On Soil Structure of Plowed Layer of Paddy Field

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Development of the soil structure of the plowed layer of paddy field has been arrested by natural and artificial conditions such as drying of soil is remarkably bad because the paddy field is mostly located in a swampy land where the water drains off slowly. It is also under submerged condition for about 100 days in the rice culture season and the structure of the plowed layer is always destroyed by puddling operations peculiar to paddy field.

The soil structure of the plowed layer influences the permeability of soil, the redox potential, the mineralization of soil nitrogen or the growth of the root of paddy rice, resulting in the yield of paddy rice.

Moreover, the structure influences the efficiency of mechanical operations on paddy field. Consequently, it could be considered that the structure of the plowed layer of paddy field is an important factor which influences the productivity of soil as well as the upland fields.

Kinds of plowed layer soil structure

In general, the plowed layer of the upland field shows aggregated structure but the structure peculiar to paddy field has been developed on paddy field since it is under submerged condition and puddling operation is conducted there.

According to Aomine, there are six kinds of fundamental soil structure in the plowed layer of paddy field: (1) single grained, (2) muddy, (3) blocky, (4) aggregated, (5) sponge-like and (6) tube-like structures. Furthermore, the plowed layer is divided into three sub-layers due to the difference of the soil structure in the layer. That is, the first sub-layer of which thickness is about 1 cm shows muddy structure on all the paddy fields. The second sub-layer is the one which shows most of the characteristics of the soil structure of the plowed layer, where it is single grained, sponge-like, aggregated or muddy.

The sponge-like structure is formed on the plowed layer where much gas is generated by the decomposition of organic matters and it contains much clay, and its thickness is 5-6 cm. The third sub-layer of which thickness is 2-3 cm has a slightly blocky or muddy structure since there is small influence of puddling operation.

Soil structure change attributed to different culture methods

Soil structure of the plowed layer is influenced greatly by the fertilization method especially by using organic fertilizer.

The soil structure of the plowed layer has been investigated after harvesting of paddy rice at the paddy field of the Central Agricultural Experiment Station in Konosu, where no fertilizer, inorganic fertilizer, stable manure and green manure had been used for the past 40 years.

The characteristics of soil structure of the plowed layer at the paddy fields without fertilizer and fertilized with green manure are

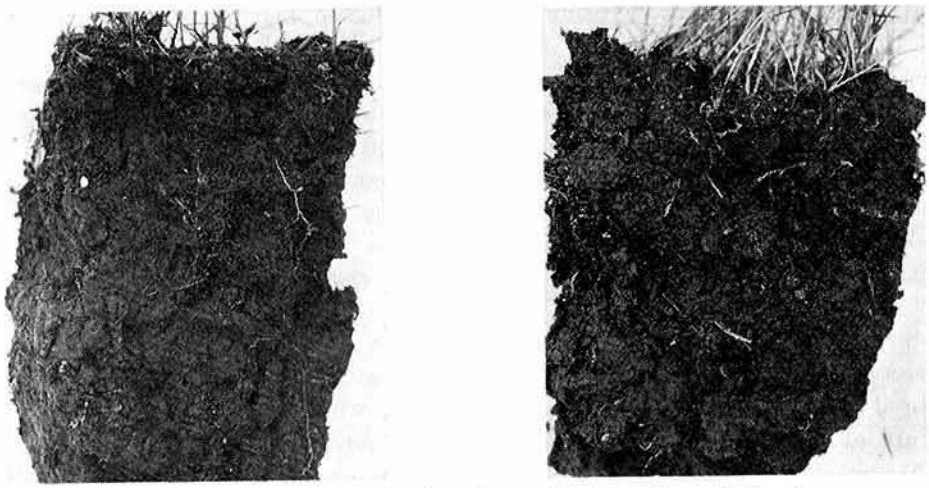

Fig. 1. The influence of fertilization method on the soil structure

shown in Fig. 1. The characteristic change due to the fertilization method is recognized on the second sub-layer: the plowed layer of the field without fertilizer shows a large and compact blocky structure, while that of the field fertilized with inorganic matters shows a soft and small blocky structure.

