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著者	HOSSAIN Md., Zahid, SHIBUYA Kyoichi, SAIGUSA Masahiko
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No-tillage Transplanting System of Rice with Controlled Availability Fertilizer in the Nursery Box. 1. Growth Characteristics and Yield of Rice in Three Representative Paddy Soils

Md. Zahid HOSSAIN, Kyoichi SHIBUYA and Masahiko SAIGUSA

Expt. Farm of Tohoku University, kawatabi, Naruko, Tamatsukuri, Miyagi, 989-6711, Japan.

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Summary

No-tillage (NT) transplanting system of rice (*Oryza sativa* L. cv. Hitomebore) was conducted using controlled availability fertilizer (CAF) to study the effect of NT system on growth characteristics and yield of rice in representative three paddy soils (light clay Alluvial soil, sandy loam Alluvial soil and clay loam Andisol).

The cumulative N release from the sigmoid type of polyolefin coated urea (POCUS)-100 was only 3-3.5% during the nursery stage. The leaf color values of rice plants at early growth stage in NT transplanting system were lower than those of the conventional tillage (CT) transplanting system. The tillering capacity of rice plant in NT transplanting system was lower than that of CT transplanting system, and the percentage of productive tiller was larger in NT transplanting system in all three soils. The number of productive tillers per m^2 of NT with straw treatment (NTS) of all types of soil were larger than that of NT treatment. There were no significant difference in root distribution in the subsoil between NT and CT treatment. At harvest stage, averaged dry matter yields over two seasons in NT or NTS treatments were about the same as the CT with rice straw (CTS) treatment in three soils. The panicle dry matter yields of NT and NTS treatments were greater than that of CTS treatment in two soils. The yield of brown rice of NT treatment was 5.58-5.93, 5.47-6.35 and 5.18-6.34 Mg/ha for the light clay Alluvial soil, sandy loam Alluvial soil and clay Andisol, respectively. In contrast, the CT treatment yielded 5.67-6.07, 4.68-6.60 and 4.13-6.74 Mg/ha in these three soils. The initial growth of rice in NT system was slower than that of CT system. However, the yield of brown rice in NT system was almost same or greater than that of CT system reflecting releasing characteristics of POCUS fertilizer.

Therefore, it was concluded that the shifting of CT transplanting system to NT transplanting system of rice by using controlled availability fertilizer in a nursery box is highly feasible not only in heavy textured light clay soil but also in light textured sandy loam and clay loam soils.

Introduction

Recently, rice cultivation in Japan has been facing with a host of problems both in the country and overseas for the following reasons : rice farming is being increasingly considered as a part-time occupation, the rural population is getting older, the scale of operations is too small, the gap between the rice price in Japan and abroad is increasing, and there is a pressing call for the liberation of market. For these reasons, nowadays, for farmers, the reduction of labor and cost of rice production is becoming a great issue. Therefore, it is necessary to place much more emphasis on research on direct seeding to promote the development of a low-cost technology. However, there are still some technical problems in no-tilled direct seeding culture of the rice plant : low percentage of seedling establishment, low efficiency of applied N fertilizer, and not being well adopted to poorly drained soil. No-tillage (NT) system reduce the labor and implements cost. On the other hand, the innovation of controlled availability fertilizer (CAF) reduces the frequency of fertilizer application and labor cost (Sato and Shibuya, (1)) and its recovery was superior to that of ammonium sulfate (Kaneta, (2)). Nowadays, the advance of improved planting machinary and increase in production costs have increased the interest in NT farming system. However, the NT transplanting system of rice was practiced only in heavy textured, low permeable, clayey soil (Kanata (2), Maurya and Lal (3), Rodriguez and Lal (4)). The practice of the NT transplanting system of rice in light textured soil is still questioned by farmers and researchers. The suitable paddy soils for the NT transplanting system in Japan, are thought to be gley soil, gley Andisol, peat soil and muck soil and the percolation rate was lower than 10 mm per day in puddling condition (O-LISA Kenkyukai (5)). High leaching losses of nitrogenous fertilizers reduce the grain yield in NT transplanting system of light textured, high permeable soil (Sprague and Triplett (6)) because the NT system accelerates the percolation rate. However, in conventional tillage (CT) system, heavy agricultural machinery has been used to cultivate the rice, and the farmers puddled their fields several times. It seems that the soil has been compacted due to the effects of wheel traffic and the farmers efforts. As a results, the percolation rate of the paddy fields seems to be decreased in the long run. Therefore, it seems that after CT practice, the NT transplanting system by using controlled availability fertilizer (CAF) may be feasible even in light textured paddy fields. However, for light textured soil such as sandy soil and Andisol, no information is available about the effect on the growth characteristics and yield. Therefore, definite data are needed on the NT transplanting system of rice with CAF in a nursery box as related to soil types. This would allow nursery box for the rice farming program and may provide definite information about the shifting from the CT to NT transplanting system in many different soils.

Crop residue placement is a significant environment difference between CT and NT soils. In CT, crop residues are frequently incorporated uniformly into the surface soil, while in NT they are left scattered on the surface or left as standing stubble. There is reason to believe that the difference in crop residue placement may have an influence on crop growth.

The objectives of this experiment are to study the effects of no-tillage transplanting system using CAF in a nursery box on the growth and yield of rice in three representative paddy soils of north eastern Japan at different climatic conditions.

