacle.com/tag/jellyfish/).

In the present study, we compared the effectiveness of two materials, rice bran and desalinated-dried jellyfish, in controlling weeds in transplanted rice. Other objectives of the study were to determine the effectiveness of rice bran and desalinated-dried jellyfish as sources of nutrients, and ultimately to develop a new organic rice farming system.

Materials and Methods

Analysis

Jellyfish can be found in every ocean in the world and in the present study desalinated-dried jellyfish chips were made from live jellyfish that were killed in a high-concentration mixed-solution of salt and alum and then cut finely and air dried. The desalinated-dried jellyfish and the rice bran were separately ground to a fine powder. Total N and C content in the subsamples were analyzed using an N-C analyzer (NC-80, Sumica Chemical Analysis Service, Japan) (Table 1).

To measure P, K, Ca, Mg, Na, Cu, and Zn contents, the subsamples were digested with HNO_3 and $HClO_4$. After digestion, the filtrate was subjected to P analysis by using the molybdate blue method and the K, Ca, Mg, Na, Cu, and Zn were analysed by atomic absorption spectrometry (AA-6200, Shimadzu Co. Ltd., Japan) (Table 1).

Table 1. Mineral and carbon contents of desalinated-dried jellyfish and rice bran (% of dry weight).

	N	P	K	Ca	Mg	Na	Cu	Zn	C	C/N
Jellyfish	13.05	0.73	0.03	0.07	0.06	2.05	0.00	0.00	41.6	3.2
SE	0.250	0.095	0.003	0.006	0.000	0.073	0.000	0.000	0.681	
Rice bran	2.51	3.04	2.30	0.05	1.03	0.01	0.00	0.00	47.7	19.0
SE	0.082	0.109	0.110	0.004	0.000	0.001	0.000	0.000	1.253	

n=3

The mineral and carbon of desalinated-dried jellyfish and rice bran are shown in Table 1. It was observed that jellyfish is high in nitrogen (13.05%) and that its C/N ratio is very low. On the other hand, rice bran has high quantities of P and K, and the C/N ratio is high (19.0).

Experiment 1: Wagner pot experiment

The experiments were conducted at the Faculty of Agriculture, Ehime University, Japan. In the pots (Wagner size 1/5000a), three seedlings of cultivar Koshihikari were transplanted on May 15, 2007. Desalinated-dried jellyfish (1.25, 2.5 and 5 g/pot) and rice bran (1.25, 2.5 and 5 g/pot) were applied to the pots in the following two ways: (a) as a mixture in the soil before the transplanting (basal application); and (b) as an application on the soil surface just after the transplanting (top application). Thus there were thirteen treatments: 3x2 jellyfish treatments + 3x2 bran treatments + control.

Each treatment was replicated three times. The number of weeds was counted and the total (top plus root) dry weight of the rice plants was measured on July 1, 2007 (47 days after the transplanting). Samples were oven-dried at 85 °C to an almost constant mass (3 days) and weighed (Sugimoto *et al.,* 2005).

Experiment 2: Field tube experiment

Field experiments were conducted at the Faculty of Agriculture, Ehime University, Japan. A tube made from plastic pipe (25 cm in diameter, 30 cm in length) was set in the field so that the treatment condition was contained and protected from the soil situation beyond. Three seedlings were transplanted to the center of each tube on July 12, 2007.

Seven different fertilizer treatments were applied (keeping the applied nitrogen constant) plus there was a control (no application). The eight treatments were:

(1) No application (0-0);
(2) Chemical fertilizer at 10gN/m^2 mixed in soil just before the transplanting (C10-0);

(3) Desalinated-dried jellyfish at 10gN/m^2 mixed in soil just before the transplanting (J10-0);
(4) Desalinated-dried jellyfish at 5gN/m^2 mixed in soil just before the transplanting and at 5gN/m^2 applied on the soil surface 1 day after the transplanting (J5-J5);
(5) Desalinated-dried jellyfish at 10gN/m^2 applied on the soil surface 1 day after the transplanting (0-J10);
(6) Rice bran at 10g/m^2 mixed in the soil just before the transplanting (R10-0);
(7) Rice bran at 5gN/m^2 mixed in the soil just before the transplanting and at 5gN/m^2 applied on the soil surface 1 day after the transplanting (R5-R5);
(8) Rice bran at 10gN/m^2 applied on the soil surface 1 day after the transplanting (0-R10) (Table 2).

