Physical Properties of Paddy Soil in Japan

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In Japan the paddy field area occupies about 50 per cent of all the arable land, and the improvement of physical properties of paddy soil has become very important in recent years accompanying with the degradation of soil fertility owing to the decline of dressing amount of organic matter and the intensive adaption of farm mechanization.

Soil classification of paddy soils in this country has been undertaken systematically by Kamoshita[1], Kanno[2], Oyama[3], Matsuzaka[4] and others. The paddy fields are mainly distributed in the lowland area associating with the irrigation water used for rice culture.

The ill-drained paddy fields with an underground water table appearing relatively in shallow depth from the soil surface have a gley layer well developed throughout the soil profile and they belong to the so-called ground water soil type[1].

On the other hand, the well-drained paddy fields with an underground water table appearing relatively in deep depth and strongly influenced by irrigated water, as well as having a gray layer formed by the grayzation process belong to the irrigation water soil type[2]. In other words, soil profiles of paddy field are characterized genetically and morphologically by the underground and irrigation waters.

The major soil groups*1 of organic paddy soil are classified into peat and muck soils. The major soil groups of inorganic paddy soils are classified into Strong Gley Soils, Gley Soils, Gray Soils, Grayish Brown Soils, Lowland Soils and Yellowish Brown Soils in order from ill-drained paddy soil to the well-drained one[3,4].

In this paper, the relationship between the major soil groups of paddy soil and their physical properties are presented from the view point of improving them.

Soil hardness of major soil groups

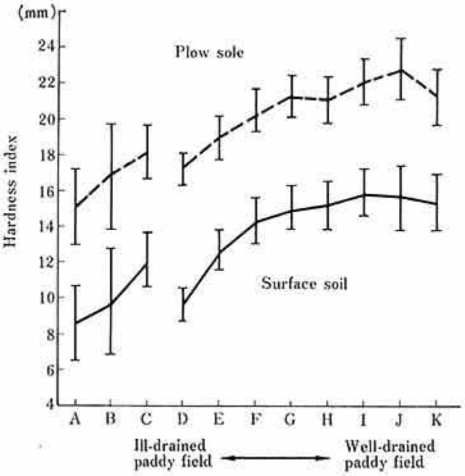
Soil hardness relating to tillage of soil varies according to parent materials, soil texture, soil structure, water regime and the contents of humus and salts and it may be called a mechanical property—the most comprehensively manifesting one of physical properties. The results shown in Fig. 1 are the statistical data of the hardness index*2 of the major soil group determined in the fundamental soil survey project organized by the Ministry of Agriculture and Forestry.

Soil hardness of surface soil is invariably

*1 Matsuzaka says "Major soil group" is a group of soil series or soil sub-groups having the same diagnostic horizon just below the surface layer and derived from the particular type of parent materials and mode of sedimentation[4]. Soil sub-group is a group of soil series having the same diagnostic horizon in their profile[4]. Soil series is a group of soils derived from the particular type of parent material and its deposition and having soil horizons genetically similar in differentiating characteristics and arrangement in the soil profile[4].

*2 Hardness index is determined by Yamanaka's soil hardness meter, and expressed by the compressing distance of spring when the corn-type tip (vertical angle 12°40′) is put into the soil. Hardness index can be coverted in gravitational units.

Hardness index	mm	10	20	30
Absolute hardness	kg/cm^3	0.17	1.18	14.42
Penetrating hardness	kg/cm^2	1.40	6.29	37.7



Major soil groups
A: Peat Soil, B: Peaty Soil, C: Muck soil, D: Strong Gley Soil, E: Gley Soil, F: Gray soil, G: Grayish Brown Soil, H: Ando Low-land soil, I: Yellowish Brown Soil, J: Gravel Soil, K: Gravelly Soil

Fig. 1. Changes of soil hardness for major soil groups

smaller than that of plow sole. High hardness of plow sole might be due to the result of soil compaction and cementation of soil particles by hydroxides.

In the organic paddy field, muck Soils are greater in hardness than Peaty Soils on the surface soil and plow sole. Such difference between both soils might be caused as a result of the depth to underground water table and the decomposing grade of organic matter.

In inorganic paddy field, soil hardness increases clearly as ill-drained paddy field shifts to the well-drained one. Since soil hardness is closely related with the drainage class of soils, other physical properties of paddy soil may be also changed among major soil groups.

