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N Top-Dressing and Rice Straw Application for Low-Input Cultivation of Transplanted Rice in Japan

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ABSTRACT : An efficient low-input system (LIS) for fertiliser use in rice cultivation is necessary to reduce fossil energy use and pollution. Japanese people like Japonica rice, especially cv. Koshihikari. However, it has very low lodging resistance in Japanese weather condition. Our objective was to develop a LIS with the minimum sacrifice of grain yield in rice. Koshihikari was grown using conventional fertilization as a control (CON) with 4 g N m^{-2}, 8 g P_2O_5 m^{-2} and 8 g K_2O m^{-2} as a basal fertilizer dressing. It was compared with a low fertilizer treatment (LF) with only 4 g P_2O_5 m^{-2} as a basal dressing in the first year and no basal phosphorus fertilizer in the second year. Chopped rice straw was incorporated into the soil before the cropping season in both years. Fertilizer of 4 g N m^{-2} was top-dressed at 15 days before heading in CON plots and 30 days before heading in LF plots in both years. Lodging was significantly less in LF than in CON plots, however, no rice straw effect was found in low fertilized condition. Grain yields in LF plots were reduced by 15-16% below those of CON plots. Lower yields in LF plots were associated with a reduced number of spikelets per unit area. However, big spikelet size was acquired in LF by 10 days earlier N top dressing than CON plots. A close relationship was found between spikelet numbers and N content of the plant at heading, and between grain yield or shoot dry weight and N content of the plant at maturity. Regardless of the fertilizer application methods, N use efficiency for the number of spikelets, final total dry matter and grain yield was essentially identical among fertilizer treatments. The reduced growth and yield in the LF plots resulted from low absorption of nitrogen. Conclusively, LIS can drastically reduce chemical fertilizer use and facilitate harvest operations by reducing lodging with some yield reduction.

Keywords : Grain yield, Low-input, fertilizer, Lodging, Nitrogen.

In rural society, attention is given to the low input rice cultivation system to reduce the cost of agricultural materials and mitigate environmental pollution caused by the use of chemical fertilizers, insecticides or herbicides (Evans 1993; Hashikawa, 1996; Loomis and Connor, 1992; York 1994). Fertilizer use, particularly nitrogen for rice production, ranges from 6 to 27 g m^{-2} during a normal season in Korea and Japan, and nitrogen supply has increased during the past decades (Cassman *et al.* 1996; Yoon 1998). Production of nitrogen fertilizer requires high costs and energy inputs for the industrial process (Goulding *et al.* 1998). Excess use of nitrogen fertilizers pollutes the environment through overflow or leaching (Keeney 1982), although there is comparatively less water pollution from fertilizer in paddy than in other upland fields.

Organic materials or application methods of N fertilizer may reduce the use of chemical fertilizer. Rice straw is the major organic source and may enhance nutrient recycling based on organic matter while its decomposition immobilize N fertilizer by soil microorganisms (Dei 1970; Williams *et al.* 1968). The timing of nitrogen fertilizer is considered to be one of the most important factors for increased nitrogen use efficiency (N absorbed by the plant/N applied during whole season) and thereby for decreased nitrogen use (Shoji *et al.* 1986; Dingkuhn *et al.* 1990). Nitrogen top dressing at panicle initiation stage is recommended to increase N use efficiency (Rao and Mikkelson 1976). A combination of low basal nitrogen and a top dressing of nitrogen fertilizer has been recommended for reducing fertilizer use and increasing nitrogen use efficiency (Hashikawa 1996). A combination of reduced fertilizer with straw incorporation and an efficient application of fertilizer could be a possible solution to the problems of efficient N use and reducing lodging in cv. Koshihikari, especially.

A reduction of nitrogen fertilizer use may also reduce the yield losses due to the lodging. Cultivar Koshihikari is well known for its grain and eating-quality but it frequently lodges when fertilized with nitrogen (Watanabe *et al.* 1988). Hara and Toriyama (1997) indicated the maximum grain yield and spikelet numbers were obtained from the high-density-plot with large amount of N (20 g N/m^2) in Cv. Dontokoi in Japan.

Our objectives were to find out the possibilities to sustain grain yield and improve the N use efficiency by reduced or no basal application of N. Secondly, rice straw effect for the

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reduced lodging damage also tested with low or no N fertilized condition.

