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Root Growth of Paddy Rice with Application of Organic Materials as Fertilizers in Thailand

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Abstract

Application of organic materials are fertilizers in Thailand sometimes resulted in the interruption of elongation of rapid decrease of the diameter of nodal roots along the axis at the early stage of rice growth. However, the damage caused to the roots at the early stage did not lead to the suppression of plant growth at later stages but rather resulted in high yield. The use of organic materials as fertilizers affected the amount of roots throughout the plant growth and increased the percentage of nodal roots that elongated to the deep soil layers. These effects on root growth were ascribed to the restrained uptake of the nitrogen released from organic materials at early stages of rice growth, whereas the application of nitrogen by chemical fertilizer may have caused excessive growth in vegetative phase.

Discipline; Crop production
Additional key words: castor meal, *Oryza sativa* L., rice straw compost

Introduction

In Thailand, the price of chemical fertilizers, which are imported or produced with newly introduced technology, is relatively high in taking account of the low price of agricultural products, especially of rice. Besides, the rapid development of the Bangkok metropolis and agro-industries has caused severe problems with waste materials. Application of organic waste materials as fertilizers to paddy rice (*Oryza sativa* L.) is anticipated to alleviate these problems.

However, information on the growth habit of rice roots affected by the application of organic materials under the climatic and soil conditions in Thailand is very limited, though the root is the organ exposed to the changes in the soil conditions caused by fertilizer management. In this paper, the effects of the application of organic materials to paddy rice in Thailand on morphological characteristics of rice roots will be reported.

Effects of organic materials on rice roots at the seedling stage

Organic materials sometimes cause a severe suppression of the growth of rice plants at the seedling stage shortly after transplanting. The effect of organic materials on the roots at the early stage was investigated in rice plants grown on Rangsit and Surin soils. Rangsit is located in the northern suburbs of Bangkok, where acid sulfate soils with a heavy clay structure predominate. Surin is a province in northeast Thailand located near Cambodia, where low humic grey soils with a sandy loam structure classified as Roi et soil series prevail[6]. Due to the sandy properties, compaction is so severe in Surin soil that the diameter of the nodal roots of rice seedlings often decreases remarkably during elongation. Rice is a popular product in Surin, whereas, in Rangsit, significant land use for agriculture is being groped.

It was found that the application of castor meal in Rangsit and Surin soils two weeks before transplanting as basal dressing resulted in the dying-

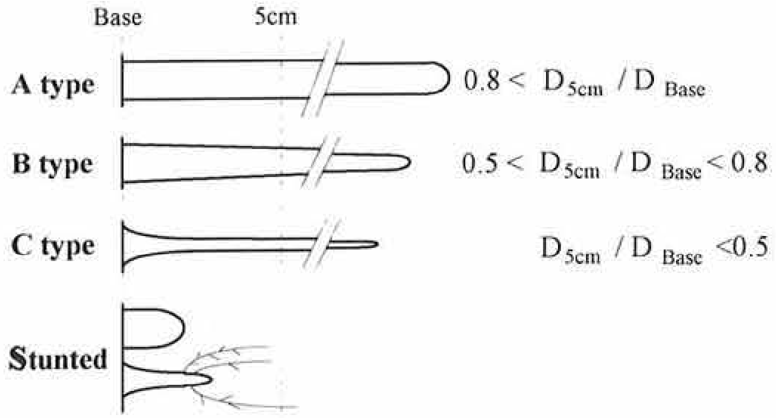

Fig. 1. Classification of nodal roots based on the changes in root thickness for a convenient diagnosis of roots[22)]

The diameter of the main axis of a nodal root at its base (D_{Base}) and at 5 cm from the base($D_{5\ cm}$) is compared by visual observation. The diameter of A-type roots along the axis remains almost constant, while B-type and C-type roots show a progressive and rapid decrease of diameter, respectively. Nodal roots in which elongation stopped before reaching a value of 5 cm for length are designated as stunted roots.

