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https://doi.org/10.5109/1526310

出版情報：九州大学大学院農学研究院紀要. 60 (1), pp.65-71, 2015-02-27. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **60** (1), 65–71 (2015)

Production of Rice for Whole Crop Silage Using Manure in Itoshima Region, Fukuoka Prefecture

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(*Received October 31, 2014 and accepted November 14, 2014*)

The cultivation area of rice for whole crop silage (WCS) has rapidly increased in the last decade in Japan due to increasing demand for domestic livestock feed as well as a measure for the use of redundant paddy field. On the other hand, the production cost of rice for WCS is largely supported by subsidy now, so it is required to reduce the production cost. Manure application is a prospective way to reduce the cost of fertilizer and to sustain soil fertility. Thus, we investigated the production of rice for WCS using manure in Itoshima region, Fukuoka Prefecture, Japan, from the aspects of soil fertility, plant growth, and dry matter weight. The fields where manure was applied showed relatively high TN contents in soil whereas fields where manure was not applied showed low TN contents. This result indicated that soil fertility can be deteriorated by the continuous production of rice for WCS when organic matter is not supplied by manure and other materials. Plant length (r=0.748*) and tiller number (r=0.891**) at panicle initiation stage were closely correlated with TN content in soil whereas SPAD readings (r=0.846**) at the same stage was closely correlated with mineralized N in soil. Dry matter weight was positively correlated with TN content in soil (r=0.767**). Fields where manure was not applied had small dry matter weight although nitrogen was supplied from fertilizer. These results indicated that dry matter weight was significantly affected by soil fertility.

Key words: Dry matter weight, Plant growth, Soil fertility

INTRODUCTION

Rice consumption in Japan has declined since the 1960s (MAFF, 2006), and the use of redundant paddy field has become an important subject. In this situation, the cultivation area of rice for whole crop silage (WCS) has increased rapidly in the last decade and exceeded 15000 ha in 2010 (Tamura *et al.*, 2012) due to increasing demand for domestic livestock feed. Japan largely imports livestock feed; its self–sufficiency ratio is only 25% (Sakai *et al.*, 2008; Tamura *et al.*, 2012). For bulky feed such as hay and rice straw, the supply from overseas is as low as 20%. However, it is still important to enhance the domestic supply because imported feed can cause environmental problems through the excessive accumulation of organic matter as animal discharge and is also an assumed infection route of foot and mouth disease (Sakai *et al.*, 2008).

Currently, the production of rice for WCS is largely supported by subsidy due to its low market price, about 40 JPY/kg (Taniguchi *et al.*, 2010). Thus, it is required to increase yield while simultaneously reduce the production cost. Chambers (2000) and Holm–Nielsen (2009) have reported that appropriate applications of animal manure can supply nutrient required for crop and maintain soil fertility. Therefore, manure application can be a prospective way to reduce the cost of fertilizer input and to increase yield by the improvement of soil fertility.

In this study, we investigated current situation in the production of rice for WCS using manure in Itoshima region, Fukuoka Prefecture, Japan. The objectives were to evaluate the effects of manure application in terms of soil fertility, plant growth, and dry matter weight.

MATERIALS AND METHODS

Surveyed fields

Field surveys were conducted in 2013 in Itoshima region, Fukuoka Prefecture, Japan (33°30'N–33°34'N, 130°08'E–130°15'E). Table 1 shows physicochemical properties of soil in the surveyed fields. The total number of surveyed fields was 9. Fields 1, 2–5, 6–7, 8 and 9 were cultivated by farmers A, B, C, D and E, respectively. There were four soil types: clay loam (CL), sandy clay loam (SCL), sandy loam (SL) and light clay (LiC). Cation exchange capacity (CEC) varied from 5.81 to 18.74 cmol kg^{-1}. Soil types and CEC were determined by pipette method (Dane and Topp, 2002) and ammonium acetate shaking extraction method (Muramoto *et al.*, 1992),

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Table 1. Physicochemical properties of soil in the surveyed fields

Field	Farmer	Soil type	CEC (cmol kg^{-1})
1	A	CL	14.11
2	B	SCL	8.48
3		SCL	9.68
4		SL	5.81
5		SCL	7.50
6	C	LiC	15.85
7		LiC	17.30
8	D	LiC	18.74
9	E	SCL	11.43

CL, SCL, SL, and LiC represent clay loam, sandy clay loam, sandy loam, and light clay, respectively.

respectively. The Tachiaoba cultivar (*Oryza sativa*) was grown in all surveyed fields. The periods of transplanting and heading were from June 14 to June 25 and from September 6 to 18, respectively.