MATERIALS AND METHODS

A field experiment was carried out for two years in a sandy clay loam paddy field in Shimane University, Matsue, Shimane, Japan. The soil pH was 6.4 and soil bulk density was 0.93 g cm^{-3} at the experimental site. The 30-day-old seedlings of Koshihikari were transplanted at a density of 22.2 hills m^{-2} (15×30 cm) on 13 May in 1994 and 15 May in 1995.

In the conventional fertilization control (CON), 4 g N m^{-2} as ammonium sulfate, 8 g P_2O_5 m^{-2} as calcium super phosphate and 8 g K_2O m^{-2} as potassium chloride were applied as a basal dressing; and 4 g N m^{-2} was top-dressed at panicle initiation stage (approximately 20 days before heading in 1994 and 1995). In the low-fertilized treatments (LF), 4 g P_2O_5 m^{-2} was applied as a basal dressing in 1994 but none was applied in 1995. In LF plots, N was top-dressed at the panicle initiation as 4 g N m^2 (approximately 30 d before heading). In LF plots, chopped rice straw of Koshihikari (650 g m^{-2}) was spread in soil sundaeein the previars october and before incorporated into the soil in the 20-d before trarsplanting. In 1995, testifying the effect of rice straw, both the rice straw (0F+straw) and without rice straw (0F) were additionally established. Randomized block design with three replications was used for the experiment.

Grain yield as brown rice was measured from 1 m^2 (22.2 hills) from each replicate and calculated on 14% moisture basis. Ten hills per replicate of above ground plant were sampled at the start of reproductive stage, heading, and at full maturity, dried in the oven at 80°C for 48 h and weighed for the measurement of dry weight. Total nitrogen content in shoot was measured on 3 replications for each sample by the Kjeldahl method with Digestion System-2000 and Kjeltec System-1002 for distilling. A CHN-analyzer (Sumigraph NC-90A, Japan) was used for C/N ratio of chopped rice straw. For measuring leaf color, chlorophyll meter SPAD-502 (Minolta, Japan) was used. Leaf diffusive conductance was measured in the morning (8-9h, JST) and/or at midday (12-14h) of a fine day with AP-4 diffusion porometer (Delta device CO., Cambridge) at different growth stages. Fully expanded second leaf blades were used in the measurement for SPAD-value and leaf diffusive conductance until heading stage and flag leaf was used after heading stage.

The degree of lodging of culms on 20 hills per replication was measured and categorized as follows: 1-no lodging, 2-15-30° (slant from vertical), 3-30-45°, 4-45-60°, 5-60-80°, and 6-basal culm broken and lying down.

RESULTS

Yield and yield components

Grain yield in LF was 84% of conventional fertilization control (CON) in 1994 and 85% of CON in 1995 (Table 1). Grain yield was similar in the 0F and 0F+straw treatments in 1995 and much lower than that in the CON or LF (low-fertilized) treatments (Table 1). The panicle number (m^{-2}) of LF in both years was reduced compared to that of CON, although the number of spikelets per panicle in LF was greater than in CON in both years. The small number of panicles was the major component contributing to low yield in 0F treatments. The percentage of ripened grain and thousand-grain weight of LF in both crop years was not affected by fertilizer or straw treatments. Harvest index (HI) for the LF treatment was higher

Table 1. Yield components: grain yield, grain N use efficiency, harvest index, shoot dry weight, shoot N content and shoot N use efficiency of rice as affected by fertilizer N level and straw incorporation in a rice single cropping system in 1994 and 1995.