off of most of the leaves especially in the Rangsit soil plot. Moreover, based on visual observation (Fig.1)[22)], many stunted roots (i.e. nodal roots less than 5 cm in final length) and C-type roots (i.e. nodal roots tapering rapidly along the axes) were found in nodes at low positions, that emerged a few weeks after transplanting, in rice plants fertilized with castor meal[1)], indicating that the root growth was markedly inhibited. Similar symptoms appeared in rice plants fertilized with ammonium sulfate in this experiment. The magnitude of the damage to roots also depends on the amount of organic material applied. With the application of castor meal at a high rate, the tips of most of the nodal roots shrank and displayed a brown color while the lateral roots were much shorter than those in normal seedlings (personal communication from Jongruk Chanchareonsook). Although the mechanisms responsible for such abnormal structures are unknown, the application of castor meal may have increased ammonium concentration to a level which inhibits root growth. The amount of ammonium released by castor meal was two- to threefold greater than that by other organic materials after several weeks of incubation in a laboratory experiment[2)]. It is generally recognized that the application of ammonium to plants often decreases the length of root axes and promotes lateral root formation, while the application of nitrate induces reverse effects[10)]. It was also reported that the elongation of root axes of rice seedlings grown in solution culture was inhibited by ammonium application[19)]. On the other hand, the reducing condition caused by the application of organic materials[2)] may have led to the increase of the contents of organic acids (and hydrogen sulfide in Rangsit soil) in soil solution that could be toxic to rice roots[5)]. Moreover, the severe suppression of plant growth by the application of castor meal in the plots with Rangsit soil was ascribed to the low pH of the soil. In general, the membrane permeability of some organic acids increases with the decrease of medium pH, resulting in more obvious inhibitory effect of decomposition products of organic matter on root growth[10)].

Stunted roots and C-type roots can often be found in nodes at low positions that develop at the early stage of plant growth in Thai paddy rice, partly due to the elongation of low internodes of the stem often observed in tropical paddy fields. The appearance frequency of stunted roots and C-type roots may be affected by the fertilizer management and soil properties as mentioned above. It should be noted that stunted roots and C-type roots are usually found only in the upper nodes that form nodal roots in the reproductive phase in Japan[22)].

However, in the later stages of the growth, the rice plants fertilized with castor meal showed vigorous growth and attained a high yield[1,15)], suggesting that the suppressed growth at the early stage may have contributed to the effective use of nitrogen.

Effects of organic materials on root amount and branching at late stages

Organic materials affected the number of emerged and elongated nodal roots especially in the reproductive phase of rice growth. The application of rice straw compost did not increase the numbers of tillers and nodal roots as much as the application of chemical nitrogen fertilizer until the panicle initiation stage, when the effects of chemical fertilizer (ammonium sulfate) and rice straw compost on the numbers of tillers and nodal roots of a Thai variety were studied in a field experiment at Ratchaburi Rice Experiment Station (Table 1). However, the increase in the number of elongated nodal roots after the panicle initiation stage in the plot with compost application was larger than that in the plot with chemical fertilizer application. Furthermore, compost application contributed to a high percentage of elongated roots (i.e. 40.0%) during the reproductive phase, whereas chemical fertilizer increased the percentage of stunted roots. This fact may be ascribed to the lack of excessive vegetative growth in the plots with compost application. The increase in the percentage of elongated roots by the application of rice straw compost was more conspicuous in an experiment carried out with the same variety in Japan, exceeding 70% at the booting stage in the plot with compost application.

Branching degree of roots is an important factor determining the total length and surface area of roots as well as the number of nodal roots[3]. Then, the contribution of lateral roots to the function of the root system is considered to be very large. In fact, bleeding rate of each nodal root, which can be an index of total activity of the nodal root, is positively correlated with the number of lateral roots[21].

