Characteristics of Heavy Paddy Soil in Japan

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Classification and distribution

Heavy soils which are widely distributed on alluvial plain, polder and diluvial upland in Japan are mostly used as paddy soil. These soils are often unsuitable for plant growth and cultural operation, since generally they have such properties as they are poorly drained and very sticky, and form very hard clods when they are dried.

Consequently, it is very important to improve the drainage of this kind of soil for the sake of betterment of agricultural productivity.

The soil with a clay content of above 25% is taken as heavy soil in this report, because such properties of the heavy soil are mainly due to high clay content. Peat soils, muck soils and ando soils, however, are not included in heavy soil as a rule, since they are slightly sticky and their permeabilities are not very low as the humus content is high and the clay mainly consists of allophane.

Heavy soils used as paddy field in Japan are as follows[1]:

Yellow soils (fine textured)

Yellow soils are soils with low humus content, in which B horizon which is yellower than 5 YR and higher in both value and chroma lies under A horizon which is not dark colored. When they are used as paddy field, various shapes of mottles are produced on A and B horizons.

These soils are developed from Dilluvium, Tertiary, andesite and other parent rocks and are mainly distributed on upland and piedmont gentle slope.

Generally, the soils have a low ground water level and a compact B horizon and are, therefore, used as well drained paddy field. When the land form is flat, however, the removal of surface water becomes difficult due to rather impermeable B horizon.

The clay minerals are mainly kaolin, vermiculite and Al-vermiculite.

Gray upland soils (fine textured)

Gray upland soils are soils which have a gray subsurface horizon and a surface horizon low in humus content, having various shapes of mottles. They are distributed on upland and their parent material is mostly derived from Dilluvium and Tertiary formations.

The ground-water level is generally low, but the removal of surface water is difficult since the land-form is flat and the subsurface horizon is compact. Major clay minerals are kaolin, vermiculite and Al-vermiculite, etc.

Gray lowland soils (fine textured)

The hue below the plowed layer of gray lowland soils which have various shapes of mottles is 10 YR, 2.5 Y or 5 Y, the value is 4 or more and the chroma is 2 or less. They are widely distributed on alluvial plain and polder, etc., and are mostly used as paddy field.

Among these soils, soils which have a gray horizon with no structure below the plowed layer are imperfectly drained, while soils which have prismatic structure, even if the hue below the plowed layer is gray, and soils which have a grayish brown horizon under the plowed layer, are rather well drained. Major clay minerals are montmorillonite, kaolin, vermiculite, Al-vermiculite and chlorite.

Gley soils (fine textured)

Gley soils indicate soils which have a gley horizon* within 50 cm below the surface, and are poorly drained. They are distributed on alluvial plain and polder, and are mainly used as paddy field.

Among these soils, soils in which whole horizon are gley without mottles are the most poorly drained, while soils in which gley horizon appears from about 50 cm below the surface and has some structures below the plowed layer, are better drained than the former soils. Major clay minerals are montmorillonite, kaolin, vermiculite, Al-vermiculite and chlorite, etc.

* Gley horizon: Profiles of pronounced stagnant-water or ground-water soils have gray, gray blue, gray green to olive green colored gley horizons. These are characterized by a deficiency in oxidation, predominately reduction processes and anaerobic conditions for soil organisms.

The acreage of the above-mentioned heavy soils used as paddy field is shown in Table 1.

Table 1. Acreage of heavy paddy soils in Japan

Soil subgroups	Acreage	Percentage of total acreage of paddy fields in Japn
Yellow soils (fine textured) Gray upland soils (fine textured)	89,000 ha	3.0%
Gray lowland soils (fine textured)	162,000	5.5
Gley soils (fine textured)	271,000	9.2
Other soils (fine textured)	15,000	0.5
Total	537,000	18.2

There are various kinds of heavy soils and each kind carries its own characteristics.[2] It is seen that the characteristics of one kind of heavy soils depend on the quantity and quality of the clay constituents containing in the soils.

It is proved in Table 2 that the soils with high clay content are high not only in the amount of clay finer than 2μ but also especially in the proportion of the amount of clay finer than 0.5μ to that of the whole clay.

Consequently, since the finer clay plays more important roles in the activity of a heavy soil, the soil with high clay content acts as a heavy soil to a higher extent than that expected from the determined clay content. Major clay minerals of heavy soils are montmorillonite, vermiculite, Al-vermiculite, kaolin, and chlorite, etc.