N and straw treatment	Panicle Numbers (m^2)	Spikelets Number Per panicle	Spikelet Numbers Per m^2	Ripened grain (%)	1,000-grain weight (g)	Grain yield (kg/10a)	Grain N use Efficiency (g/m^2)	Harvest Index	Shoot D.W. (kg/10a)	Shoot N Content (g/m^2)	Shoot N use efficiency (g shoot/g shoot N)
						1994					
CON	457a†	74b	33818a	85.0a	23.6b	660a	49.3a	0.38b	1720a	13.4a	128a
LF	302b	88a	26576b	86.0a	24.6a	553b	50.3a	0.43a	1200b	11.0b	109b
						1995					
CON	382a	77c	29414a	92.3a	25.7a	682a	54.8c	0.52a	1385a	12.4a	111d
LF	273b	98a	26754b	92.1a	24.0c	578b	60.1a	0.53a	1177b	9.62b	122b
0F	239c	73c	17447d	93.2a	25.1b	399c	56.0bc	0.48c	930c	7.13c	130a
0F+straw	206d	88b	18128c	92.9a	24.2c	398c	54.3c	0.50b	851d	7.33c	116c

†Means by the same letter within a column are not significantly different [DMRT (P=0.05)]. CON-conventional fertilized plot; LF-low basal fertilizer dressing; 0F-no-fertilized plot; 0F+straw- no-fertilized with straw plot.

than CON in 1994 but similar in 1995.

Shoot N content and N use efficiency

The shoot N content of rice grown without N fertilizer was less in 1994 and 1995 (Table 1). Nitrogen fertilizer increased the shoot N content in all treatment in both years. In 1994 the apparent uptake of the 4 g N/m^2 application was higher in LF than CON. In 1995 the apparent N uptake in the 4 g N/m^2 (LF) appliedd plot was 63% but 66% in 8 g N/m^2 (CONV) plot; there was no significant difference between both treatments. The shoot and grain nitrogen use efficiency (NUE) for the N treatments was lower in LF than CONV in 1994 but it was higher in 1995. However, shoot and grain NUEs was the greatest in 0F in 1995.

Plant growth

Biomass production and nitrogen absorption

Both the numbers of productive and total tillers were smaller for LF and 0F treatments than for the CON but the productive tiller ratio (productive/maximum tiller numbers) was higher (Fig. 1). SPAD values for LF plants steeply increased from 30 to 36 days after transplanting in 1994 and from 28 to 40 days in 1995 in response to nitrogen top-dressing. SPAD values were dropped for CON and 0F around those periods. Top dry weight and leaf area index (LAI) in LF and 0F were lower than in CON (Fig. 1). In 1994, the crop growth rate (CGR) between panicle initiation and heading period was higher in LF than in CON but in 1995 the CGR in CON was always higher than in LF. The net assimilation rate (NAR) after N top-dressing was higher in LF than in CON. Absorbed nitrogen in LF during whole growing period was lower than in CON in both years. Straw incorporation in LF and 0F plots in 1995 did not affect growth parameters clearly (Table 1) but rather suppressed early growth a little in the second year experiment.

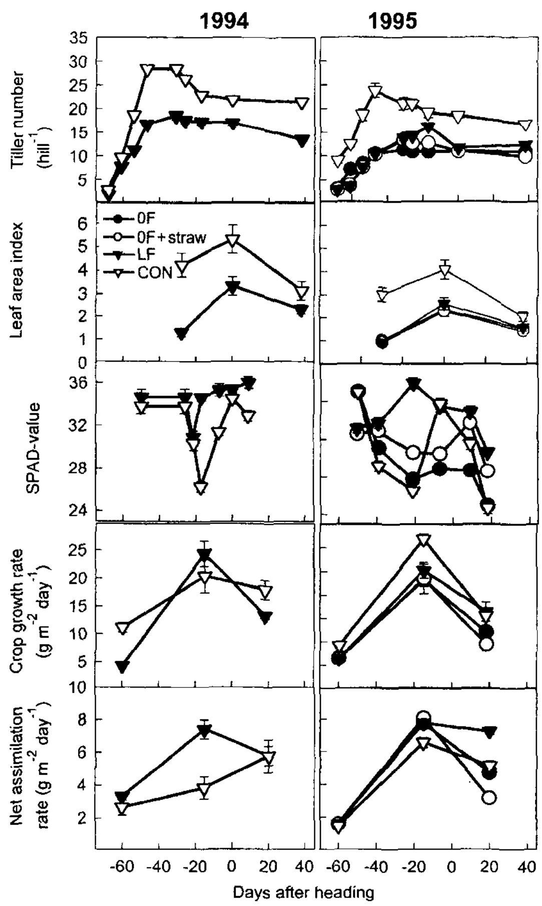

Fig. 1. Changes of tiller number, leaf area, SPAD-value, crop growth rate, and net assimilation rate of rice grown under different fertilizer conditions.