Soil structure of paddy soils

In paddy soils, soil particles are obstructed to form aggregates by the influence of irriga-

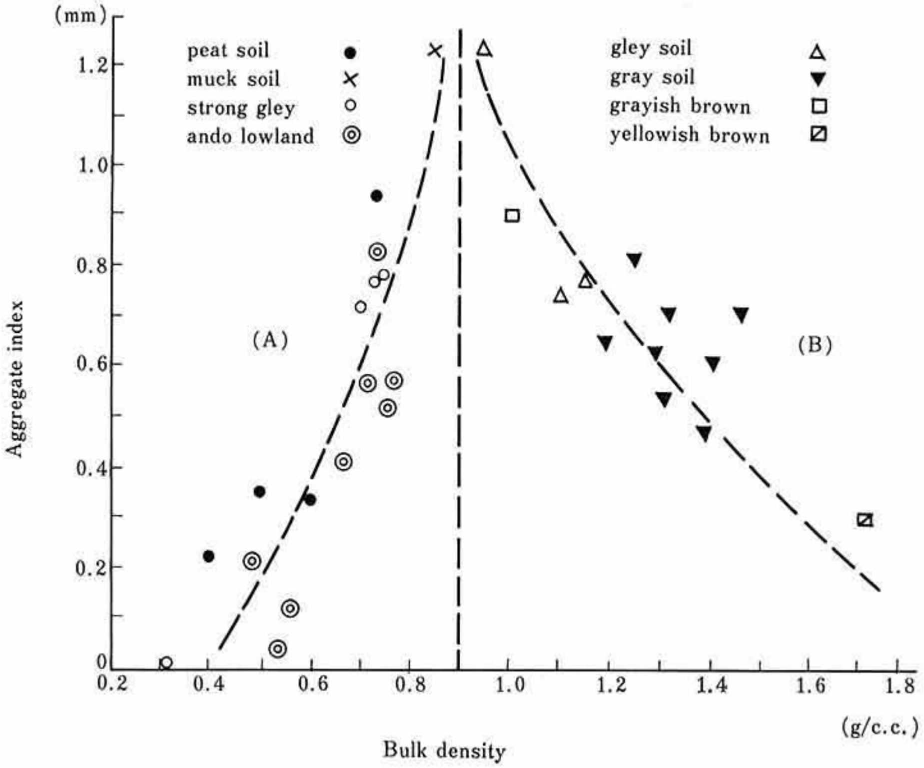


Fig. 2. Relationship between aggregate index and bulk density of paddy soils

tion water. But in the non-irrigation period after harvest, aggregation might be hard due to the immobilization of cementing materials and increasing of biological activity owing to drainage, tillage, soil drying and manure application.

Middleton's dispersion ratio which is an index of water table aggregate, recognized a decreasing tendency as ill-drained paddy field shifts toward the well-drained one. In other words, soil structure is developed as the reformation into well-drained paddy soil.

Macropore space increases generally by the development of aggregation of soil particles and bulk density decreases inversely. It seems that the relationship between bulk density and aggregate index*3 may be in a certain regularity as shown in Fig. 2; namely, in region (A), soils have bulk density of less than 0.9 and the aggregate index decreases with the fall of bulk density while in region (B) greater than 0.9, the tendency of decreasing aggregate index is observed with the increase of bulk density.

Region (A) consists mainly of ill-drained paddy soils having high humus content, and region (B) is covered with well-drained paddy soils.

Consequently, in order to accelerate the aggregation of soils belonging to region (A), it is necessary to improve soil for increasing bulk density.

For region (B) soils, such soil treatment as tillages and dressing of organic matter will be essential to decrease bulk density.

Water retaintivity

Water retaintivity of soil varies with the dominant clay minerals, soil texture, soil structure, etc. In order to know the functions of water retaintivity, soil characteristics of major soil groups are shown in Table 1. Typical water characteristic curves of their soils are expressed in Fig. 3.

As a feature of water retaintivity of paddy soils, the irreversible decrease of water retaintivity by air-drying can be mentioned. Water retaintivity by air-drying has a tendency to decrease greatly in the case of ill-drained paddy soils especially for Strong Gley Soils (No. 1) except Ando Lowland Soils

Table 1. Soil characteristics of major soil groups

Number of soil	Parent materials	Modes of sedimentation	Dominant clay minerals	Major soil group of paddy soil	Nos. of soil layer	Texture
1	Unconsolidated sedimentary rock	Marine deposit	Montmorillonite	Strong Gley Soil	1 2 3	LiC LiC LiC
2	do.	River alluvial deposit	Kaolin, Mont./Ver.	Gley Soil	1 2 3	HC LiC HC
3	do.	do.	do.	Gray Soil	1 2 3	CL LiC LiC
4	do.	do.	Montmorillonite	Grayish Brown Soil	1 2 3	CL LiC LiC
5	do.	Diluvial deposit	Kaolin	Yellowish Brown Soil	1 2 3	CL LiC LiC
6	Igneous rock	Aeolian volcanogeneous deposit	Allophane	Ando Lowland Soil	1 2 3 4	CL L FSL LCoS

*3 Aggregate index is expressed as the difference between mean weight diameter of aggregates and that of single particle.