Materials and Methods

Field experiments were conducted in 1994 and 1995 on clayey Alluvial soil and sandy Alluvial soil at Furukawa (flat area) and Andisol at Kawatabi (hilly area), Miyagi prefecture, Japan. Rice (*Oryza sativa*. L. cv. Hitomebore) was used as a test crop. Soil samples from the 0-15 cm depth were taken for physical and chamical analyses before tillage treatments (Table 1). The clayey Alluvial soil, sandy Alluvial soil and Andisol are classified as fine textured strong gray soil, medium and coarse textured gray low land soil and humic wet Andosols (Classification Committee of Cultivated Soils (7)). The most important soil properties related to NT system is soil texture, and the texture of clayey alluvial soil, sandy alluvial soil and Andisol were light clay, sandy loam and clay loam, respectively. Characteristics of seedlings were shown in Table 2. Four treatments, NT or CT with or without straw (i.e., NT, NTS, CT and CTS), were tested in three plots. No-tilliage treatments were sprayed with 4.1 L a.i. ha^{-1} of Isopropy ammonium=N (phosphomethyl) glycinide at 20 days before transplanting. The experimental fields were submerged in water, 10 days before transplanting. Rice straw was scattered on the surface of soil for NTS, while in CTS, straw was incorporated into soil by tilling. Planting destiny was 24.2 hills m^{-2} (30 cm $\times$ 13.75 cm).

TABLE 1. *Some properties of test soils*

Place and type of soil	Texture	CEC (cmol(+)/kg)	pH (H_2O) (1 : 2.5)	Total N (g/kg)	Total C (g/kg)	Bray P (mg/kg)	Exchangeable cation K (cmol(+)/kg)	Na	Ca	Mg
Furukawa clayey Alluvial soil	Light clay	27.0	4.71	2.8	31.9	176	0.56	1.36	5.2	1.95
Furukawa sandy Alluvial soil	Sandy loam	12.8	4.87	1.4	13.1	386	0.66	0.91	0.2	0.23
Kawatabi Andisol	Clay loam	19.2	5.25	2.4	27.3	571	0.22	0.12	4.2	0.70

TABLE 2. *Characteristics of mat seedlings for CT and NT system*

Types of seedlings	Year	Plant length (cm)	Leaf age	DW/plant (mg)		Nitrogen % of shoot
				Shoot	Root	
Mat seedlings	1994	12.6	5.1	20.4	15.7	4.7
for CT system	1995	12.8	4.6	19.4	14.8	4.1
Mat seedlings	1994	12.4	4.7	20.6	16.4	4.3
for NT system (POCU S100)	1995	10.2	4.7	19.7	15.2	3.3

Sigmoid type of Polyolefin Coated Urea (POCUS)-100, as a source of CAF was used as a single basal application of total nitrogen of 70 kg N ha^{-1} in a nursery box at the time of sowing for NT treatments. In CT treatments, rapidly available compound fertilizers of 12-12-12 and 12-18-14 were applied at the rate of 50 kg N ha^{-1} at the transplanting time as a basal source of N, P_2O_5 and K_2O at Furukawa and Kawatabi, respectively. Ammonium sulfate was top-dressed twice at the rate of 10 kg N ha^{-1} at 15 and 25 days before heading in CT treatments.

Leaf color of completely developed uppermost leaf of the main culm of the 9 selected hills was measured by chlorophyll mater (Minolta Co. Model SPAD-502). Root samples of the 0 to 30 cm depth were taken from the center of each hill using monolith (45 cm × 30 cm × 5 cm). Each root sample was cut into three 10 cm segments. Roots were then dried at 70°C for 2 days and weighed. Number of tillers, and yield components of 9 selected hills in each plots were recorded. Grain yields of 35 hills of each plot were recorded at harvest. Nitrogen content of POCUS-100 was measured by the spectrophotometric method (Watt and Chrisp (8)) At young panicle initiation stage (12th July) and at harvest, six averaged hills from each plot per treatment were sampled and separated into leaf sheath and stem, and panicles. Each part oven-dried at 70°C for 48 h, and weighed.

Climatic data at Kawatabi and at Furukawa was obtained from the Automated Meteorological Data Acquisition System (AMeDAS). Mean air temperature and duration of sunshine hours during the rice growing season in 1994 and 1995 as compared with the averages of the last 22 years are shown in Fig. 1. Statistical differences were determined by Least Significant Difference (LSD) at 5% level.

