Improvement of Permeability and Water Retentivity in Heavy Soils

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So-called heavy soils, classified as pseudogley, stagnogley, acid brown earth, and podzolic soils[2], are widely distributed on uplands and hills in northern Hokkaido. The soils are characterized by the poor properties of permeability, available moisture and soil tilth.

Recently, land improvement measures such as underdrainage, subsoil breaking and sand dressing have been applied to these soils, which bring about suitable results in terms of prevention of crops from wet injury and improvement of soil tilth. It has been reported that, however, the sub-soil breaking has an adverse effect on soil moisture status in such a way that soil dries more quickly and holds less available moisture than the soil untreated[4]. Furthermore, sand dressing is recognized to increase non-capillary porosity but decrease capillary one[1,3].

The average annual precipitation is about 850 mm in northern Hokkaido, being the lowest in Japan. In some years, drought occurs in the spring and the summer. Under such climatic condition, therefore, a countermeasure of supplying enough water for crop growth is necessary in addition to drainage. Intermittent supply of small quantity of irrigation water to such soils as having limited amount of capillary porosity is a positive but troublesome measure for keeping a favable moisture status during a cropping season. For these soils, it seems to be rather reasonable to increase capillary porosity and hold rain water in soil pores as much as possibe. Soil improvement by increasing non-capillary porosity is also important to let rain water penetrate fast into the soils.

Accordingly, soil amendments effective to increase non-capillary and capillary pores simultaneously must be found out to improve permeability and availability of moisture in heavy soils.

The object of the present paper is to describe 1) effect of various soil amendments on crop yields and soil physical properties and 2) physical properties of soil amendments required for simultaneous improvement of permeability and water retentivity. For this pursuit, various soil amendments were applied to Komukai heavy soil, a typical pseudogley (subsoil), and their effect on the soil pore composition was investigated.

Effect of various soil amendments on crop yields and soil physical properties

As soil amendments for Komukai heavy soil, perlite, saw dust, chaff manure, barnyard manure, powdered chaff, and Notoro pumice were selected. Notoro pumice is the constituent of an unconsolidated pyroclastic flow deposit, which covers the Notoro upland near the southern border of the heavy soil area.

Air-dried soil was crushed by a roller, mixed with different soil amendments at the rates equivalent to the thickness of 2.5 to 7.5 cm, and the duplicates were packed into plots of 0.5 m^2 frame. The thickness of soil within the frames was set to 23 cm in all plots.

The chemical properties and particle size composition of the amendments are shown in Table 1 and Fig. 1. Both perlite and Notoro pumice are chemically inactive and composed mostly of fractions of particles less than 0.5 mm in diameter. Saw dust and powdered

Table 1. Chemical properties of amendments

Amendment	T-C (%)	T-N (%)	C/N	0.1N HCl-soluble (%)				Soil & sand (%)
				P_2O_5	K_2O	CaO	MgO	
Perlite	tr.	tr.	—	tr.	0.02	0.06	0.03	—
Saw dust	51.5	0.07	736	0.01	0.02	0.15	0.03	0
Chaff manure	33.6	1.07	31	2.64	2.10	3.56	0.25	24.3
Barnyard manure	40.5	2.57	16	2.50	2.91	2.51	0.76	12.6
Notoro pumice	tr.	tr.	—	0.10	0.01	0.10	0.09	—
Powdered chaff	44.5	0.49	91	0.79	0.02	0.92	0.28	0

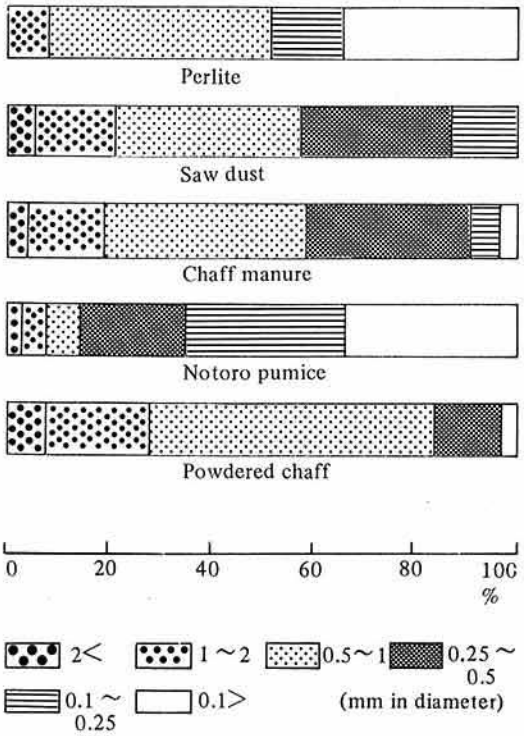

Fig. 1. Particle size composition of amendments

chaff have high C/N ratio. Powdered chaff is the most coarse in particle size composition, but the majority of the particles belong to fractions less than 2 mm in diameter.