Although the effect of organic materials on the branching habit of rice roots in Thai paddy fields has not been investigated, the promotion of root branching by organic materials was observed in maize plants (*Zea mays* L.) grown in a Thai farm[23]. Roots of maize plants fertilized with chicken manure developed a larger number of lateral roots than those of maize plants treated with chemical fertilizer alone. In Japan, it was reported that long-term application of farm compost in paddy fields remarkably promoted the development of lateral roots in superficial roots[7]. Moreover, rice plants to which nitrogen had been supplied continuously until the flowering stage by frequent top dressing of chemical fertilizer also formed superficial roots with well-developed lateral roots[8]. These findings suggest that the maintenance of an adequate nitrogen content in soil at the late stage of growth, caused by the slow release of nitrogen from the compost can promote root branching in rice plants.

It was found that the application of organic materials alleviated the decline of roots occurring

Table 1. Effects of rice straw compost on the number of tillers and nodal roots of a Thai paddy variety, RD7 grown at Ratchaburi Rice Experiment Station in 1987

Treatment*	No. of tillers per hill**	No. of nodal roots per hill***	No. of elongated roots per hill***	No. of stunted roots per hill***	No. of elongated roots per tiller	Percentage of elongated roots (%)	Grain yield (kg/ha)**	Straw weight (kg/ha)**
	mean	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
Panicle initiation stage								
Check	15.8	747 ± 147	484 ± 53	263 ± 93	30.7 ± 4.91	65.3 ± 5.65		
CF	18.7	869 ± 164	529 ± 61	339 ± 103	28.3 ± 0.38	61.4 ± 4.59		
RSC	16.7	670 ± 102	398 ± 35	272 ± 68	23.8 ± 1.25	59.7 ± 3.98		
CF + RSC	19.0	907 ± 162	610 ± 8	297 ± 170	32.2 ± 0.81	68.5 ± 13.10		
Harvest stage								
Check	11.0	1,112 ± 212	444 ± 75	668 ± 137	40.2 ± 4.70	40.0 ± 0.89	3,116 ± 103	2,884 ± 173
CF	13.4	1,839 ± 168	622 ± 86	1,216 ± 82	46.4 ± 4.27	33.8 ± 1.58	3,887 ± 114	4,202 ± 437
RSC	13.1	1,654 ± 122	660 ± 20	994 ± 102	50.4 ± 4.32	40.0 ± 1.76	3,735 ± 216	3,707 ± 468
CF + RSC	14.0	1,992 ± 95	737 ± 23	1,255 ± 118	52.7 ± 0.76	37.1 ± 2.91	3,880 ± 164	4,253 ± 192

* The abbreviations refer to the basal dressing. Check: no fertilizer, CF: chemical fertilizer (N,P,K: 25,25,25 kg/ha), RSC: rice straw compost (12 t/ha; total nitrogen content was around 2%). Chemical nitrogen fertilizer (N: 25 kg/ha) was top-dressed in CF and CF + RSC plots at panicle initiation stage.

** Averages of three replicated plots. The number of tillers at harvesting stage indicates the numbers of panicles.

*** The number of nodal roots per hill was obtained by correcting the numbers of tillers of the sampled rice hills on the basis of mean number of tillers in three replicated plots.

in rice plants with chemical fertilizer application at the late stage of growth, in a case study of rice cultivation in Kyushu, a warm region in Japan[13]. It would be important to study the effects of compost on the maintenance of root biomass and activities.

Effect on vertical distribution of roots

Growth direction of nodal roots is one of the determining factors in the spatial distribution of roots in soil[14]. In the field experiment at Ratchaburi Rice Experiment Station, the Thai rice variety, RD7, was grown with chemical fertilizer (ammonium sulfate) and/or rice straw compost as nitrogen source, and the effect of rice straw compost on the growth angles of nodal roots was investigated by the method described in Fig. 2[12]. The application of rice straw compost decreased the percentage of nodal roots with a low value for the growth angle (less than 30°) to the horizontal in comparison with the application of chemical fertilizer (Fig. 3). This phenomenon may have been associated with the difference in the time course of the increase in the number of nodal roots in the plots with chemical fertilizer and compost application mentioned above. Moreover, the improvement of the soil physical properties by the compost may have promoted root elongation to deep soil layers.