Results and Discussion

Release of N from POCUS-100 Fertilizer

The cumulative N release from the CAF (POCUS-100) with time during the raising of seedling and throughout the growing period at the soil depth of 5 cm in 1994 and 1995 is shown in Fig. 2. The cumulative N release from the CAF was

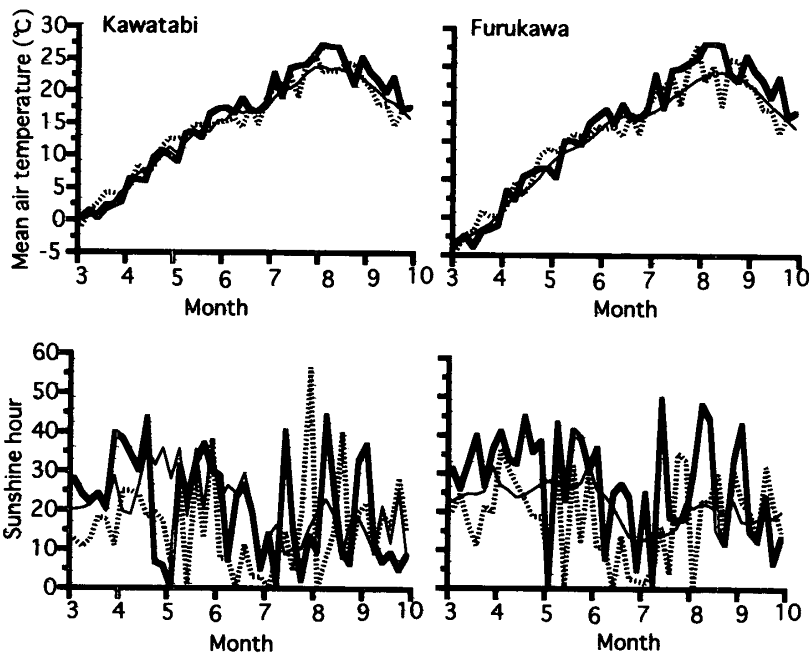

FIG. 1. Climatic data at Kawatabi and Furukawa
1994 1995 Average year

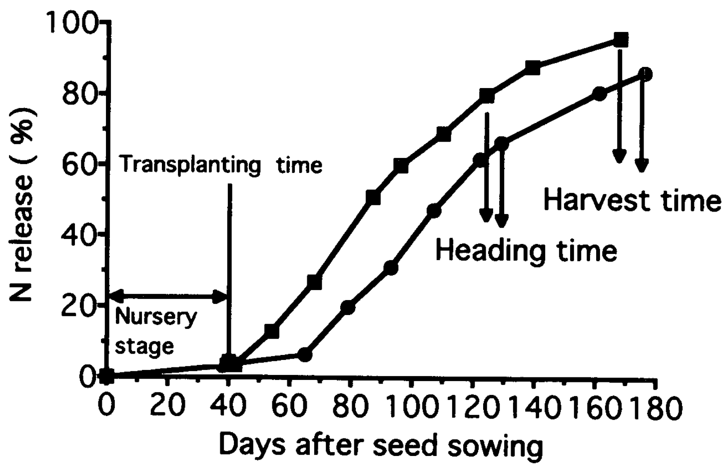

FIG. 2. Cumulative nitrogen release from sigmoid type of polyolefin coated urea (POCU S100)
1994 1995

only 3% and 3.5% during the nursery stage in 1994 and 1995, respectively. Kaneta (2) reported that the N release from POCUS-100 was 2.8% during the nursery stage. After transplanting, the rate of N release from the CAF gradually increased during the tillering stage and the young panicle formation stage. After this stage, the nitrogen release lowered relatively. Finally, the cumulative N release from the CAF was about 93% and 86% at the harvest stage in 1994 and 1995, respectively, which might effect on the growth and yield of rice plant.

Leaf Color Value

The effects of the tillage system on leaf color value of rice plants in 1994 and 1995 are shown in Fig. 3. The leaf color values of rice plants at the early stage