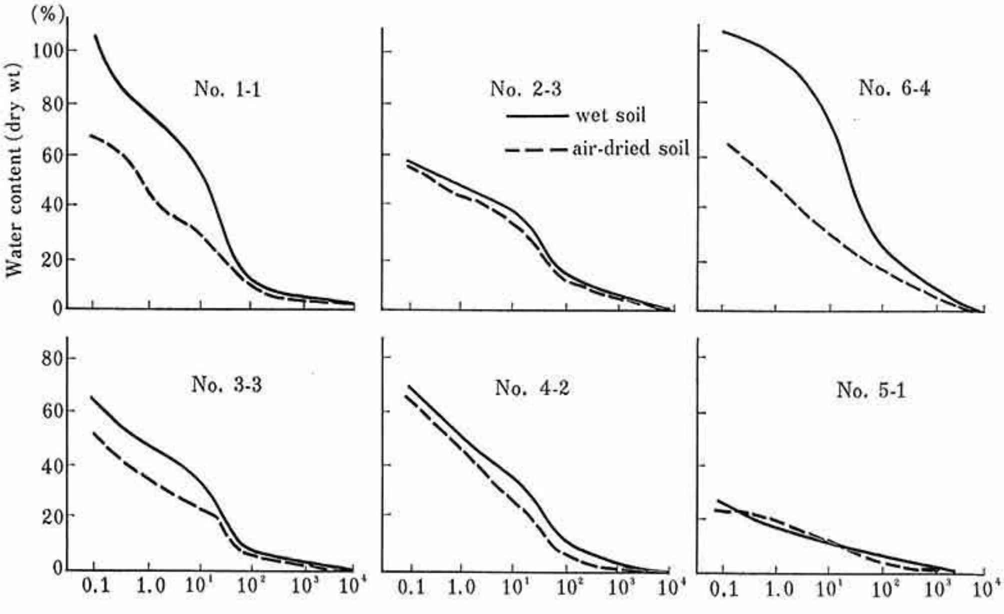


Fig. 3. Soil water characteristic curves of various paddy soils

(No. 6).

Each soil of Nos. 1 and 6 is dominated by montmorillonite and allophane respectively for they have high hydration of soil particles. Air-drying of wet soil changes the surface activity of soil particles and strengthens the combination among soil particles. For this reason, it is surmised that, in relation to rehydration of imbibitional water and capillary water, water retaintivity decreases as stated above.

The remarkably high-water retaintivity of Strong Gley Soils and Ando Lowland Soils, and the relation of lower value for well-drained paddy soils can be seen as a feature of water retaintivity of major soil groups. Especially on Yellowish Brown Soil in diluvial area, water retaintivity is extremely low owing to the kaolin having low hydration.

For ill-drained paddy soils, a large amount of unfree water around primary particle is gained by hydrophilic colloid, that is, ill-drained paddy soils are always under waterlogged condition, and cementing materials among particles may be in the state of hydroxide having high imbibitional water.

In the case of well-drained soils, soil colloid changed to hydrophobic is concentrated on the soil particles and contributes in forming soil granule.

Ando Lowland Soils which mainly belonged to well-drained paddy soils have an extremely high-water retaintivity. It is closely related with the microstructure and hydration of allophane.

Consistency of major soil groups

The differences of consistency among major soil groups are observed as similar features stated in the item of water retaintivity. Plasticity of major soil groups shown in Table 1 is expressed in Casagrande's plasticity chart of Fig. 4. The plasticity of paddy soils of Nos. 1 to 5 is distributed in the plasticity side on "A" line, and Ando Lowland Soil of No. 6 is only in the compression side under "A" line.

The liquid limits of soils are distributed widely over the plasticity range from medium (III-cm) to very large (I-ch), and those are grouped in certain plasticity ranges depend-