The field where organic fertilizer, especially green manure has been used shows a well-developed aggregated structure. It could be considered that the large blocky structure at the field without fertilizer has been secondarily formed from the muddy structure during the submerged period due to drying after harvesting of paddy rice.

Tillage practices also have a remarkable effect on the soil structure of the plowed layer. Compared with rotary tilling, the depth of plow tilling is deep but at the same time there is a large formation of large blocks with above 4 cm in diameter.

The time of plowing influences the state of drying of soil, changing the soil structure of the plowed layer. Being plowed in autumn and dried sufficiently in winter, soil blocks of fields above 2 cm in diameter decrease obviously and aggregates increase, as shown in Table 1. The puddling operation decreases the content of large blocks with above 2 cm in diameter and that of aggregates, but increases the content of fine fraction.

The soil structure in the field of direct sowing culture of paddy rice on dry field is substantially different from that on transplanted paddy field as the field of the former is plowed in autumn in order to improve the

Table 1. Changes of soil blocks and aggregates due to the time of plowing and puddling operation

Treatment		Content according to diameters of soil particle (Wet soil %)					
		Diameter (cm)					
		>4.0	2.0~4.0	1.0~2.0	0.5~1.0	0.05~0.5	<0.05
Without puddling operation	Autum plowing	1.5	2.5	6.6	6.1	9.5	63.8
	Plowing just before rice-planting	6.1	10.8	4.7	3.5	11.1	63.8
Puddling operation	Autumn plowing	0	5.3	3.9	5.0	18.3	67.5
	Plowing just before rice-planting	0	8.4	3.3	2.7	14.6	71.0

tilth condition, resulting in accelerating the drying of the plowed layer, omitting from the field puddling operation. That is, the plowed layer of transplanted paddy field mainly has a muddy structure, while that of direct sowing paddy field maintains a well aggregated structure, which is well developed and stabilized by repeating direct sowing culture every year.

The soil structure of paddy field which has been rotated into upland field is obviously different from that of the paddy field which has been used as paddy field every year. The soil structure of paddy field which has been rotated into upland field generally has a tendency to be aggregated. The degree of the development increases with the number of years used as upland field, and it depends on the kinds of crops which are cultivated at upland field.

Relationship between soil structure of plowed layer and physical and chemical properties of soil

How the degree and the condition of soil structure are controlled comes into question when the relationship between the soil structure of plowed layer and the change of soil properties or the growth of paddy rice is studied.

In a series of study described in this report, it is provided that muddy structure is the one where soil particles are sufficiently dispersed by agitating or puddling the soil, and the aggregated structure is the one where the treatment of dispersing soil particles are not conducted, and various properties between the two are compared.

On the relationship between the soil structure of plowed layer and the three-phase distribution of soil, a characteristic change is recognized with the water management of paddy field as a turning point as shown in Table 2.

A clear difference of three-phase distribution of soil due to the soil structure of plowed layer is not recognized during the submerged period after transplantation of paddy rice. But, when the surface water is drained in mid-summer, the soil air is increased rapidly on aggregated soil, while on muddy soil it is hardly increased.

On the other hand, on muddy soil the shrinkage of solid phase occurs in the course of drainage and the volume of solid phase increases 30 per cent due to the drainage for about two weeks.

At the same time, the formation of many cracks is noted on the plowed layer. These changes are irreversible since they would not return to the former condition even by resubmergence. The solid phase of aggregated soil hardly changes even by the drainage.

As the result of the following change in water tension (pF) of the plowed layer after draining of surface water, the internal draining on aggregated soil is proceeded quickly and pF is increased rapidly as time passes, but the increase of pF on muddy soil is moderate.