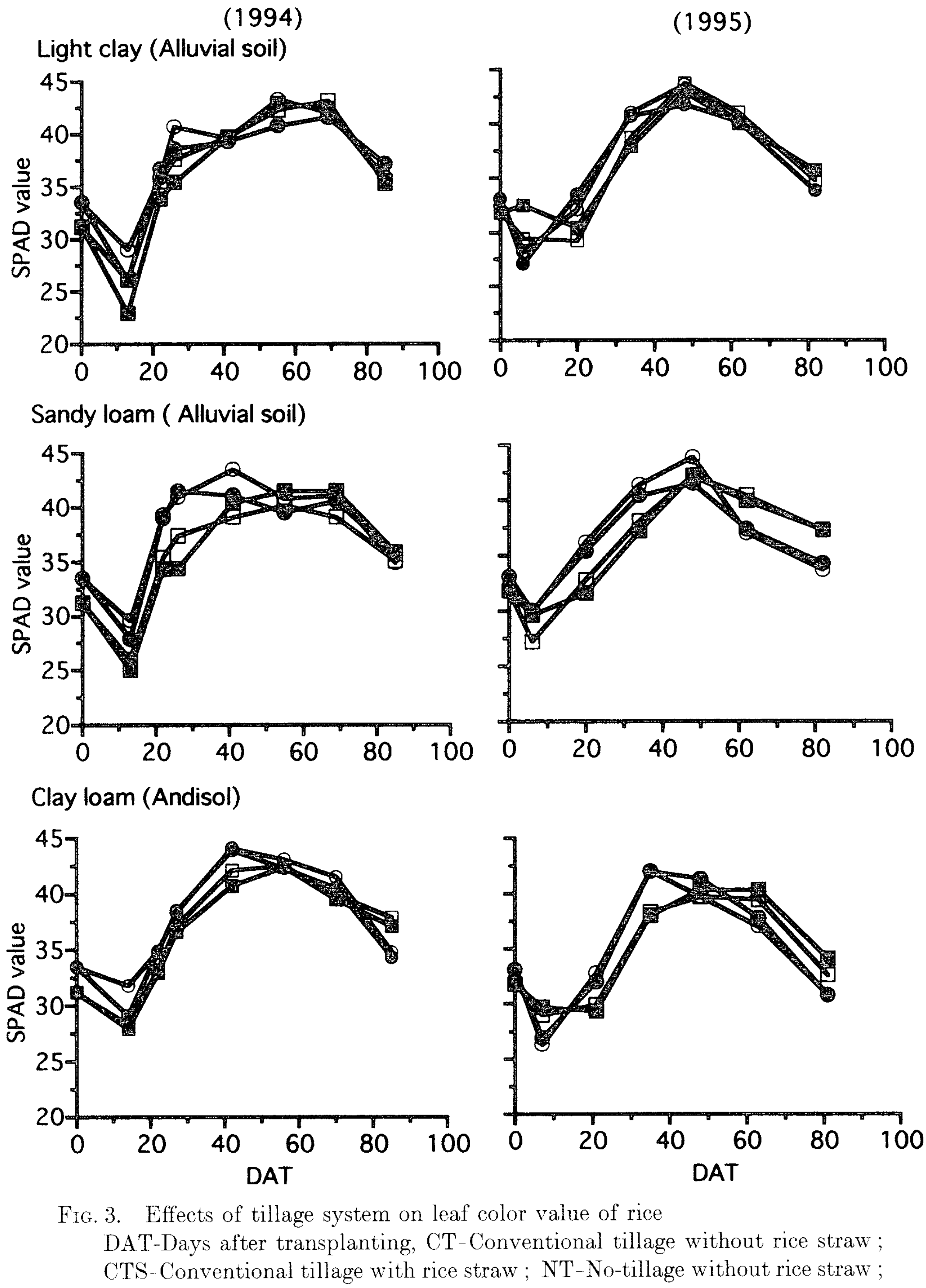

FIG. 3. Effects of tillage system on leaf color value of rice
DAT-Days after transplanting, CT-Conventional tillage without rice straw ; CTS-Conventional tillage with rice straw ; NT-No-tillage without rice straw ; NTS-No-tillage with rice straw
CTS CT NTS NT

in NT and NTS treatments were significantly lower than those of CT and CTS treatments in all soils. However, there were no significant difference among the leaf color values at 40 and 50 days after transplanting in light clay soil, sandy loam soil and clay loam soil in 1994, In 1995, the same results were obtained in clay loam soil, but in sandy loam and light clay soil, leaf color values of NT and NTS treatments were greater than those of CT and CTS treatments, which might have an effect on the number of tillers per unit area.

Number of Tillers per m^2

The effects of the tillage system on the number of tillers per m^2 of rice in 1994 and 1995 are shown in Fig. 4. In 1994 and 1995, it was found that the rice plant in NT and NTS treatments of light clay soil produced a smaller number of tillers per m^2 than those in CT and CTS treatments at around 45 days after transplanting. However, there was no significant difference in the number of productive tillers per m^2 at harvest time among the treatments (Table 3.). In 1994, similar results were obtained in sandy loam soil at around 45 days after transplanting. However, in 1995, there was no difference in the number of tillars per m^2 among the treatments up to 45 days after transplanting. However, the number of productive tillers per m^2 of NT and NTS treatments at harvest time were significantly lower than those of CT and CTS treatments in 1994, and in 1995, the number of productive tillers per m^2 at harvest time among the treatments were similar (Table 3).

In clay loam soil, there were no clear differences in the number of tillers per m^2 among the treatments up to 45 days after transplanting in 1994. After that time, the number of tillers per m^2 of the rice plant of CT and CTS treatments increased more than those of NT and NTS treatments. Similar results were obtained up to 45 days transplanting in 1995. However, in 1994, the rice plant of NT and NTS treatments produced statistically lower productive tillers per m^2 than those of CT and CTS, and in 1995, the number of productive tillers per m^2 produced by the rice plant of NTS treatments were similar to CTS treatment and statistically larger than that of NT and CT treatments (Table 3).

From the Fig. 4, it was clear that the tillering capacity of the rice plant in the NT transplanting system was smaller than that of the CT transplanting system, while the percentage of productive tillers was larger in the NT transplanting system in all soils reflecting releasing characteristics of POCU fertilizer. Although, the difference of productive tillers per m^2 among the treatments in light clay soil was not as big as in sandy loam and clay loam soil, reflecting the soil properties (Table 1) and the number of productive tillers per m^2 in NTS treatments of all three soils were larger than that of NT treatments, except sandy loam soil in 1995. It seems that the straw deposited on the surface of the soil was rapidly decomposed at oxidative condition and may supply an extra amount of