Measurements of physicochemical properties of manure

Manures applied in the surveyed fields were produced from waste of dairy cow in one cattle shed and fattening cattle in two different cattle sheds. Three samples of manure from each cattle shed were collected and kept in plastic Ziploc bags in May 2013. Although we did not collect samples directly from manure applied in the surveyed fields, the samples had approximately same maturity with the manures applied. Raw manure samples were stored in a refrigerator at 4°C, while some portion of each raw sample was air–dried and was then passed through a 1–mm sieve. The samples were ground with a Wiley Mill.

First, moisture content of raw manure was measured by oven–drying at 105°C for 24 h. Then, raw manure, which was equivalent to 15 g on a dry weight basis, was placed in a beaker. The beaker was left for 1 h after hot water with approximately 70°C was added. The volume of hot water was adjusted to make total volume of water in the solution 150 mL. Then, manure extract was collected by filtering the solution through a filter paper of No. 5B (Advantec, Tokyo, Japan). Electrical conductivity (EC), pH, ammonium (NH_4–N), and nitrate (NO_3–N) were measured using the manure extract. The EC and pH were measured using an EC meter (B–173, HORIBA, Ltd., Kyoto, Japan) and a pH meter (B–212, HORIBA, Ltd., Kyoto, Japan), respectively. The NH_4–N and NO_3–N were measured by the indophenol method (Cataldo *et al.*, 1974) and Cataldo method (Cataldo *et al.*, 1975), respectively.

The contents of total nitrogen (TN), total phosphorus (TP), and total potassium (TK) were measured using dry milled samples. Each of milled samples was digested by the H_2SO_4–H_2O_2 Kjeldahl digestion method (Ohyama *et al.*, 1991) with three replications. The contents of TN and TP were measured once for each digested sample by the indophenol method and ascorbic acid method (Murphy and Riley, 1962), respectively, and the average value for each sample was calculated. Absorbance at 625 nm and 710 nm were determined for TN and TP, respectively, using a spectrophotometer (V–630, JASCO, Tokyo, Japan) with a rapid sampler (NQF–720, JASCO, Tokyo, Japan). The TK content was measured for digested samples by using atomic absorption spectrophotometry (Z–5300, Hitachi High–Technologies Co., Tokyo, Japan). Total carbon (TC) content was measured for dry milled sample by using total organic carbon analyzer (TOC–5000A, Shimazu, Kyoto, Japan) and solid sample module (SSM–5000A, Shimazu, Kyoto, Japan).

Measurements of TN content in soil and soil mineralized N

Soil samples were collected at 5 locations with a criss-cross arrangement in each surveyed field. The soil from 0 to 10 cm depth was sampled using a soil core sampler of 5 cm in diameter and 10 cm in length. Soil samples were collected before transplanting on May 31 and June 3 in 2013. The soil samples were air–dried, and were then ground and passed through a 2–mm sieve by a Soil Sample Crusher (SSM–1, FUJIHIRA, Tokyo, Japan). The samples were analyzed for contents of TN following the same procedure with the measurements of manure. For the measurement of mineralized N, first 20 g of dry soil was placed in a glass bottle, and then distilled water of 50 mL was poured in. Next, the headspace in the bottle was replaced with nitrogen gas and capped with a rubber stopper. The flooded soil in the bottle was incubated at 30°C for 4 weeks. After incubation, ammonium was extracted with 100 ml of 0.5 M K_2SO_4 by shaking the bottle for 20 minutes. The extract was filtered through a filter paper of No. 5B (Advantec, Tokyo, Japan) and ammonium was in the extract was measured by the indophenol method.