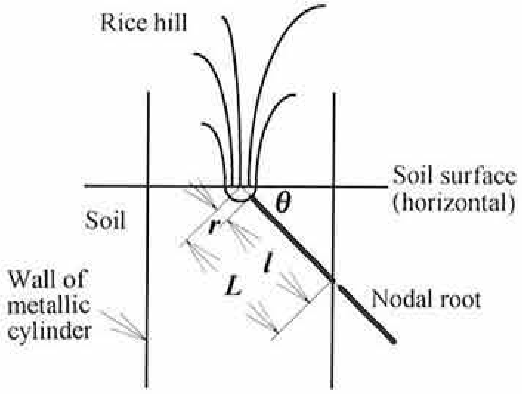

Fig. 2. A method of estimating the growth angle of each nodal root[12]
A soil monolith was taken including a rice hill at the center. The distance between the center of the rice crown and the cut end of a nodal root (L), that can be estimated by the length of cut main axis of the nodal root (l) and the radius of crown (r), should be correlated with the cosine of the growth angle of the nodal root (θ). Therefore, $\theta = \arccos$ (radius of the cylinder/L).

The findings on the root growth angle suggest that rice straw compost stimulates root development not only in the superficial layers of soil but also in deep layers in Thai paddy fields, as reported in rice roots in the northern part of Japan[7], although root length or root weight at each soil depth has not been investigated yet.

Effect of application of organic materials on yield and possible relation to root structure

Field experiments have been carried out in several experimental stations in Thailand to examine the long-term effect of organic materials on the growth and yield of paddy rice. Although the results varied with the locations and years, paddy yield often

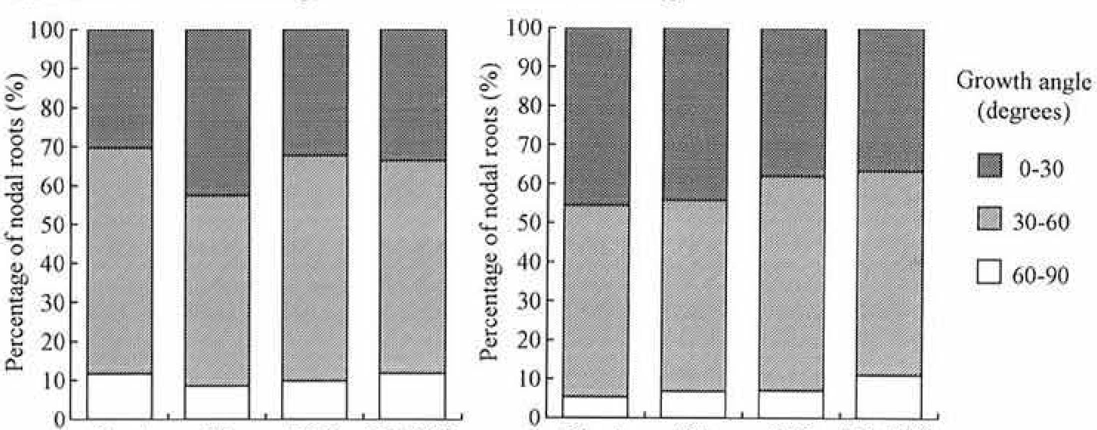

Fig. 3. Effect of chemical fertilizer and rice straw compost on growth angle of nodal roots
See Table 1 for the abbreviations.

increased linearly with the increase in the amount of compost applied[16,17,18]. It was suggested that the grain yield may be related to the time course of nitrogen use depending on the properties of organic materials and soils (Table 2)[2,15]. For example, application of castor meal led to a small and large uptake of nitrogen at the early and late stages of plant growth, respectively, and resulted in a high yield. The large yield index (i.e. ratio of grain yield to straw weight) in the plots with compost application (Table 1) could also be attributed to the effective use of nitrogen at the late stage of growth. Moreover, organic materials seemed to be more effective than chemical fertilizer as slow-release nitrogen source under field conditions in Surin, where the runoff of nutrients is a serious problem due to the sandy properties of the soil[20]. However, in general, combined use of an organic material for basal dressing and some amount of chemical fertilizer for top dressing should be suitable, as it is often difficult for farmers to prepare a sufficient amount of organic materials as complete source of nitrogen.