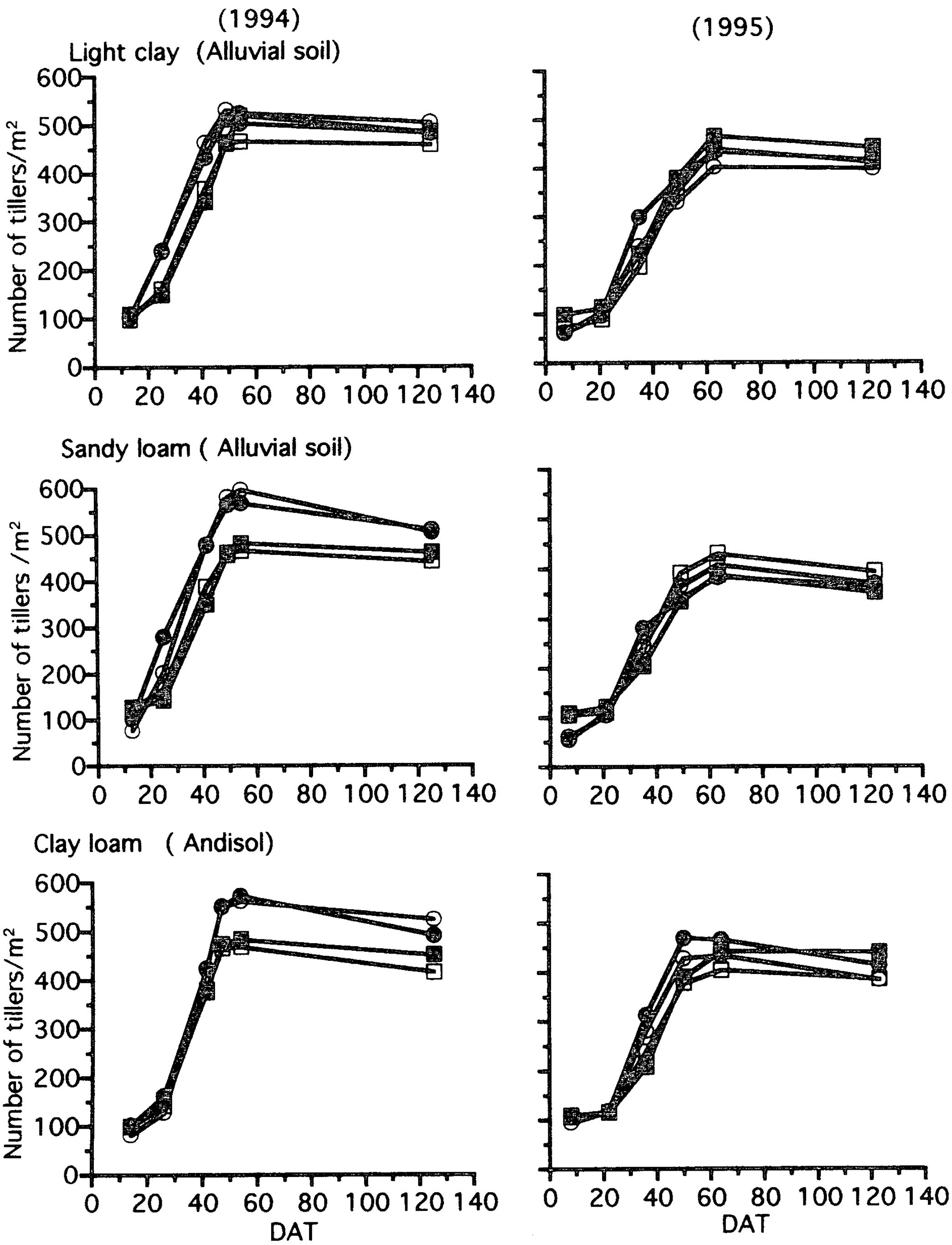

FIG. 4. Effects of tillage system on number of tillers of rice plant.
CT-Conventional tillage without rice straw ; CTS-Conventional tillage with rice straw ; NT-No-tillage without rice straw ; NTS-No-tillage with rice straw DAT-Days after transplanting
CTS CT NTS NT

TABLE 3. *Effects of tillage system on yield components of rice*

Soil types	Treatments	Number of panicles/m^2		Number of spikelets/panicle		Number of spikelets/m^2 ($\times$1,000)		1,000 kernel weight (g)		% of ripened grains	
		1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
Light clay	NT	458	410	67	69	30.7	28.3	22.9	24.0	83.5	84.9
(Alluvial soil)	NTS	484	441	65	67	31.5	29.6	23.0	23.1	80.9	81.9
	CT	504	397	64	76	32.2	30.2	22.2	23.7	77.6	79.2
	CTS	482	414	66	69	31.8	28.6	22.9	23.0	85.3	86.1
	LSD at 5%	–	–	4.4	2.8	–	–	0.33	0.32	–	2.7
Sandy loam	NT	442	394	61	71	27.0	28.0	23.4	23.9	89.3	91.9
(Alluvial soil)	NTS	462	351	58	71	26.8	24.9	22.9	23.7	89.2	92.4
	CT	505	369	56	59	28.3	21.8	22.9	23.7	90.3	92.7
	CTS	510	364	54	59	27.5	21.5	22.9	23.9	84.0	91.3
	LSD at 5%	45.5	42.3	2.8	4.8	–	–	0.29	–	–	–
Clay loam	NT	416	385	62	66	25.8	25.4	23.8	23.8	92.3	85.7
(Andisol)	NTS	451	440	59	66	26.6	29.0	23.7	23.7	91.6	79.6
	CT	524	384	64	52	33.5	20.0	23.2	23.4	91.1	88.4
	CTS	491	414	58	52	28.5	21.5	23.1	23.3	85.6	86.6
	LSD at 5%	56.5	41.9	4.5	5.2	–	–	0.51	0.32	–	–