Leaf conductance

Stomatal conductance as a measure of stomatal aperture is considered as an indicator of root activity or photosynthetic activity in paddy rice (Ishihara *et al.* 1978). The nitrogen top-dressing at the early panicle initiation stage increased the leaf conductance of LF and 0F at midday in both years, compared to those of CON. There were only small differences between treatments in leaf conductance measured in the morning (Fig. 2).

Relationships between shoot N and shoot dry weight, grain yield, and spikelet numbers

There was a positive correlation between shoot dry weight

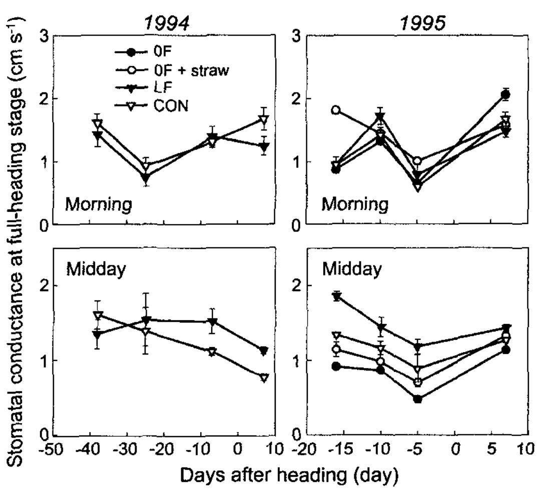

Fig. 2. Stomatal conductance at morning and midday indifferent fertilizer treatements.

at harvest time and grain yield or N content of the shoot at harvest time (Fig. 3). Spikelet number (m^{-2}), which mostly determined grain yield (Table 1), was correlated with the nitrogen content of rice plant at the heading stage (Fig. 3). The efficiencies of N use in determining yield, indicated spikelet numbers per shoot N content at heading, and shoot dry weight and grain yield per shoot N at harvest, were similar among different fertilizer treatments. In the LF treatment in 1995, it appears that spikelet production was a little more efficient than in CON and 0F treatments.

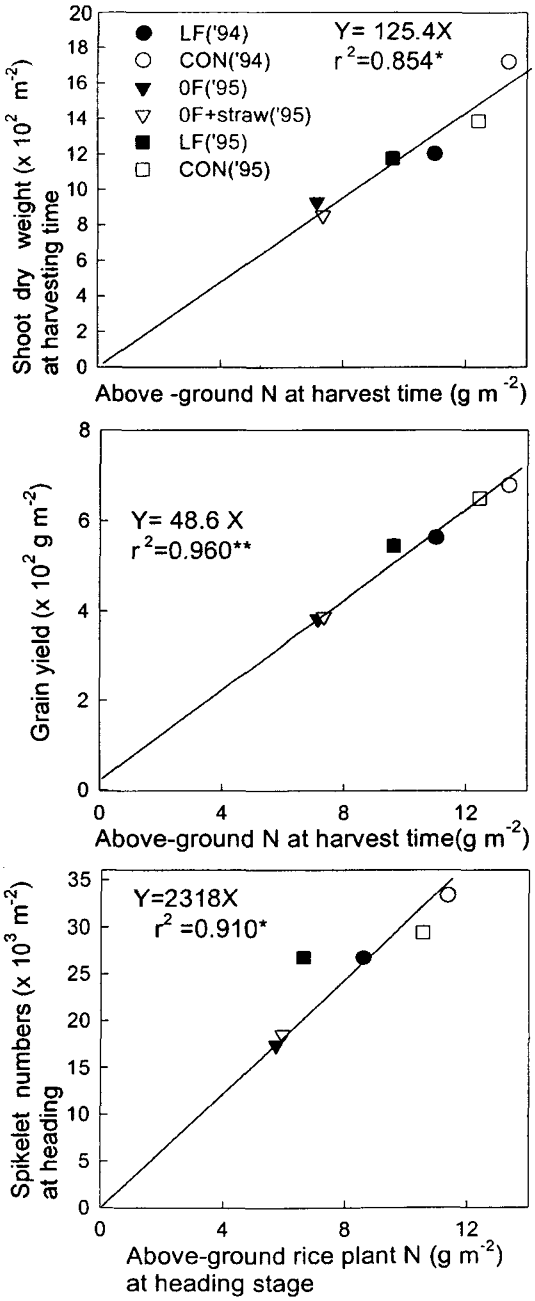

Fig. 3. Relationships of Shoot N and dry weight, grain yield, and spikelet numbers.