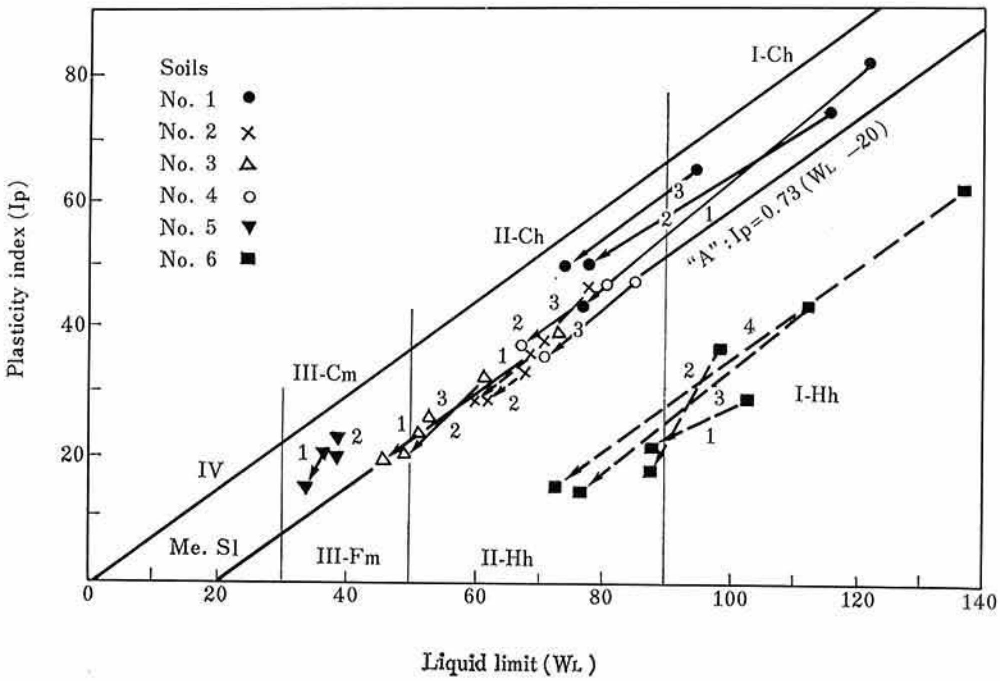


Fig. 4. Casagrande's plasticity chart of paddy soils. Each point in direction of the arrow expresses the air-dried soil. Number in the figure is the horizon number

ing on each major soil group.

Strong Gley Soils are distributed in I-ch range which shows high liquid limit, and Yellowish Brown Soils of well-drained paddy field are in the III-cm range showing low liquid limit.

Gley Soils, Gray Soils and Grayish Brown Soils of moderately or well-drained paddy soils are in the intermediate range. It is clear that plasticity lowers as the poorly drainage condition develops into a well-drained one.

Plasticity of wet soil is always larger than that of air-dried soil. The remarkable decreases of plasticity by air-drying are recognized generally for soils having a large liquid limit especially on Strong Gley Soils and Aando Lowland Soils. Soils having the smallest effect of air-drying are Yellowish Brown Soils containing kaolin.

Soils of Nos. 1 and 4 which contain montmorillonite show generally a high plasticity on the wet soil and conspicuous decreases of plasticity by air-drying. Besides these two values of No. 1 of ill-drained paddy soils are larger than that of No. 4 of well-drained one. The same phenomenon as mentioned above can be recognized in the soils containing a mixture of kaolin-montmorillonite/vermiculite as Nos. 2 and 3, that is, even though the soils contain the same dominant clay minerals, the soil colloid in ill-drained paddy soils may be relatively in a state of hydrophilic.

As well-drained paddy soils are in a dry condition, the soil colloids may be changed into hydrophobic. It is acknowledged that such plasticity change might be caused by the changes of colloidal behavior under different drainage conditions.

The Yellowish Brown Soils dominated by kaolin has a texture of CL to LiC; however, its plasticity is in the low range and plasticity decrease by air-drying is also very small.

Ando Lowland Soils dominated by allophane are in the lower side of "A" line of the Casagrande's plasticity chart, and plasticity decreases of the upper soil by air-drying are relatively smaller than that of the subsoil.

As the upper soils are affected by air-drying or freezing during the non-irrigation period, water retaintivity of allophane decreases irreversible. But the water retaintivity of subsoil is not affected by air-drying in the field.

As mentioned above, it can be concluded that the differences of consistency among major soil groups are related to the existence of dominant clay minerals and soil water regime in the field, and their consistent change is strongly affected by the water retaintivity of paddy soil.

From the above results, the principal physical properties among major soil groups are discriminated not only on the surface but also on the diagnostic horizons, and their physical properties are influenced by underground and irrigation waters which are directly related to soil formation and soil profile development.

References

1) Kamoshita, Y.: On soil type of Tsugaru Plain in Aomori Prefecture. *Bull. Nat. Agr. Exp. Sta.*, 3, 401–120 (1940).

2) Kanno, I.: A scheme of soil classification of paddy field in Japan with special reference to mineral paddy soil. *Bull. Kyushu Agr. Exp. Sta.*, 4(2), (1956).

3) Oyama, M.: A classification system of paddy rice field soils based on their diagnostic horizons. *Bull. Nat. Int. Agr. Sci.*, B. 12, 211–304 (1962).

4) Matsuzaka, Y.: Study on the classification of paddy soils in Japan. *Bull. Nat. Ins. Agr. Sci.*, B. 20, 155–331 (1969).

5) Terasawa, S.: Studies on the physical behavior of various large groups of paddy soils. *Bull. Nat. Ins. Agr. Sci.*, B. 22, 211–304 (1971).