The amount of jellyfish or rice bran applied in the tube was determined by calculation on the basis of the tube size and the amount of nitrogen in the specific product. The amount of desalinated-dried jellyfish was 4.09 g or 2.05 g/tube and that of rice bran was 19.6 g or 9.8 g/tube.

The weight of the chemical fertilizers was 3.77g/tube and chemical fertilizer was applied as N:P_2O_5:K_2O=13%:13%:13% (3.77x0.13=0.49 g) (Table 2).

Table 2. Treatment combinations used in the field tube experiment (Experiment 2).

Treatment (Abbreviation)	Kind of fertilizer	Amount of fertilizer (g/tube)		Applied nitrogen	
		Mix in soil	Surface	(g/tube)	(g/m^2)
0-0	Nil	-	-	-	-
C10-0	Chemical Fertilizer	3.77	-	0.49	10
J10-0	Jellyfish	4.09	-	0.49	10
J5-J5	Jellyfish	2.05	2.05	0.49	10
0-J10	Jellyfish	-	4.09	0.49	10
R10-0	Rice bran	19.6	-	0.49	10
R5-R5	Rice bran	9.8	9.8	0.49	10
0-R10	Rice bran	-	19.6	0.49	10

Jellyfish: Desalinated-dried jellyfish

Each treatment was replicated four times. The oxidation-reduction potential was measured at a soil depth of 1-2 cm using a soil oxidation-reduction meter with platinum electrodes (Ehs-120, Fujiwara Seisakusyo, Japan). The number of weeds inside the tube was counted on August 13 (35 days after the transplanting). Plants were harvested on October 12. The grain yield and yield components were measured. 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. The 1,000-grain weight was measured, and the grain weight was calculated at a moisture content of 15%. Analysis of variance (ANOVA) was performed to statistically analyze the data using a software package (Excel Statistics 2006 for Windows, Social Survey Research Information Co. Ltd., Tokyo, Japan).

Results and discussion

Experiment 1

It was observed that both desalinated-dried jellyfish and rice bran controlled weeds better when mixed in the soil before the transplanting compared to an application on the soil surface just after the transplanting. In both cases, an application amount of 5 g/pot showed better weed control ability than the lower doses of 2.5 and 1.25 g/pot (Figure 1).

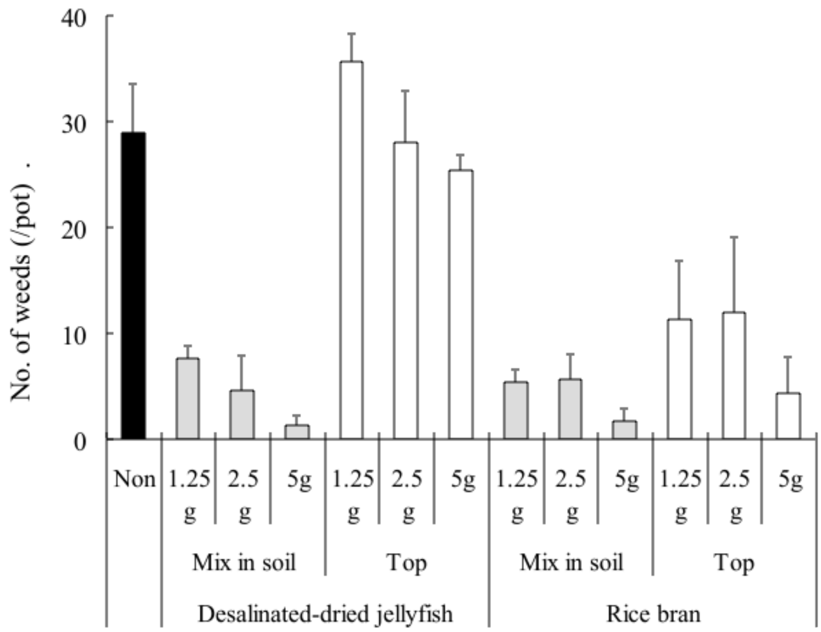

Figure 1. Effects of desalinated-dried jellyfish and rice bran on the number of weeds (Experiment 1).

The total dry weight of rice plants was observed to be much higher in the desalinated-dried jellyfish application plots compared to the rice bran-treated plots, probably due to the higher nitrogen content of jellyfish (Figure 2). The highest dry weight was observed for the jellyfish treatment when mixed in the soil at 5 gN/pot, followed by the top application of jellyfish at 5 gN/pot. The application of rice bran was not effective for improving the growth of the rice plant (Figure 2).