Effects of fertilizer N on shoot N and grain yield

There was a good linear relationship between shoot nitrogen content (g m^{-2}) at harvest and total applied nitrogen (Fig. 4). The slope of the line was less than 1 indicating that the efficiency of absorbed N from applied N decreased without an increase in N application rate. Consequently grain yield was also linearly correlated with total applied N in both years (Fig. 5).

Lodging at harvesting time

The percentage of severely lodged plants (grade 6) was

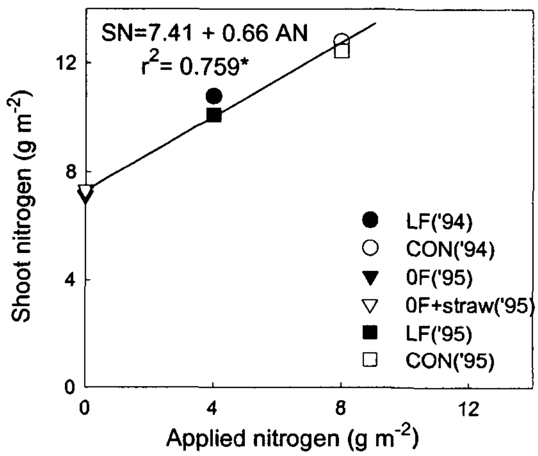

Fig. 4. The Relationship of applied nitrogen (AN) and shoot nitrogen (SN) in paddy rice plant.

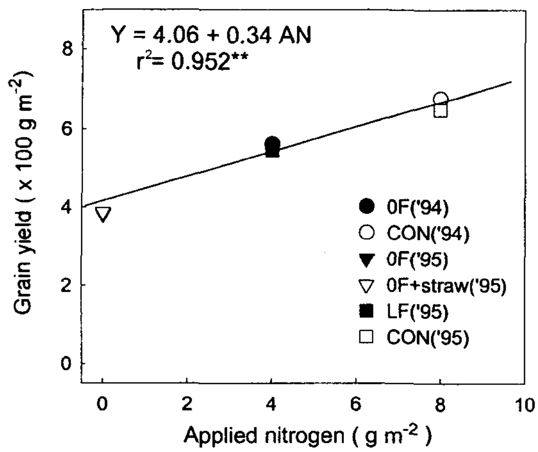

Fig. 5. The relationship of total applied nitrogen and hulled-grain yield in paddy rice under different fertilizer conditions.

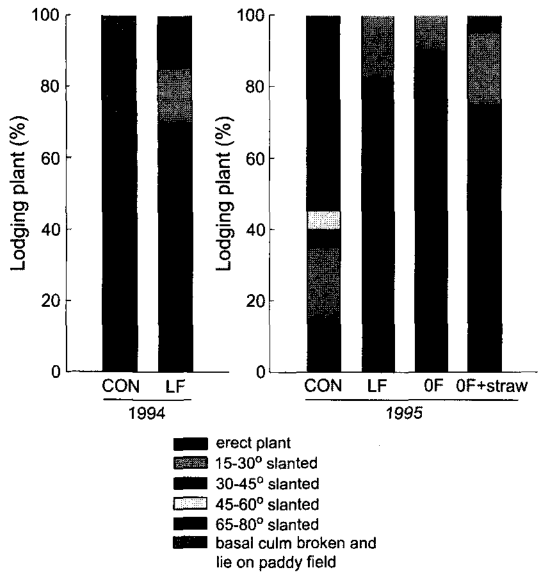

Fig. 6. Differences of loged degree in paddy rice plant under different fertilizer treatment.

significantly lower in LF and 0F than CON in both cropping years (Fig. 6). Most of the hills (from 85% in 1994 to 82% in 1995 of total observed plants) did not lodge in LF but a relatively greater number of CON plants lodged completely.