Table 2 shows potato yields obtained. The yield was the highest in the barnyard manure plot and followed by the chaff manure plot, while it was the lowest in the saw dust plot. In perlite and Notoro pumice plots, the yields were higher than the plot without amendment treatment.

Physical properties of the soils with or without amendment treatment are shown in Table 3. All the soils treated with either amendments showed lower values in bulk density, solid ratio and hardness of the surface crust, but higher values in porosity at pF below 1.6 and in permeability than the soil without treatment.

Table 2. Average yields of potato

Treatment	Quantity (cm)	Yield (g/m^2)	Yield index	Starch content (%)
Perlite	2.5	3775	103	19.4
	5.0	3798	104	18.8
	7.5	3794	104	18.7
Saw dust	2.5	2955	81	18.3
	5.0	3092	85	16.8
	7.5	3040	83	18.2
Chaff manure	2.5	4628	127	15.5
	7.5	4483	123	15.7
Barnyard manure	2.5	5315	146	15.3
	7.5	7916	217	16.1
Control		3650	100	18.9
Notoro pumice	2.5	4390	105	17.8
	7.5	4750	114	17.0
Powdered chaff	2.5	4505	108	15.6
	7.5	4270	102	15.9
Control		4170	100	16.9

Each soil amendment seems to be effective for improving permeability and soil tilth, and becomes much more effective when the amount of applied amendment increases.

Porosity at pF 1.6–3.9 of the soils treated with amendments was higher than without treatment, although there was an exception for powdered chaff. This trend is quite remarkable when the soils were treated with perlite and Notoro pumice. However, no significant changes in porosity at pF 3.1–3.9 were

Table 3. Soil physical properties

Amendment applied	(cm)	Bulk density (g/cm³)	Solid ratio (%)	Porosity (pF) 0–1.6 (%)	1.6–3.1 (%)	3.1–3.9 (%)	Specific gravity	Saturated permeability (cm/sec)	Index of soil strength of crust (mm)
Perlite	2.5	1.208	48.3	9.5	8.5	6.9	2.50	1.3×10^{-5}	20.0
	1.0	1.024	42.2	15.0	13.2	6.9	2.42	2.0×10^{-4}	15.5
	7.5	0.822	35.1	15.5	22.5	7.6	2.34	2.1×10^{-4}	13.0
Saw dust	2.5	1.187	45.5	12.7	7.9	6.3	2.61	1.5×10^{-4}	17.5
	5.0	1.120	43.1	15.9	8.2	6.2	2.60	3.3×10^{-4}	16.6
	7.5	0.948	37.0	20.3	11.5	8.6	2.57	7.7×10^{-4}	14.3
Chaff manure	2.5	1.164	44.1	12.4	9.2	6.1	2.64	2.7×10^{-5}	18.5
	7.5	0.973	37.3	15.9	14.2	5.8	2.60	6.3×10^{-4}	17.3
Barnyard manure	2.5	1.213	45.0	11.6	8.4	6.0	2.70	1.6×10^{-5}	20.0
	7.5	0.941	35.8	20.5	10.4	6.8	2.63	3.6×10^{-4}	19.0
Control		1.316	51.2	8.4	5.5	5.8	2.57	1.1×10^{-5}	20.7
Notoro pumice	2.5	1.276	47.6	8.1	15.6	7.2	2.68	1.1×10^{-5}	18.9
	7.5	1.159	43.5	12.9	19.5	6.0	2.66	$1{\cdot}1\times10^{-4}$	12.2
Powdered chaff	2.5	1.239	47.5	9.8	12.2	7.0	2.62	3.6×10^{-4}	14.2
	7.5	0.979	38.4	20.8	12.1	6.9	2.55	6.1×10^{-3}	15.5
Control		1.307	48.6	6.8	13.5	6.9	2.69	2.3×10^{-5}	24.9

appeared by the addition of the soil amendments. Therefore, the differences of the porosity at pF 1.6–3.9 found among the plots are mainly attributable to those of the porosity at pF 1.6–3.1. The porosity at pF 1.6–3.1 tends to be higher in the soil treated with amendments containing many particles of less than 0.5 mm in diameter.

Unsaturated permeability and the change of soil moisture of the soil treated with Notoro pumice were measured during a cropping season. The unsaturated permeability was five to ten times faster in the range of soil moisture potential up to 100 cm H_2O for the soil treated with 7.5 cm-Notoro pumice than without treatment. The moisture potential for the pumice-treated soil after a heavy rainfall increased faster, while during a drying period, it was kept lower at a depth of 5 cm and higher at 15 cm in comparison with the soil without treatment. This fact can be explained by the improvement of permeability and hydraulic conductivity of the soil by an application of Notoro pumice.