Growth survey of rice for WCS

Growth surveys were conducted at the panicle initiation stage on August 12 in 2013. The plant length was measured in 2 plots for 2 continuous hills in the direction of a planting row (i.e., 4 hills in total). The number of tillers and SPAD readings (soil plant analysis development chlorophyll meter reading) were monitored in 2 plots for 10 continuous hills in the direction of a planting row (i.e., 20 hills in total). The two plots were located in a diagonal direction across the field and were not close to a water inlet or levee. The number and location of the hills for monitoring were determined on the basis of the reports by Kusuda (1990a, 1990b, 1992) as well as the required labor effort in the fields during the surveys. The SPAD readings were measured for the second fully expanded leaf blade in the longest tiller of a hill by a chlorophyll meter (SPAD–502, Konica Minolta Holdings, Inc., Tokyo, Japan). Measurements were taken four times on both sides of the midrib of the leaf blade (two times on each side), midway between the leaf base and tip, and then the average value was calculated. The position of SPAD measurements was determined according to

Chubachi (1986). The growth indicators in each field were calculated as the average values of all the measured hills.

Measurement of dry matter weight of rice plant

Dry matter weight of rice plant was estimated by quadrat sampling of 60 hills. The 30 hills were manually harvested in each of 2 plots located in a diagonal direction across the field on October 17 in 2013. Weights of straw and head were separately measured, and moisture contents were measured by oven–drying at 70°C for 48 hours. Then, dry matter weights of straw and head were calculated by subtracting moisture weights. The dry matter weight of rice plant was obtained by summing both weights of straw and head.

RESULTS

Physicochemical properties of manure

Table 2 shows physicochemical properties of three different manures applied in the surveyed fields. Manures 1, 2 and 3 were applied in fields 6 and 7, field 8, and fields 1 and 9, respectively. Manure 1 was produced from waste of dairy cow in one cattle shed. Manures 2 and 3 were produced from waste of fattening cattle in two different cattle sheds. Moisture content was higher than 50% in manures 1 and 2. The pH values ranged from 6.1 to 7.9. Manure 2 had a relatively high EC value of 10.1 mS cm^{-1}. The contents of NH_4–N, TN, TP, and TK ranged from 0.69 to 5.56 g kg^{-1}, from 12.03 to 26.32 g kg^{-1}, from 3.08 to 12.95 g kg^{-1}, and from 15.72 to 26.95 g kg^{-1}, respectively. Those values were the highest in manure 2 and the lowest in manure 1. The ratio of NH_4–N to TN in manure 2 was 21.2% that was very high compared with around 6% in other two manures. Nitrate contents were negligible in all manures. TC and C/N ratio ranged from 265.63 to 354.05 g kg^{-1} and from 11 to 29, respectively.

Outline of manure and fertilizer applications

Table 3 outlines manure and fertilizer applications in the surveyed fields. Three types of application manners were found: combination of manure and chemical fertilizer (field 1), only chemical fertilizer (fields 2–5), and only manure (fields 6–9). The application amount of manure ranged from 40 to 250 ton ha^{-1} in fresh weight or 19 to 84 ton ha^{-1} on dry weight basis. The application periods of manure were from December in 2012 to March in 2013. Although the application amounts were especially high in fields 6 and 7, TN amount applied in these fields was lower than that in field 9 because the manure applied was the lowest in TN contents and the highest in moisture content (Table 2). TN amounts supplied from manure ranged from 511 to 1213 kg N ha^{-1}. TN amounts supplied from basal fertilizer were smaller in field 1 (32 kg N ha^{-1}) than those in fields 2–5 (70 kg N ha^{-1}) since manure was applied in field 1. TN amount supplied from topdressing was same among fields 1–5 (18 kg N ha^{-1}).

Table 2. Physicochemical properties of applied manures

Manure	Field	Moisture content (%)	pH	EC (mS cm^{-1})	NH_4–N (g kg^{-1})	NO_3–N (g kg^{-1})	TN (g kg^{-1})	TP (g kg^{-1})	TK (g kg^{-1})	TC (g kg^{-1})	C/N ratio
1	6, 7	66.3	7.9	5.0	0.69	0.02	12.03	3.08	15.72	354.05	29
2	8	51.5	6.1	10.1	5.56	0.01	26.32	12.95	26.95	295.20	11
3	1, 9	37.6	7.7	4.4	1.35	0.05	19.45	8.09	16.38	265.63	14

Manure 1 was produced from waste of dairy cow. Manures 2 and 3 were produced from waste of fattening cattle.