DISCUSSION

Grain yield in LF plots was lower than in CON in both years. Nitrogen top dressing at the early panicle formation stage, however, was not able to completely compensate for the growth suppression due to the reduced N absorption from low fertilizer inputs at transplanting. The close relationship between the shoot dry matter, yields and spikelet number, and the shoot nitrogen content suggested that nitrogen absorption dominantly affected biomass production and grasa yield. Fertilization methods here might have not affected total N absorption.

The lower basal fertilization seems to lessen lodging but with reduced yield. There was also some evidence that reduced fertilizer application increased fertilizer use efficiency, in which case it utilizes the soil nutrition reservoir under the no-fertilizer cultivation system (Yoon, 1998). Low or no basal dressing suggested an increase of N absorption rate or gas exchange activity of leaves because high stomata conductance in midday was observed in LF plots. That stomatal conductance might be higher because the LF plants were smaller (Tab. 1) than the CON plants, and so had used less water and had a reduced demand. To maintain high rice quality, protecting the crop from lodging is particularly important for Koshihikari because it is very sensitive to lodging under heavy fertilization (Watanabe, 1988). Chopped straw was added as a replacement of reduced fertilizer in LF plots. Rice straw contained 0.6% N (3.6 g m^{-2}), 0.1% P_2O_5 (0.6 g m^{-2}) and 1.5% K_2O (9 g m^{-2}) etc. (Rao, 1976). The amounts of nutrients, particularly nitrogen and potassium, were supposed to compensate for the requirements of plants at basal dressing, however, the growth of rice with the incorporation of straw was similar to that without straw. The initial growth of rice declined when straw was incorporated, which may reflect lower N availability due to slow decomposition of straw under low soil temperature during the tillering stage (Cho *et al.* 1999). Another problem may be that due to high C/N ratio, straw is unsuitable for rice growth from the N starvation (Dei 1970). The C/N ratio of the straw used in 1994 was 60 and this figure seemed to be high enough to delay initial growth. From the results, straw incorporation seems to be not effective as a basal dressing in such a short period of experimentation.

Grain yield was reduced in the low fertilized plot evidently due to the reduced panicle numbers. It is possible to increase the panicle numbers by a higher planting density rather than by adding a little higher basal fertilizations (Cho *et al.* 2000). The long-term effects of soil fertilization with fertilizer and straw on yield and the improvements of the grain yield should be further examined for practical application in a sustainable rice production system (Yoon 1988). Reduction of nitrogen fertilizer top-dressing to protect the cultivar from lodging requires a very careful operation depending on leaf color and plant growth (Yoshida and Coronel 1976). The methods applied to this experiment were designed to cover a particular technical operation.

CONCLUSIONS

In the experiments carried out, chopped rice straw was added as a replacement of reduced fertilizer in LF plots. Rice straw contained 0.6% N (3.6 g m^{-2}), 0.1% P_2O_5 (0.6 g m^{-2}) and 1.5% K_2O (9 g m^{-2}) etc. (Rao, 1976). The amounts of nutrients, particularly nitrogen and potassium, were supposed to compensate for the requirements of plants at basal dressing, however, the growth of rice with the incorporation of straw was similar to that without straw. The initial growth of rice declined when straw was incorporated, which may reflect lower N availability due to slow decomposition of straw under low soil temperature during the tillering stage (Cho *et al.* 1999). Additionally, high C/N ratio of the straw is unsuitable for rice growth (Dei 1970). The C/N ratio of the straw used in 1994 was 60 and this figure seemed to be high enough to delay initial growth due to soil N starvation. From the results, straw incorporation seems not to be effective as a basal dressing in such a short period of experimentation.

Reduced grain yield was due to the reduced panicle numbers in the low fertilized plot evidently. It is possible to increase the panicle numbers by a little increased planting density rather than by adding a few basal applications, even though yield components are extremely plastic, and increasing panicle numbers may simply result in smaller panicle size unless the crop is supplied adequate nitrogen at the time of panicle development (Hara and Toriyama, 1997; Cho *et al.* 2001). The long-term effects of soil fertilization with fertilizer and straw on yield and the improvements of the grain yield should be further examined for practical application in a sustainable rice production system. Even low grain yield in LF though big spikelet size was acquired by the 10 days earlier N top-dressing than CONV.

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