Moreover, as the result of the investigation of pF distribution on the plowed layer, it is proved that there are few large porosities

Table 2. Soil structure of plowed layer and three-phase distribution of soil

Period	Aggregated soil			Muddy soil		
	Submerged period	Water-removed period*	Resubmerged period	Submerged period	Water-removed period	Resubmerged period
Solid phase (%)	38.5	39.8	38.1	38.8	51.1	47.4
Vapor phase (%)	59.6	25.9	60.5	60.8	43.1	51.7
Soil air (%)	1.9	34.3	1.4	0.4	5.8	0.9

* The water-removing period is adjusted on the 13th day after removing water

with below 1.7 pF on muddy soil compared with that on aggregated soil. This shows that the coefficient of permeability on aggregated soil is much larger than that on muddy soil.

Changes of soil nitrogen and redox potential

The mineralization of soil nitrogen depends on the diameter of soil aggregate. An example of the relationship is shown in Table 3, of which result has been investigated about the mineralization of soil nitrogen under submarged condition where the aggregates with 3-5 mm in diameters have been collected from the plowed layer and crushed into one with different diameters.

Table 3. Size of soil particles and mineralization of soil nitrogen

Diameter (mm)		Amount of nitrogen mineralized (mg/100g) 30℃, 30 days				
		3~5	1~3	0.5 ~1.0	0.5	1~3 (Muddy)
Soil	A	1.3	1.6	2.1	3.8	2.5
	B	2.4	2.8	5.8	7.2	3.0
	C	2.2	2.4	2.1	3.6	2.7
	D	2.4	2.8	2.6	5.0	3.4

As a result, the ammonium nitrogen mineralized increases with the smaller diameter of soil aggregate, especially the amount formed increases remarkably when the soil particles are crushed finely into one with below 0.5 mm in diameter.

The mineralization of soil nitrogen is apparently promoted when the soil is made muddy by agitating in the water, but the amount mineralized is less than that of the soil which is crushed in the air.

The mineralization of soil nitrogen by agitating during the submerged period has been investigated concerning aggregated soil and muddy soil, where the mineralization of nitrogen on muddy soil is hardly increased by agitating, but the one on aggregated soil is remarkably promoted with the collapse of aggregates by agitating. (See Fig. 2)

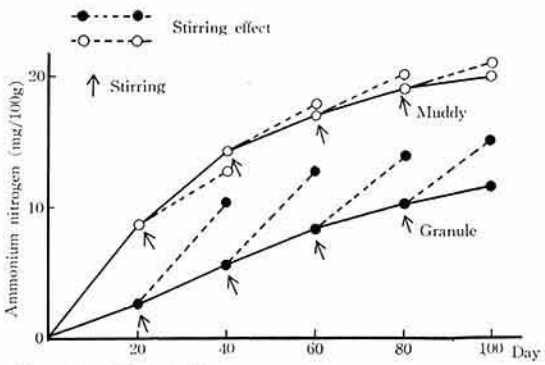

Fig. 2. The influence by aggregation of soil nitrogen on mmineralization

It is presumed from this fact that the soil nitrogen on aggregated soil could be released up to the later growing period of paddy rice, while the release of nitrogen on muddy soil would be partial to the early growing period, if the aggregate should collapse during the cultivated period of paddy rice.

The relationship between the behavior of nitrogen applied and the soil structure depends on the conditions of water percolation. On the paddy field where the level of underground water is low, the amount of percolation increases with the aggregation of soil, and the leaching loss of the nutrients, especially nitrogen is promoted.

On the other hand, on the paddy field where the level of underground water is high and the water percolation seldom occurs, the nitrogen applied on the soil surface is distributed up to the deep layer by the diffusion on aggregated soil, as shown in Fig. 3, while it tends to remain on the surface layer on muddy soil.

The experimental results show that the loss of nitrogen applied on aggregated soil is less than that on muddy soil. It is recognized from these facts that the residual rate of nitrogen applied on aggregated soil is tended to be higher than that on muddy soil.