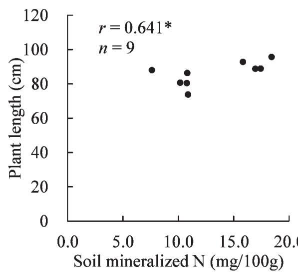
Table 3. Outline of manure and fertilizer applications

Field	Farmers	Manure		Fertilizer	
		Application amount (ton ha^{-1})	TN amount (kg N ha^{-1})	Basal TN amount (kg N ha^{-1})	Topdressing TN amount (kg N ha^{-1})
1	A	60 (37)*	728	32	18
2	B	0	0	70	18
3		0	0	70	18
4		0	0	70	18
5		0	0	70	18
6	C	250 (84)	1015	0	0
7		250 (84)	1015	0	0
8	D	40 (19)	511	0	0
9	E	100 (62)	1213	0	0

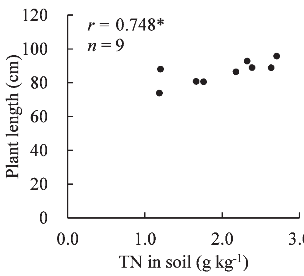
*Figures in parentheses are dry weight. Application amounts of manure were rough values obtained by interviewing cattle farmers on phone.

Relationships between soil mineralized N or TN content in soil and rice growth indicators at panicle initiation stage

Figure 1(a) and (b) show the relationships between soil mineralized N and plant length and between TN content in soil and plant length, respectively. Plant length varied from 73.8 cm to 95.7 cm and was positively correlated with soil mineralized N (r=0.641*) (Fig. 1(a)). The values of plant length tended to be low in fields 2 to 4 ranging from 73.8 to 80.7 cm, while they were high in fields 6 and 7 ranging from 92.8 to 95.7 cm. Soil mineralized N ranged from 7.6 to 18.4 mg/100 g, which were low in fields 1 to 5. The correlation between TN content in soil and plant length was higher (r=0.748*) (Fig. 1(b)) than the case in the mineralized N. TN content in soil of all fields ranged from 1.2 to 2.7 g kg^{-1} in which fields 2 to 5 were found to have low TN content varying from 1.2 to 1.8 g kg^{-1}.

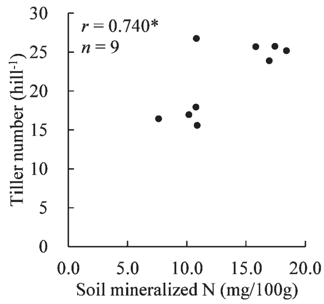


(a) Relationship between soil mineralized N and plant length at panicle initiation stage

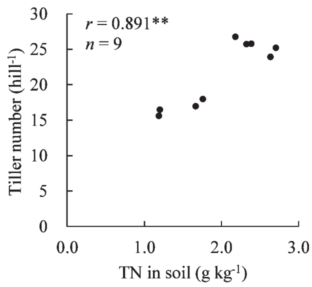


(b) Relationship between TN content in soil and plant length at panicle initiation stage

Fig. 1. Relationship between soil mineralized N or TN content in soil and plant length. * indicates that correlation coefficient r is statistically significant at 5% level.

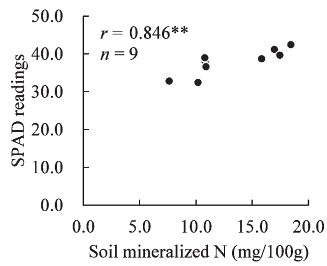


(a) Relationship between soil mineralized N and tiller number at panicle initiation stage

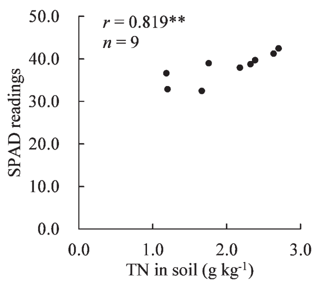


(b) Relationship between TN content in soil and tiller number at panicle initiation stage

Fig. 2. Relationship between soil mineralized N or TN content in soil and tiller number. * and ** indicate that correlation coefficient r is statistically significant at 5% level and 1% level, respectively.



(a) Relationship between soil mineralized N and SPAD readings at panicle initiation stage



(b) Relationship between TN content in soil and SPAD readings at panicle initiation stage

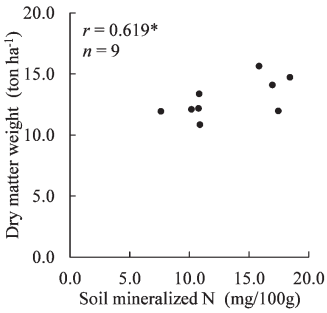
Fig. 3. Relationship between soil mineralized N or TN content in soil and SPAD readings. * and ** indicate that correlation coefficient r is statistically significant at 5% level and 1% level, respectively.