NT-No-tillage without rice straw; NTS-No-tillage with rice straw; CT-conventional tillage without rice straw; CTS-Conventional tillage with rice straw

LSD = Least Significant Difference

nutrients for the rice plant in the NT system, because rice straw contains about 0.6% of N, 0.1% each of P and S, 1.5% K, 5% Si, 40% C (Ponnamperuma (9)). Application of rice straw was assumed to promote synchrony and reduce gaseous N losses from basely applied mineral N fertilizer (Azam et al. (10)). In addition to this effect on N losses, supply-demand synchronization was speculated to reduce the number of unproductive tillers and to increase harvest index and agronomic N use efficiency (Morris et al. (11), Becker et al. (12)). On the other hand, the nitrogen release from POCUS-100 depends on temperature (Shoji and Gandeza (13)). Therefore, after transplanting, the rate of N release from POCUS-100 was slower at the initial growth stage and gradually increased at the late tillering stage and the young panicle formation stage as shown in Fig. 1. Whereas, the rice plant could rapidly absorb N from the readily available N fertilizer during the early growth stage, and the amount of mineralized soil N from CT soil was greater than that of NT soil (Kaneta et al. (14)). Therefore the initial growth of the rice plant in the NT transplanting system seems to be lower than that of the CT transplanting system.

Root Growth

Tillage effects on vertical distribution of roots are shown in Fig. 5. The roots in the NT treatment reached even the subsoil. In all soils, about 85% of the total roots were found in the top 10 cm. There were no differences in root distribution in the subsoil between NT and CT treatments.

Dry Matter Production

The total dry matter of the rice plant at the young panicle formation stage and at harvest time are shown in Fig. 6 and Fig. 7. In 1994, the dry matter yields of the rice plant of NT and NTS treatments were significantly lower than those of CTS treatments in light clay soil. However, at harvest time the dry matter yield of NTS treatments were significantly greater than those of NT and CTS treatments (Fig. 7). There were no significant differences of dry matter yield of the rice plant among the treatments of the young panicle initiation stage in 1995. However, the dry matter yields of the rice plant at harvest time of NT and NTS treatments were similar as CTS treatment in 1995.

In sandy loam soil, there were no significant differences of dry matter yields among the treatments in 1994. However, in 1995, the dry matter yields of NT and NTS treatments were statistically superior to those of CTS treatments. The dry matter yields of the rice plant at harvest time of NT treatments were similar as CTS treatments in 1994. However, the dry matter yields of rice plant at harvest time NT treatments were significantly greater than those of CTS treatments in 1995.

In clay loam soil, there were no significant difference of dry matter yields at

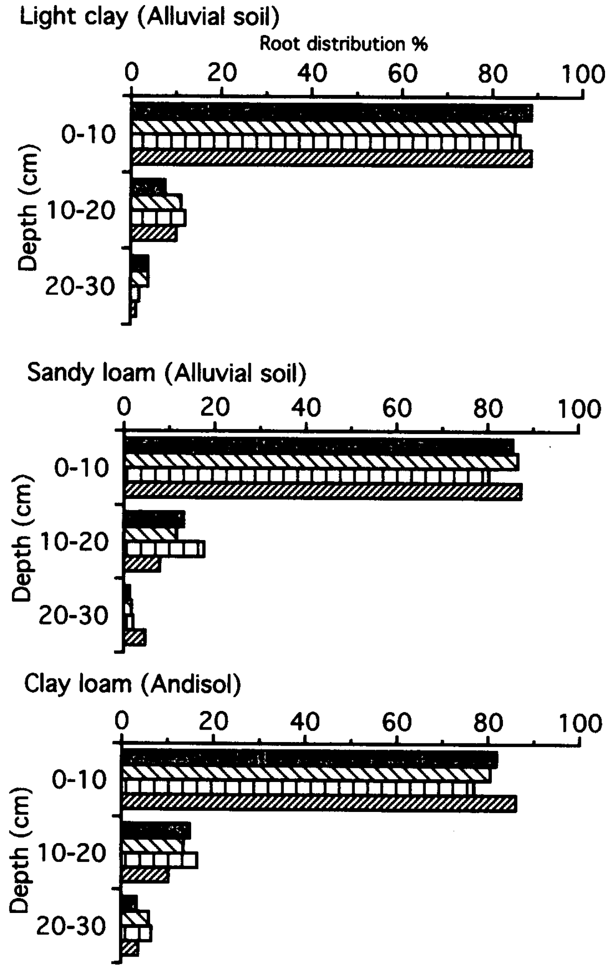

FIG. 5. Effects of tillage system on vertical distribution of root
NT-No-tillage without rice straw; NTS-No-tillage with rice straw; CT-Conventional tillage without rice straw; CTS-Conventional tillage with rice straw

■ NT ▥ CT ▧ NTS ▨ CTS

the young panicle formation stage among the treatments both in 1994 and 1995. However, at harvest time, the dry matter yields of the rice plant of NT and NTS treatment were significantly greater than those of CTS treatments in 1994. In 1995, the highest dry matter yields was obtained in NT treatment.