Physical properties of soil amendments required for simultaneous improvement of permeability and water retentivity

From the result mentioned above, an application of Notoro pumice to the soil appears to be much effective to improve permeability and water retentivity simultaneously. This could be explained in terms of particle size composition, particle shape, and surface morphology of a particle. Then, Senbiri pumice and sand which differ from Notoro pumice in the shape and surface morphology of a particle were used to investigate the influence upon soil pore composition.

The characteristics of the particle shape and the surface morphology were observed by microscopes. Notoro pumice consists mainly of elongated particles with channels of several dozens micron in width and open pores of several to dozens micron in diameter on the surface of individual particles. There are some particles showing ridgy and curved surface. On the other hand, Senbiri pumice consists of particles of various diameters with somewhat curved but smooth surface. Sand was largly composed of particles of uniform diameter with few open pore surface. Scanning electron microphotographs of Notoro and Senbiri pumices are shown in Plate 1 and 2.

The porosity of different particle size fractions in these three amendments was determined. Each fraction was poured into a 100 ml cylindrical core which was prepared by connecting two cylindrical cores with vinyl tape, saturated with water, and removed excess water on a sand column. The core sample was fixed in a centrifuge and dehydrated with the centrifugal force equivalent to pF 2.7 for 1 hr. After then, the bottom half of core was used to measure solid ratio and porosities at pF 0, 1.5, 2.7 and 3.9.

The results are shown in Fig. 2. Various pore size fractions of soil were designated as non-capillary pore (pF 1.5), large-capillary pore (pF 1.5–2.7), fine-capillary pore (pF 2.7–3.9), capillary pore (pF 1.5–3.9), and micropore (pF 3.9). When comparing fractions of same particle size of the three amend-

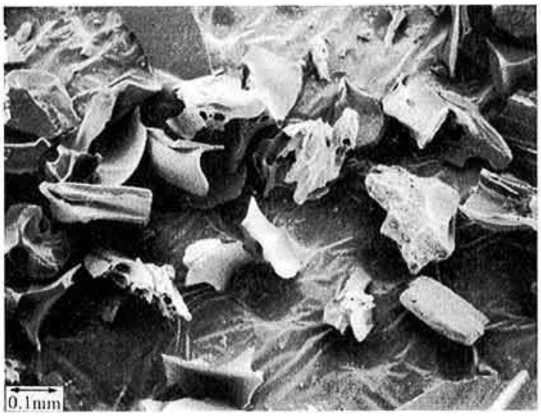

Plate 1. Scanning electron micrograph of Notoro pumice particles

Plate 2. Scanning electron micrograph of Senbiri pumice particles

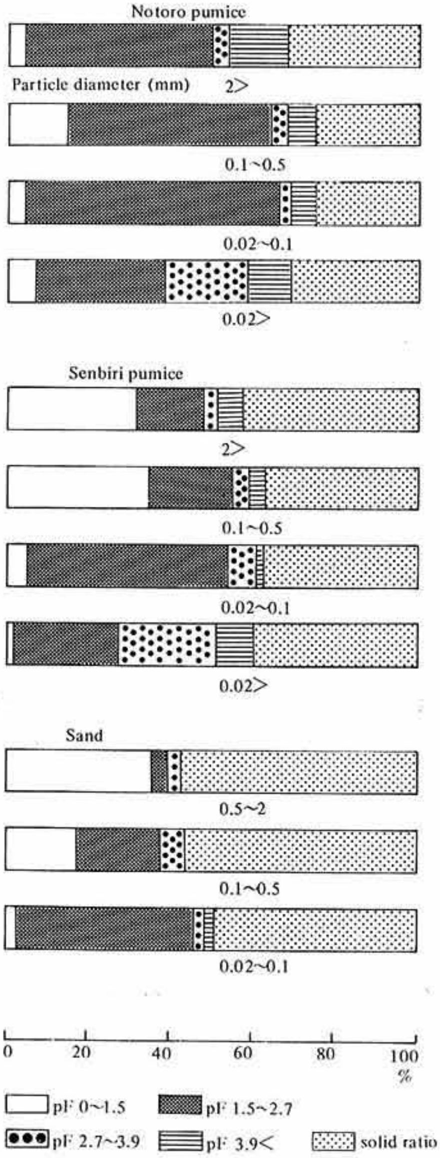

Fig. 2. Pore composition in particle size fractions of selected amendments

ments, non-capillary porosity of the fraction of 0.1–0.5 mm was the highest in Senbiri pumice, followed by lower porosities of approximately equal values for Notoro pumice and sand.