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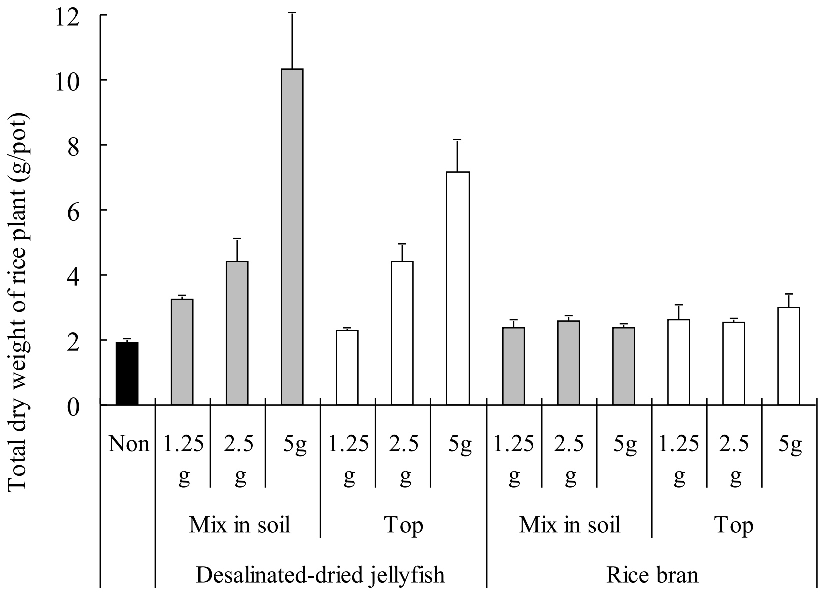

Figure 2. Effects of desalinated-dried jellyfish and rice bran on total dry weight (top+root) of rice plant (Experiment 1).

Experiment 2

The oxidation-reduction potential (Eh) was measured at regular intervals in order to evaluate the weed control ability. The oxidation-reduction potential was found to be lower in the tubes where the treatment was mixed in the soil (J10-0 and R10-0) than in those receiving the top application (0-J10 and 0-R10) (Figure 3).

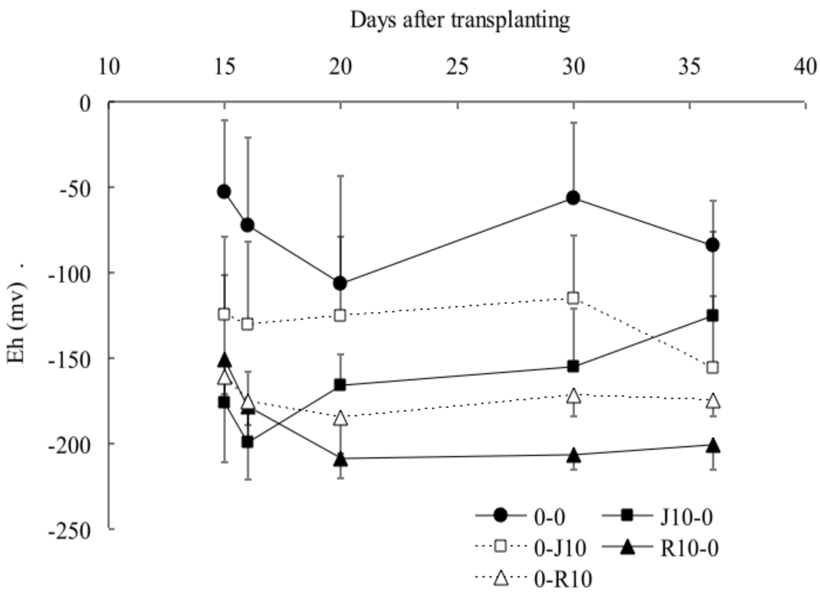

Figure 3. Changes of oxidation-reduction potential (Eh) in the soil (Experiment 2).

It was observed that the application of desalinated-dried jellyfish mixed in the soil (J10-0, J5-J5) effectively controlled rice weeds, while the top application (0-J10) was not effective (Figure 4). The numbers of weeds in the J10-0 and J5-J5 tubes were 18% and 24% of the C10-0 tube, respectively. However, in the 0-J10 tube with the top application, the number of weeds was 76% of that of the C10-0 tube. On the other hand, in the rice bran tubes, although the number of weeds in the soil mixture tube was smaller than the number in the top application tube, the difference between those tubes was not as large as in the desalinated-dried jellyfish tubes. It was taken that, as the Eh value in the soil mixture tube was lower, the number of weeds was smaller as compared with the top application (Figure 3).