From the Fig. 7, it was clear that the dry matter yields of the rice plant of light clay soil and sandy loam soil were greater than those of clay loam soil, and the dry matter yields of the rice plant in NT treatments were greater than those in NTS treatments at panicle initiation stage. Panicle dry matter yields in NT and NTS treatments were greater than those in CTS treatments in soils, except in light clay soil, suggesting higher recoveries of fertilizer nitrogen and active transport of assimilates to the panicle. The large dry matter gain in the panicles was in agreement with the generally established concept that photosynthesis

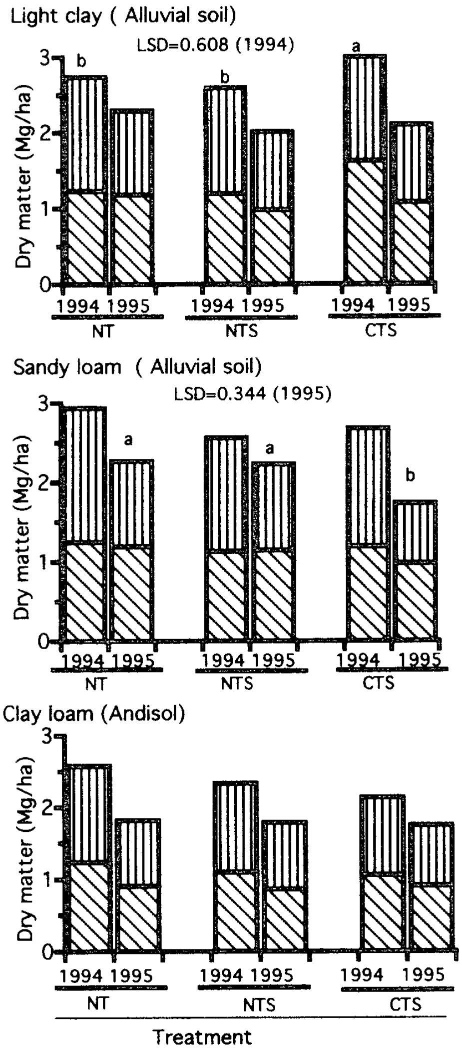

FIG. 6. Effects of tillage system on total dry matter of rice plant at panicle initiation stage
NT-No-tillage without rice straw ; NTS-No-tillage with rice straw ; CTS-Conventional tillage with rice straw ;
Leaf Stem

during grain filling is the major contribution to the grain yield of rice (Yoshida (15)).

Grain Yield and Yield Components

Brown rice yields are shown in Fig. 8. In 1994, brown rice yields of NTS treatment of light clay soil was 6.3 Mg ha^{-1}, which was similar to the yield of CTS treatment (6.6 Mg ha^{-1}). However, the highest yield was obtained from CT treatments (6.6 Mg ha^{-1}). In 1995, the differences in grain yield between the NT and CT treatment were similar. However, the highest yield was obtained from NT treatment (5.76 Mg ha^{-1}). Compared to the averaged yield of two seasons, NT

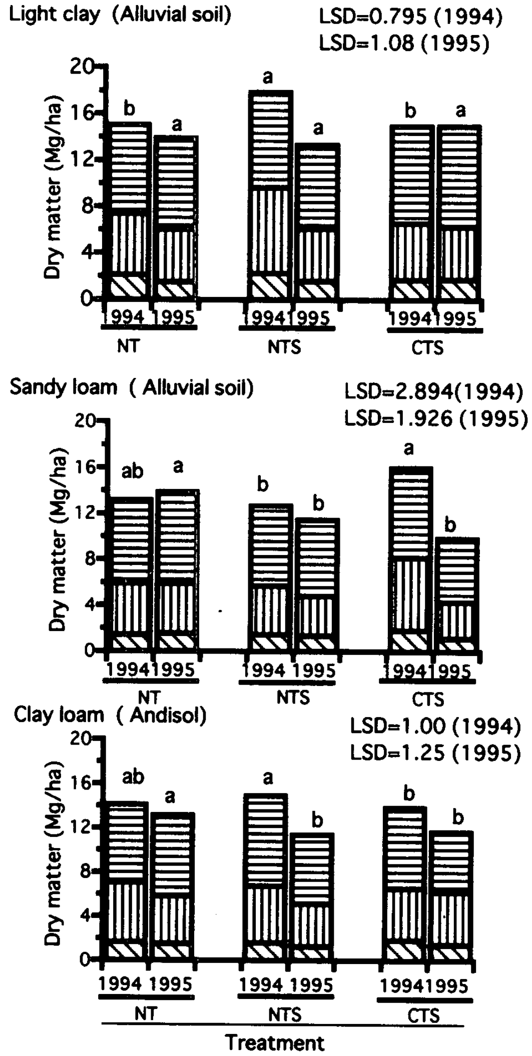

FIG. 7. Effects of tillage system on total dry matter of rice planr at harvest time NT-No-tillage without rice straw; NTS-No-tillage with rice straw; CTS-Conventional tillage with rice straw;
Leaf Stem Panicle

or NTS treatment produced about the same grain yield as CT or CTS treatment.

In sandy loam soil, NT treatment (5.93 M gha^{-1}) produced similar grain yield as CT treatment (6.07 M gha^{-1}) in 1994. NTS treatment produced significantly lower yield (5.58 Mg ha^{-1}) than that of CTS treatment (5.85 Mg ha^{-1}). However, in 1995, the yields of NT treatment were significantly higher than those from CT treatment. The highest yield was obtained from NT treatments. For the averaged yield over two seasons, NT treatment in sandy loam soil produced about 8% higher grain yield than did CT treatment.