Figure 2(a) and (b) show the relationships between soil mineralized N and tiller number and between TN contents in soil and tiller number, respectively. Tiller number varied from 15.6 to 26.8 hill^{-1} and was positively correlated with mineralized N (r=0.740*) (Fig. 2(a)). Tiller numbers were low in fields 2 to 4 that were less than 18 hill^{-1}, while those values in other fields were higher than 23.9 hill^{-1}. The correlation between TN content in soil and tiller number was higher (r=0.891**) (Fig. 2(b)) than the case in mineralized N.

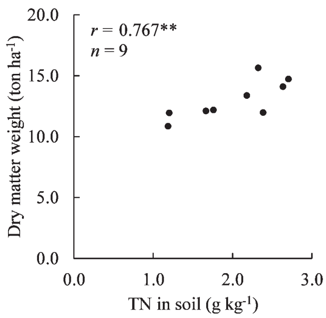
Figure 3(a) and (b) show the relationships between soil mineralized N and SPAD readings and between TN content in soil and SPAD readings, respectively. SPAD readings varied from 32.4 to 42.4 and were positively correlated with the mineralized N (r=0.846**) (Fig. 3(a)). The SPAD readings were low around 32 in fields 2 and 5, while they were higher than 41 in fields 7 and 8. The correlation between TN content in soil and SPAD readings was slightly lower (r=0.819**) (Fig. 3(b)) than the case in the mineralized N.

Relationship between soil mineralized N or TN content in soil and dry matter weight

Figure 4(a) and (b) show the relationships between soil mineralized N and dry matter weight and between TN content in soil and dry matter weight, respectively. Dry matter weight varied from 10.85 to 15.65 ton ha^{-1} and was positively correlated with soil mineralized N (r=0.619*) (Fig. 4(a)). Dry matter weights tended to be small in fields 2–5 and 9 ranging from 10.85 to 12.18 ton ha^{-1}, while they were high in fields 6–8 ranging from 14.1 to 15.65 ton ha^{-1}. Relationship between TN content in soil and dry matter (r=0.767**) (Fig. 4(b)) was higher than the case in the mineralized N.



(a) Relationship between soil mineralized N and dry matter weight



(b) Relationship between TN content in soil and dry matter weight

Fig. 4. Relationship between soil mineralized N or TN content in soil and dry matter weight. * and ** indicate that correlation coefficient r is statistically significant at 5% level and 1% level, respectively.

DISCUSSION

Physicochemical properties of manure

Manures 1 and 2 had relatively high moisture contents of 66.3% (dairy cow manure) and 51.5% (cattle manure), respectively (Table 2) as reported by the former studies for cow manure: 60% (Tahir *et al.*, 2012), 78.6% (Yang and Han, 2013), and 77.8% (Hao and Chang, 2003). On the other hand, manure 3 (cattle manure) applied in the fields 1 and 9 had low moisture content of 37.8% (Table 2). The low moisture content was because this cattle manure was aerated several times during 6 months of maturation period.

The NH_4–N content was especially high in manure 2, i.e., 5.56 g kg^{-1} (Table 2). The NH_4–N in manure is generally lost through NH_3–volatilization and denitrification during the manure maturation process (Bernal *et al.*, 2009). Thus, it was inferred that the maturity level was not high in manure 2. The NO_3–N contents were negligible. The TN content ranged from 12.03 to 26.32 g kg^{-1} in this study while former studies have reported a wide range of TN contents: 10.25 g kg^{-1} (Tahir *et al.*, 2012), 18.23 g kg^{-1} (Yang and Han, 2013), and 32.5 g kg^{-1} (Shah *et al.*, 2013). The TP content in dairy cow manure (manure 1) was the lowest among three manures, i.e., 3.08 g kg^{-1}, which was fairly close to 4.50 g kg^{-1} (Tahir *et al.*, 2012) and 5.50 g kg^{-1} (Yang and Han, 2013). Sutton and Alan (1994) have indicated that these differences in manure components were caused by composition of the feed, storage system and period, and bedding and bulking materials. Manure can be considered mature when its C/N ratio is less than 20 (Levi–Minzi *et al.*, 1986) or 25 (Bernal *et al.*, 2009). Thus, manure 1 was assumed to be not mature enough from the high C/N ratio of 29. Manure 2 was almost in the raw state of cattle waste without bulking materials, resulting in low C/N ratio of 11. Manure 3 was judged to be well mature from low C/N ratio of 14 and the maturation period of 6 months.