It should be mentioned that organic materials could be the source of other minerals as well as a nitrogen source in farms with low soil fertility[4,18]. Furthermore, organic materials may decrease the soil bulk density and alleviate soil compaction[17].

It is known that the amount of roots including laterals was correlated with grain yield while the yield was less than 5-6 t/ha[9], and the possible relation between the vertical distribution of roots and yield has been speculated[11]. Morphological responses of Thai rice roots to the application of organic materials are reported in this paper. However, many of the mechanisms controlling the morphological responses and their effects on the root function are still unknown. In order to clarify the role of roots in rice plants under the application of organic materials, further studies on root morphology combined with physiological, soil chemical and microbiological aspects are required.

Table 2. Effects of organic materials on the nitrogen content in shoot and yield components of rice[15]

Soil	Fertilizer material*		N content in shoot (mg/hill)		No. of panicles per hill	No. of filled grains per panicle	Weight of 1000 grains (g)	Grain yield per hill (g)
			Panicle initiation stage	Harvest stage**				
			mean	mean	mean ± SD	mean ± SD	mean ± SD	mean ± SD
Rangsit	Check		40.7	187.9	10.7 ± 0.58	33.9 ± 5.10	20.8 ± 1.63	7.5 ± 0.28
	CF***		200.6	1,210.5	38.0 ± 3.61	48.9 ± 6.51	19.0 ± 1.00	35.8 ± 8.84
	RSC	s	136.9	269.0	10.7 ± 0.58	51.2 ± 6.14	24.0 ± 1.02	13.1 ± 1.19
	AS	r	205.3	570.1	20.3 ± 3.06	46.5 ± 5.47	21.0 ± 0.75	19.6 ± 0.81
	FC	s	93.3	351.6	14.3 ± 1.15	58.8 ± 8.87	23.1 ± 0.43	19.3 ± 2.54
	SW	r	142.6	432.9	16.0 ± 1.00	45.5 ± 3.15	22.2 ± 2.29	16.1 ± 1.67
	CM	dr	88.9	1,107.8	20.0 ± 4.58	58.4 ± 4.24	20.8 ± 0.37	24.0 ± 4.08
Surin	Check		46.1	187.4	8.0 ± 1.00	47.8 ± 3.99	23.4 ± 0.16	8.9 ± 0.82
	CF***		199.7	1,459.9	34.7 ± 2.52	61.6 ± 9.70	21.9 ± 0.58	47.2 ± 11.59
	RSC	s	132.0	296.6	9.0 ± 1.00	67.1 ± 7.76	25.0 ± 0.93	15.0 ± 0.96
	AS	r	159.2	472.5	19.0 ± 2.65	68.5 ± 5.81	22.7 ± 2.20	29.2 ± 0.49
	FC	s	118.5	238.2	9.7 ± 1.15	59.3 ± 3.30	24.6 ± 0.28	14.1 ± 1.43
	SW	r	146.9	543.3	18.3 ± 2.08	67.9 ± 14.71	23.5 ± 2.05	28.8 ± 4.32
	CM	dr	28.1	1,087.2	28.0 ± 3.46	81.3 ± 1.86	21.5 ± 1.44	48.6 ± 1.86

* The abbreviations indicate the materials applied in the pot experiment. Check: no nitrogen fertilizer, CF: chemical fertilizer (ammonium sulfate), RSC: rice straw compost, AS: activated sludge, FC: filter cake, SW: sludge from whiskey factory, CM: castor meal. Types of the materials in nitrogen release are indicated by the small letters, r: rapid release, s: slow release, dr: delayed rapid release[2]. The amount of total nitrogen applied in each pot was the same (200 ppm) except for the check plots. Phosphate and potassium were supplied by chemical fertilizer in all plots.

** The data at harvest stage include the grain nitrogen.

*** It was reported that chemical fertilizer was not as effective in increasing yield under field conditions as in pot experiments, especially in Surin, probably due to the runoff of nitrogen[18].

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