The water retention of montmorillonite is remarkably higher than the other clay miner-

Table 2. Clay mineral and clay content of heavy paddy soils

Soils	Soil subgroups	Dominant clay minerals	Clay $>2\mu$	Fine clay $<0.5\mu$	$\frac{\text{F. clay}}{\text{Clay}}$	Texture
Hr-1	Gley soils	Mt	59.6%	38.3%	0.64	HC
Ni-4	Gley soils	Mt	42.2	28.2	0.67	LiC
Sa-24	Gray lowland soils	Mt	43.2	29.3	0.68	LiC
Sa-22	Gray lowland soils	Mt, Al-Vr	32.8	20.8	0.63	SiC
Ot-6	Gley soils	Mt (Chl, Vr, K)	27.3	12.1	0.44	SiC
Ko-3	Yellow soils	K, Al-Vr	26.5	12.3	0.46	LiC
Si-1	Gray lowland soils	K, Vr	40.7	19.6	0.46	LiC

Notes: Mt : Montmorillonite, Vr : Vermiculite, Al-Vr : Aluminum-Vermiculite, K : Kaolin, Chl : Chlorite als. Consequently, the heavy soils, of which clay mainly consists of montmorillonite, have remarkable characteristics on swelling, shrinkage and the other physical properties related to them.

As shown in Fig. 1, it is proved that montmorillonitic soil with high clay content (Hr-1, Ni-4, Sa-24) has higher moisture content at pF 4.1 and has larger volumetric change on drying, when compared with the other soils.

The relationship between the clay content of soils with different clay mineral compositions and the moisture content at pF 4.1 is shown in Fig. 2. As is obvious from the figure, the moisture content at pF 4.1 increases with an increase in clay content in every soil.

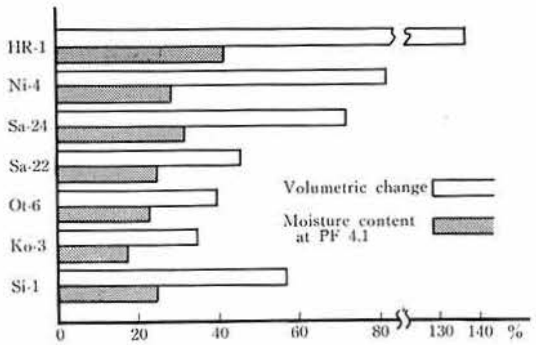

Fig. 1. Volumetric change and moising con-tent at PF 4.1 of heavy paddy soils

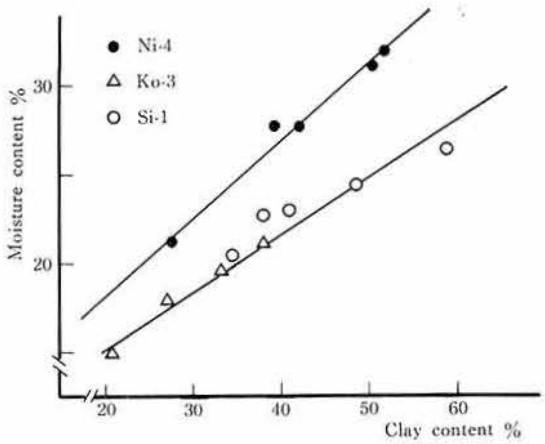

Fig. 2. Quality and quantity of clays and moisture content at PF 4.1

In this case, compared with the same clay content, the moisture content at pF 4.1 of Ni-4, montmorillonitic soil, is higher than that of Si-1 and Ko-3, kaolin-vermiculitic soils, which clearly shows the importance of the quality of clay. Thus, it is seen that the characteristics of heavy soil depend on the amount of clay and kind of clay mineral species.

Consequently, it would be very convenient to consider a counterplan for improvement of the drainage, if heavy soils are divided into four groups: either the soil with clay content above 45% (HC) or the one below 45% (SiC, LiC, SC), and either montmorillonitic soil or the one with the other clay minerals.

Physico-mechanical property

It is a matter, of course, that the property which becomes the most serious problem on heavy paddy soils is permeability. On the paddy field with poor permeability not only are the mechanical manipulations very difficult but also rice growth is apt to be limited due mainly to the strong reduction in summer.

Generally speaking, impermeable horizon lies in rather shallow horizon on heavy paddy soil. Consequently, even if the surface water is removed, the soil is very hard to be dried because the excess water remains in the soil.

Table 3 shows the permeability coefficient and bulk density of several representative soils, which were determined with the soils under field condition and with the air dried sieved soils.

The permeability coefficients of the field conditions are extremely low in gley horizon of gley soil, in the second horizon of gray lowland soil and in the third horizon of yellow soil, while the bulk density of these impermeable horizons largely varies with the subgroup of soil; the bulk density of gley soil is very small, while those of gray lowland and yellow soils are rather large.