The yield and the yield components are shown in Figure 5 and Table 3. The grain yields of desalinated-dried jellyfish treatments were consistently higher than the corresponding rice bran treatments. The yield of J10-0, F5-J5 and 0-J10 were 104%, 94% and 93% of that of C10-0, respectively. The grain yield of the rice bran treatment R10-0 was 49% of that of the chemical fertilizer treatment C10-0. Initial growth was inhibited, the number of panicles was less and the ripening ratio was low in the R10-0. This is considered to result from the Eh reduction value being remarkably low in this treatment (Figure 3).

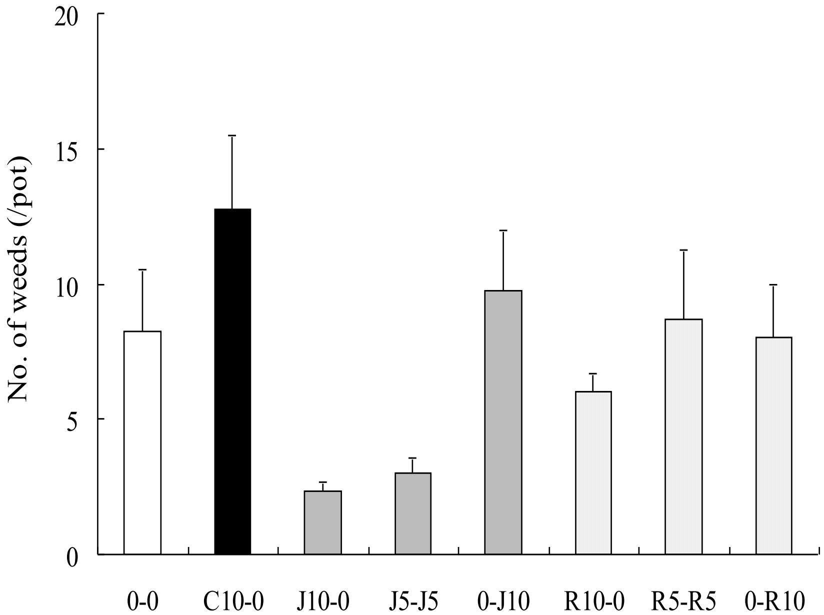

Figure 4. Effects of desalinated-dried jellyfish and rice bran on the number of weeds (Experiment 2).

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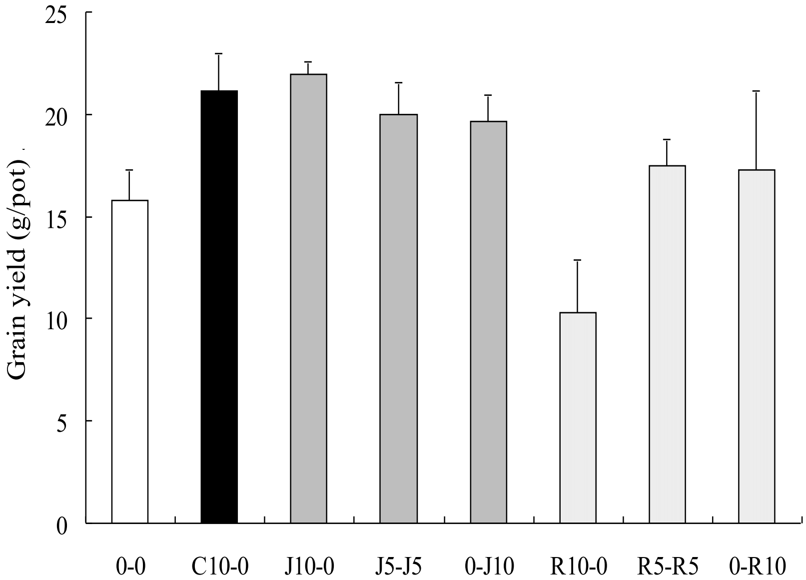

Figure 5. Effects of desalinated-dried jellyfish and rice bran on rice grain yield (Experiment 2).

Table 3. Yield and yield components (Experiment 2).