The influences of soil structure on the redox potential of soil are very clear. The redox potential (Eh) during the submerged period is constantly low on muddy soil, since the

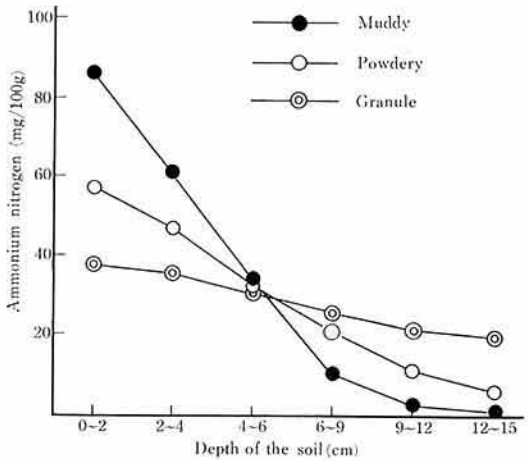

Fig. 3. Soil structure and diffusion of nitrogen fertilized

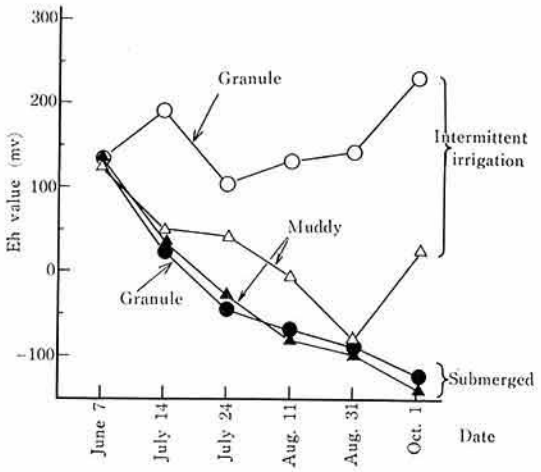

Fig. 4. Relationship between soil structure and redox potential

decomposition of soil organic matters on muddy soil is more than that on aggregated soil.

When surface water is drained during the middle growing stage of paddy rice, the amount of air permeation into the soil increases on aggregated soil, resulting in rapid increase in Eh. (See Fig. 4) The change in Eh on muddy soil, on the contrary, is moderate even when the intermittent irrigation is conducted. It is believed that, these differences influence the activity of the root of paddy rice.

Growth of the paddy rice root

The soil structure of plowed layer influences the growth and the activity of the root of paddy rice. The results of the investigation about the relationship between the amount of the paddy rice root and the structure of plowed layer at the maximum tillering stage and at the heading stage, in relation to the amount of nitrogen applied are shown in Table 4.

At the maximum tillering stage the amount of the root on muddy soil gradually decreases with an increase in the amount of nitrogen applied, while the amount of the root on aggregated soil increases up to two kg/a of the amount of nitrogen applied.

At the heading stage, the amounts of the root augment with an increase in the amount of nitrogen in both structures, while the tendency on aggregated soil is larger than that on muddy soil, and the amount of the root on aggregated soil is more than that on muddy soil.

There is a great deal of paddy rice rootlet on aggregated soil, which consists of small roots on a whole, while on muddy soil there are few rootlets which consist of big crown

Table 4. Soil structure, growth and activity of the roots

Nitrogen application (g/m^2)		Aggregated soil				Muddy soil			
		0	1	2	4	0	1	2	4
Amount of roots (g/root)	No. of tillers stage	1.33	1.47	1.57	1.21	1.46	1.24	1.18	0.70
	Heading stage	4.30	4.58	5.17	6.32	4.39	4.00	4.32	5.10
Oxidizing power (mg/g·hr)	Max. No. of tillers stage	0.89	1.10	0.91	0.99	0.94	1.03	1.01	0.79
	Heading stage	0.40	0.49	0.46	0.49	0.39	0.39	0.42	0.43