The size fractions of 0.02–0.1 mm of all the amendments contained several % of non-capllary porosity. But large-capillary porosity was much higher in Notoro pumice than in Senbiri pumice or sand. Fine-capillary and micro porosities differed somewhat among the amendments, but the differences were smaller than those found in large-capillary porosities.

The fraction of 0.1–0.5 mm held both non-capillary and large-capillary porosities more than 15%. The fraction of 0.02–0.1 mm had more large-capillary porosity, but much less non-capillary porosity than the fraction of 0.1–0.5 mm. The fraction of less than 0.02 mm had little non-capillary porosity, and compared with the fraction of 0.02–0.1 mm, it had more fine-capillary and less large-capillary porosities.

Soil pore composition was measured with Komukai soil treated with and without the amendments. The method was the same as above mentioned. Fig. 3 shows the results of application of the fractions of 0.1–0.5 mm of three amendments. Increasing amount of any amendments increased non-capillary and large-capillary porosities, but decreased fine-capillary porosity of the soils. Notoro pumice remarkably increased large-capillary porosity and consequently capillary porosity.

Besides, the pore composition of the Komukai soil treated with each of the fractions less than 2 mm, 0.5–2.0 mm, and 0.02–0.1 mm of these amendments was measured. Their effects on simultaneous increase of non-capillary and capillary porosities were lower than the effect observed when the fraction of 0.1–0.5 mm was applied.

Based on these experimental results, the relation between the properties of amendments and their effect in improving permeability and water retentivity is considered as follows.

As to the particle size, fractions less than 0.1 mm contribute to improve water retentivity but not permeability. The fractions of 0.5–2 mm are much effective to increase permeability but ineffective to water retentivity. The fractions of 0.1–0.5 mm except Senbiri pumice can improve both permeability and water retentivity.

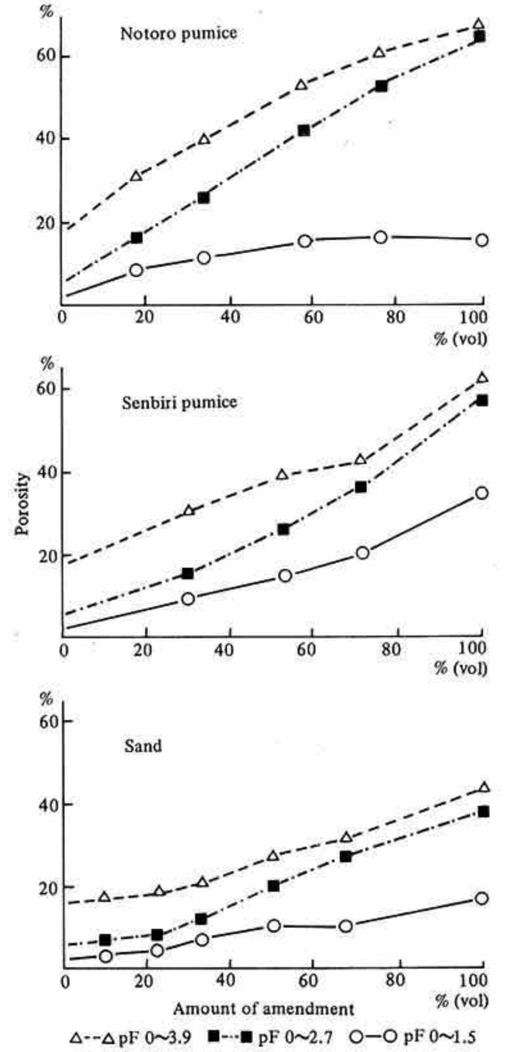

Fig. 3. Pore composition of Komukai heavy soil mixed with a 0.1~0.5 mm fraction of amendment

As to the surface morphology, amendments such as perlite and Notoro pumice are considered to have excellent water retentivity due to their open pores on a particle surface which are suitable for holding capillary porosity.

The effect of particle shape on the porosities could be well illustrated as an example by comparing the 0.1–0.5 mm fractions of Senbiri pumice and sand, which consists mainly of particles with few open pores. Senbiri pumice composed of particles with unequal diameters was more effective to increase non-capillary porosity than sand which is rather rich in particles with uniform diameter, while the difference of capillary porosity observed was small.

For the soil amendment suitable for simultaneous improvement of permeability and water retentivity in heavy soil, especially when the amendment to be used is a substance chemically inactive and abundant in particles of less than 2 mm in diameter, amendments which have high water retentivity due to their porous surface, and have little amount of the fraction of less than 0.1 mm in diameter should be selected.

The fraction of 0.1–0.5 mm composed of particles without porous surface also tends to increase large-capillary porosity as well as non-capillary porosity, but is less effective to improve water retentivity than that of amendment rich in particles with porous surface.

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