Treatment	No.of panicles (/hill)	No.of spikelets (/panicle)	No.of spikelets (/hill)	Ripening ratio (%)	1,000 grain weight (g)	Weight of filled grains[a)] (g/hill)	Ratio to C10-0 (%)
0-0	15.3	65	996	71	22.1	15.8 ± 1.5	75
C10-0	23.0	66	1505	64	21.8	21.2 ± 1.8	100
J10-0	22.5	70	1567	66	21.4	21.9 ± 1.3	104
J5-J5	21.3	67	1420	62	22.5	20.0 ± 2.6	94
0-J10	18.8	67	1253	71	22.1	19.6 ± 1.3	93
R10-0	16.8	52	944	39	23.7	10.3 ± 3.8	49
R5-R5	20.8	63	1310	60	22.2	17.5 ± 0.6	83
0-R10	20.8	51	1064	70	23.6	17.3 ± 1.1	82
F value	2.57*	4.25**	1.39ns	3.10*	3.39*	3.19*	

a): Average ± SE. *, **shows significant at $P<0.05$ and $P<0.01$ level, and ns is not significant.

It was found that both desalinated-dried jellyfish and rice bran could effectively control rice weeds when mixed in the soil before the transplanting (Figure 1) and that it controlled rice weeds to the maximum at the 10-0 tube treatments (Figure 4). The yield from the desalinated-dried jellyfish treatments were comparable to the chemical fertilizer treatment. The highest yield across the eight treatments was observed in the J10-0 jellyfish treatment, all three jellyfish treatments out yielded the three rice bran treatments (Table 3).

Kuk *et al.* (2000) stated that rice by-products could reduce weed emergence and shoot weight in broadleaf species. The weed population was decreased by the application of rice bran at 5 days after rice transplanting, and the weed occurrence rate decreased by 68% after the application of 3.5Mg ha^{-1} (www.hari.go.kr). Maeda *et al.* (2003) also mentioned that scattering rice bran on the surfaces of fields effectively controlled both the germination and growth of weeds. Paper mulching and feeding by ducks had the highest weed control efficiency (more than 99% of weeds were controlled.) followed by growing *Azolla spp.* and spreading rice bran (Chen, 2006).

Many farmers in Japan spread rice bran and culled soybeans in their rice fields as a form of weed control. Japanese farmers use rice bran (200 g m^{-2}) for weed control and as a fertilizer for transplanted rice, resulting in weed reduction and high-quality grain (http://www.jaec.org/jaec/english/2.pdf). In the present study, although the application of rice bran was observed to provide effective weed control, this is a result not different from previous studies.

As desalinated-dried jellyfish was used here for the first time to control weeds and provide nutrients in rice production, no relevant research on jellyfish is available for comparison. However, different types of fish meal have been found to be effective as an organic fertilizer. Fish powder is commonly used as source of nutrients in organic farming and is a high source of nitrogen. Usually, fish powder is dried with heat and turned into a water-soluble powder.

Conclusions

It can be concluded that the application of desalinated-dried jellyfish, small pieces of jellyfish which are desalinated and dried, mixed in soil before transplanting can effectively control weeds of rice fields and has a nutrient effect, presumed because of the high nitrogen content (10-13%). Desalinated-dried jellyfish has potential as an agricultural material to replace herbicides and chemical fertilizer. It also contributes to environment-friendly rice production. A similar result was observed in the case of rice bran, and it controlled weeds better when mixed in the soil before the transplanting compared to an application on the soil surface just after the transplanting. On the other hand, dry matter production was observed as higher in the jellyfish treatments compared to the rice bran treatments, probably due to higher nitrogen concentration of jellyfish. It can be concluded that the application of desalinated-dried jellyfish mixed in the soil effectively controlled rice weeds rather than top application. But, in the case of rice bran there are only small differences between treatments of mixture with soil or the top application. In the case of the grain yield of the jellyfish treatments, there was little difference observed due to the application method (mixed with soil or top) application, whereas in rice bran, the top application achieved a higher rice yield than the mixed with soil application.

The use of rice bran is an existing practice for weed control in Japan and other rice growing areas as a part of organic rice production, but, as a new product, jellyfish was also used in the present study to control weeds and provide nutrients in rice production, and it was found to have potential to improve organic rice production. It is important to perform further studies of direct-seeding rice (both wet and dry seeding) and transplanted rice to determine the optimal amounts of desalinated-dried jellyfish to be applied and the most effective timing of the application.

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