Table 5. Soil structure, growth of aquatic rice and absorption of nitrogen

Humus content of soil	Fertilization of nitrogen	Type	Growth of rice plant (No., mg/stab)			Nitrogen absorption (mg/stab)		Absorption ratio of nitrogen (%)
				No. of ear	Wt. of ear	Soil nitrogen	Applied nitrogen	
Low	Non-application	Granule	8.1	266	257	—	—	—
		Muddy	7.9	247	234	—	—	—
	Application	Granule	16.5	495	542	394	264	61.6
		Muddy	16.2	460	501	365	205	47.8
High	Non-application	Granule	9.8	318	367	—	—	—
		Muddy	7.7	266	265	—	—	—
	Application	Granule	17.3	487	576	400	230	53.6
		Muddy	13.5	417	484	360	170	39.6

Ammonium sulfate, heavy nitrogen is used for nitrogen fertilized

roots. From the investigation of the activity of the root by the naphtylamine method, it is acknowledged that the paddy rice root on aggregated soil has a greater activity than that on muddy soil.

Structure of plowed layer and growth of paddy rice

How the relationship between the structure of plowed layer and the physical and chemical properties of soil on paddy field, about which is described before, influences the growth of paddy rice depends on the conditions of location of paddy field, the fertility of soil or the culture method.

The percolation of paddy field depends on the level of underground water and the watere permeability of plowed layer. During the culture season of paddy rice, the prevention of excessive percolation is primarily important on paddy field where the level of underground water is low.

To make muddy condition on plowed layer by puddling operation on such a paddy field has favorable effects upon the growth of paddy rice in order to prevent excessive percolation, decrease in leaching loss of nutrient, especially nitrogen and an increase in soil temperature in the cold district.

Meanwhile, there are some paddy fields where the water percolation is exceedingly small because the level of underground water becomes higher during the culture season of paddy rice or the coefficient of permeability of the subsoil is small.

On such a paddy field the amount of percolation does not increase so much even if the plowed layer is made aggregated, and there are many cases that the formation of aggregated condition of plowed layer has a favorable effect upon the growth and the yield of paddy rice by controlling mineralization of soil nitrogen, the increase of efficiency of fertilized nitrogen, the mitigation of redox potential of soil, etc. Table 5 shows the results of the investigation on the relationship between the soil structure and the growth of paddy rice under the non-percolated conditions on two soils having different fertility.

The growth of paddy rice on aggregated soil is inferior to that on muddy soil for a while after transplantation, but after that the color of leaves is always dark, it shows a good growth, and the yield increases apparently.

As a result of investigating the condition of absorption of nitrogen by paddy rice using heavy nitrogen (^{15}N), the absorption rate of nitrogen applied increases on aggregated soil, of which reason it could be that the denitrifing action is weak on aggregated soil.

When crude organic matters such as straw are applied, the difference between the growth

on aggregated soil and that on muddy soil is increased; the reason is that it could be that the reduction of soil is vigorously promoted and the activity of the root is decreased on the latter.

As for the relation to the method of water management, the growth of paddy rice on aggregated soil is inferior to that on muddy soil when the high frequent intermittent irrigation is conducted, but it shows the reverse tendency when the low frequency intermittent irrigation is completed.

Conclusion

In general, the structure of plowed layer on paddy field is less developed, but the structure peculiar to paddy field is observed. It shows that the characteristics in the structure are influenced by application of compost, by puddling operation, and by the time of plowing. Furthermore, the direct sowing culture maintained a favorable aggregated structure.

In the case of aggregated structure, the shrinkage of solid phase by drainage operation is not observed and the volume of air phase is constantly large. The apparent difference between aggregated soil and muddy soil is observed on the redox potential and the mineralization of soil nitrogen. The development of the paddy rice root on aggregated soil is more favorable than that on muddy soil.

The influences of the structure of plowed layer upon the growth of paddy rice depend on the degree of percolation on paddy field, and under the condition where the amount of percolation is few, the aggregation of plowed layer has a favorable effect on the growth of paddy rice by adjusting the mineralization of soil nitrogen or by mitigating the strong reduction of soil.