The similar tendency is recognized between

Table 3. Water permeability coefficient

Soil subgroup	Horizon	Field condition: Permeability coefficient (cm/sec)	Field condition: Bulk density (g/cm³)	Air dry sieved: Permeability coefficient (cm/sec)	Air dry sieved: Bulk density (g/cm³)
Gley[1]	1	6.0×10^{-5}	0.58	2.7×10^{-5}	0.68
	2	8.1×10^{-4}	0.48	1.4×10^{-5}	0.77
	3(G)*	2.1×10^{-6}	0.44	5.8×10^{-6}	0.74
Gray lowland[2]	1	1.0×10^{-5}	1.03	1.1×10^{-5}	0.93
	2	9.1×10^{-7}	1.19	3.1×10^{-5}	1.00
	3	2.9×10^{-5}	1.12	1.7×10^{-5}	0.93
	4(G)*	2.9×10^{-6}	0.75	1.0×10^{-5}	0.83
Yellow[3]	1	5.2×10^{-5}	1.23	5.1×10^{-6}	1.23
	2	1.7×10^{-5}	1.48	5.5×10^{-6}	1.36
	3	2.5×10^{-7}	1.28	1.9×10^{-7}	1.29

* Gley horizon

1) Hachirogata Polder, Akita Prefecture 2) Saga Prefecture. 3) Fukushima Prefecture

the gley horizon and the other horizons of gray lowland soil. It could be said that the gley horizon has a peculiar property since a permeability generally increases with a decrease of bulk density or an increase of porosity.

As being pointed out by Motomura, et al.[3,4] and Yokoi, one of the authors, et al.,[5] the permeability of the gley horizon is very low regardless of small bulk density due mainly to the hydrated jelly-like structure of the gley horizon. Thus, the soil structure of the heavy paddy soil largely depends on the subgroup of soil.

The similar tendency is recognized in many other physico-mechanical properties.[2] The crushing strength of the soils is shown in Table 4 as an example of the tendency. Recently the crushing strength in air dry condition has been measured as an index of tilth in Japan.

As for the field condition, on gley soil the shrinkage on drying is extremely large due to the small bulk density under the field condition and the crushing strength is generally strong. On gray lowland soil the shrinkage is not so large but the strength is pretty strong.

In the meantime, on yellow soil the shrinkage is small and the crushing strength is weak because the structure is well developed. When these soils are puddled again and the structures are destroyed, the difference of the crushing strength which is found under field condition among the soils becomes small and the crushing strength becomes large as a general property of heavy paddy soils.

Table 4. Crushing strength in air dry condition

Soil subgroup	Horizon	Field condition: Crushing strength (kg/cm²)	Field condition: Shrinkage (%)	Puddled sample: Crushing strength (kg/cm²)	Puddled sample: Shrinkage (%)
Gley	1	2.2	22.1	123.0	58.9
	2	43.8	51.6	140.0	61.7
	3(G)	81.5	66.9	210.0	68.5
Gray lowland	1	20.9	9.6	69.1	25.8
	2	43.1	14.5	89.4	29.3
	3	64.0	15.5	117.5	35.1
	4(G)	67.4	39.7	94.4	44.4
Yellow	1	5.6	6.3	43.5	21.8
	2	15.0	4.3	33.6	15.8
	3	4.6	9.3	74.6	28.1

One of the most direct methods to improve heavy paddy soil is to make the texture coarse by mixing sand. An example of the change in permeability coefficient with mixing of sand is shown in Table 5, where it is recognized that the effect of improvement is not clear until a large amount of sand is added.

Table 5. Relation of texture to permeability coefficient

Texture*	Clay content (%)	Permeability coefficient (cm/sec)	Bulk density (g/cm^3)	Porosity (%)
S	2.1	4.2×10^{-4}	1.50	42.3
LS	7.1	1.5×10^{-4}	1.47	43.4
SL	12.0	6.2×10^{-5}	1.44	44.7
SCL	19.4	2.1×10^{-5}	1.42	45.5
SC	26.4	5.6×10^{-6}	1.41	46.0
LiC	36.6	2.0×10^{-6}	1.36	47.7
HC	46.4	1.1×10^{-6}	1.22	53.1

The soil used is yellow soil

* Japanese textural classification

As Yokoi, one of the authors,[6] has reported on the relation between particle-size distribution and physical property, it is considered that small amount of mixing sand is not effective to change the soil condition where most of the pores are surrounded by clay particles.

In other words, the permeability may not be improved until such large pores as ones surrounded by sand particles are produced. It seems to be very difficult to improve the heavy soil of large area by mixing sand. Accordingly, it is considered to be better to increase permeability by developing the soil structure.

As the soil structure is related to the subgroup of soil as mentioned above, it is necessary to improve the soil according to the physico-mechanical characteristics obtained from the soil.

Also, when pipe drainage is equipped, the desired result cannot be often obtained by the similar method of equipment as general one. It is generally due to the fact that the impermeable horizon lies in the shallower position than the pipe equipped.

In case of the gley soil, too much effect cannot be expected by mere mechanical disturbance because of jelly-like structure; therefore, it is necessary to try developing by every means possible, the structure attributed to shrinkage and oxidation by drying it.

On the other hand, mechanical disturbances such as sub-soiling and mole drainage are very effective to disturb the impermeable horizons of gray lowland and yellow soils because they loosen the structure.

There still remain many problems to be studied further on the details but it is concluded that in order to improve the heavy paddy soils, it is necessary to find out a method suitable for the kind of soil on the basis of physico-mechanical properties.

Acknowledgment

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