In clay loam soil, the grain yields of the NT treatments were statistically the same. Brown rice yields of NT or NTS treatments and CT or CTS treatments,

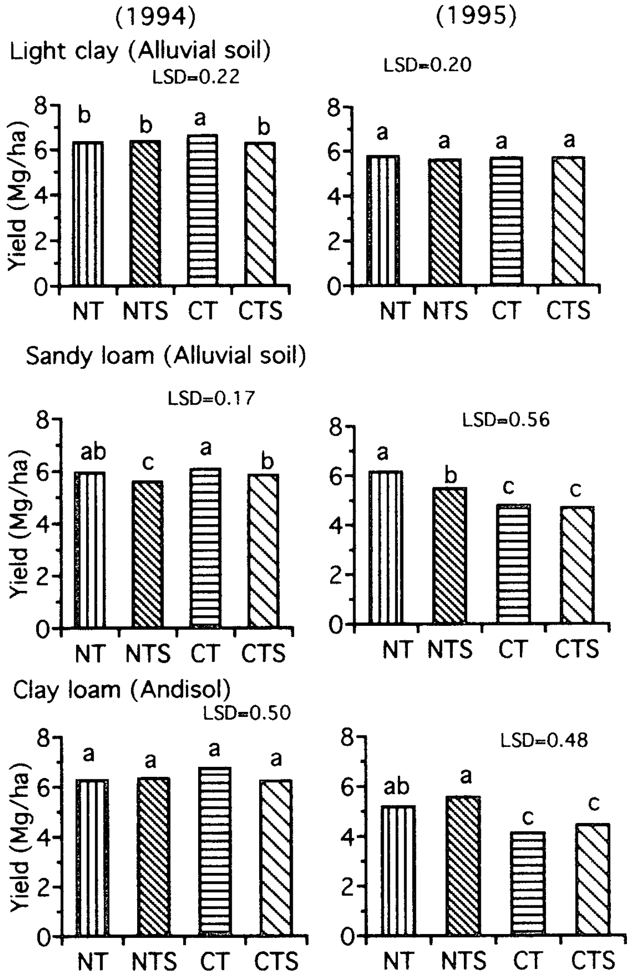

FIG. 8. Effects of tillage system on yield of brown rice.
NT-No-tillage without rice straw; NTS-No-tillage with rice straw; CT Conventional tillage without rice straw; CTS-Conventional tillage with rice straw

were 6.34 or 6.26 Mg ha^{-1} and 6.24 or 6.74 Mg ha^{-1} respectively. In 1995, NT treatments produced statistically higher yield than that of CT treatment. For the averaged yield over two seasons, NT treatment produced about 25% higher than that of CT treatment.

The effect of tillage system on yield components in 1994 and 1995 are shown in Table 3. The number of panicles per m^2 was already discussed previously as productive tillers. In light clay soil, the number of spikelets per panicle in 1994 and 1995 among the treatments were statistically the same, except the CT treatment in 1995. The thousand kernel weight among the treatments was statistically significant different. However, there was no definite increasing or decreasing tendency of both thousand kernel weight and percentage of ripened grains per panicle among the treatments. In addition, there were no definite effects of tillage system on percentage of ripened grains per panicle.

In sandy loam and clay loam soil, the NT significantly increased the number of spikelets per panicle compared to that of the CT, which might increase the grain yield in the NT and NTS. In sandy loam soil, the thousands kernel weight of NT and NTS was almost the same as those of CT and CTS treatments. However, in clay loam soil, the thousands kernel weight of NT and NTS was significantly higher than those of CT and CTS treatments. The percentage of ripened grains per panicle in sandy loam and clay loam soil were similar in 1994. However, in 1995, the percentage of ripened grains per panicle in sandy loam soil was larger than that of light clay and clay loam soil. On the other hand, the number of spikelets per m^2 of light clay and clay loam soil was larger than that of sandy loam soil. Therefore, it seems that the greater percentage of ripened grains per panicle in sandy loam soil is due to the lower number of spikelets per m^2.

It was found that the release of N from CAF (POCUS-100) rapidly increased in the middle growth stage and then decreased in the late growth stage (Fig. 2). It seems that the rice plant can readily absorb the necessary nitrogen by the young panicle formation stage, which may effect the increase in the number of spikelets per unit area and ultimately increase grain yield in NT treatments of differents soils. Kaneta (1994) reported that CAF application increased the number of total grain and yield compared to the compound fertilizer application. While the cost of POCU itself is greater than that of ammonium sulfate, the cost difference can be compensated by the saved labor in the NT system.

From the above results, it was clear that the initial growth of rice in NT system was slower than that of CT system. However, the yield of brown rice in NT system was almost same or greater than that of CT system reflecting releasing characteristics of POCU fertilizer. Therefore, the no tillage transplanting system with a single basal application of CAF in a nursery box was highly effective for grain yield not only in heavy textured soil but also in light textured sandy loam soil and clay loam soil. Furthermore, research is needed to improve the initial growth of rice in no-tillage transplanting system.

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