Effects of soil mineralized N and TN content in soil on growth and dry matter weight of rice plant

Growth indicators at panicle initiation stage and dry matter weight of rice plant were signifi–cantly correlated with both soil mineralized N and TN content in soil. Correlation coefficients were higher in the relationships with TN content in soil than those with the mineralized N for plant length (r=0.748*), tiller number (r=0.891**) and dry matter weight (r=0.767**). These results indicated that plant length and tiller number were affected by nitrogen mineralized by the date of growth survey (August 12) rather than that mineralized during the initial growth. In this study, soil mineralized N was measured under incubation at 30°C for 4 weeks. Mineralized N measured in this study can be assumed as an indicator of inorganic N supplied by the period from mid–July to end of July in the surveyed fields, considering transplanting dates from June 14 to June 25. On the other hand, TN content in soil can be assumed to be an indicator that reflects inorganic nitrogen supplied throughout a rice–growing season. This would be a possible reason that dry matter weight was more closely correlated with TN content in soil than soil mineralized N comparing with the cases of plant length and tiller number.

The fields 1 and 6–9 where manure was applied showed relatively high TN contents in soil ranging from 2.2 to 2.7 g kg^{-1} and had the trend of large dry matter weight ranging from 12.0 to 15.6 ton ha^{-1}. On the other hand, fields 2–5 where manure was not applied showed low TN contents in soil ranging from 1.2 to 1.8 g kg^{-1} and had small dry matter weight ranging from 10.9 to 12.2 ton ha^{-1} although 98 kg N ha^{-1} of nitrogen was supplied from fertilizer. This result implied that dry matter weight was significantly affected by soil fertility. In production of rice for WCS, whole straw and head are harvested and fed to livestock. Thus, soil fertility can be deteriorated by the continuous production when organic matter is not supplied by manure and other materials. Soil condition in fields 2–5 is chronically soft and wet due to its poor drainage performance. This condition made farmers difficult to apply manure using large machinery like a manure spreader. Manure has not been applied in fields 2–5 since the production of rice for WCS started about 10 years ago.

On the other hand, a correlation coefficient for SPAD readings was higher in the relationship with soil mineralized N (r=0.846**) than that with TN in soil. Since nitrogen absorbed by rice plant is more distributed in developing leaf blade (Mae and Ohira, 1981), it is considered that SPAD readings in uppermost leaf blade reflects inorganic N supply from soil at the time of growth survey. The SPAD readings were measured for the second fully expanded leaf blade in our survey. A leaf blade emerges about every 4–5 days before the initiation of panicle primordial (Yoshida, 1981). Thus, SPAD readings in second fully expanded leaf blade presumably reflected inorganic N supply from soil about 10 days before the date of growth survey. This inorganic N supply from soil may have been reflected more in mineralize N than TN content.

CONCLUSIONS

We investigated the production of rice for WCS using manure in Itoshima region, Fukuoka Prefecture, Japan, from the aspects of soil fertility, plant growth, and dry matter weight.

Conclusions include:

1. The fields where manure was applied showed relatively high TN contents in soil whereas fields where manure was not applied showed low TN contents. This result indicated that soil fertility can be deteriorated by the continuous production of rice for WCS when organic matter is not supplied by manure and other materials.
2. Plant length (r=0.748*) and tiller number (r=0.891**) at panicle initiation stage were closely correlated with TN content in soil whereas SPAD readings (r=0.846**) at the same stage was closely correlated with soil mineralized N.
3. Dry matter weight (r=0.767**) was closely correlated with TN content in soil. Fields where manure was not applied had small dry matter weight although nitrogen was supplied from fertilizer. This result implied that dry matter weight was significantly affected by soil fertility.

ACKNOWLEDGEMENTS

The research was supported in part by the grant for collaborative research between Itoshima city and Kyushu University.

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