Water Repellency of Soils

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It is generally recognized that fallen leaves, straws and fungal hyphae are water repellent, and that dried peat floats on the water.

Then, are the soils, containing humified substances of these organic matters, water repellent or not? It is also well known that the humic acid extracted from soils is difficult to wet again after being thoroughly dried.

Up to the present, water repellent property of soils has scarcely been studied, and soils have generally been considered to be completely wettable with water.

But, in these days, a number of soils which are not wettable were found, especially, in arid or semi arid zones such as California, Florida and Utah in the United States of America, and in New Zealand, Australia and so on[1,2,4,11,12,13]. It is said that they repel water much the same as a bird's feathers do and that irrigated or rain water is difficult to infiltrate into them. It has been reported that the water repellency of these soils depends mainly upon soil organic matter coating the soil particles[1,2,13].

In Japan it is pointed out[6,10] that the dry brown forest soil is difficult to wet with water.

Instead of the preconceived idea that soils are completely wettable with exception of some specially water repellent soils, on the new hypothesis that soils are not completely wettable and that they are relatively resistant to wetting,[8] some new knowledges were given to the interpretation of the effect of organic matter upon soil physical properties[9] which had not been theoretically explained.

This paper reports some results of studies on the evaluation of wetting resistance of not only water repellent soils mentioned above but also the soils which has been thought to be easy to wet, and the effect of the wetting resistance on water movement in moist soil.

The method for measuring water repellency of soils

In order to explain that soils are not completely wettable, it is necessary to establish the method for measuring the degree of water repellency of soils. For that purpose, an attempt must be made to develop the only one method which can measure water repellency of soils including completely wettable soils and completely nonwettable soils. Some measuring methods for water repellency of soils have been reported,[3,4,5] but they are not enough to measure from complete nonwettability to comp ete wettability by only one procedure. Each method which has been reported has different unit for the expression of water repellency. This is the reason why many researches had directed to only extremely nonwettable soils distributed locally.

The principle used was the theory of capillary rise.

The following formula is well known:

$$h_1 = \frac{2T\cos\theta_1}{g\gamma_w r_1}$$

where, h_1: height of capillary rise
T: surface tension of water
θ_1: water-solid contact angle
g: acceleration of gravity
γ_w: density of water
r_1: effective pore radius

Hence, h_1 is experimental value, and T, g and γ_w were constant. r_1 and θ_1 are unknown.

If the height of capillary rise of the sample which was treated to become wettable without changes in soil structure or aggregate were measured, the following equation is obtained:

$$h_0 = \frac{2T\cos\theta_0}{g\gamma_w r_0}$$

where, $r_1 = r_0$ (because of no change in soil structure)

$\theta_0 = 0$ (because the sample was completely wettable)

therefore,

$$\cos\ \theta_1 = h_1/h_0$$

Consequently the nonwettability or water repellency of soil samples is given as the cosine of the ratio of height of capillary rise of a soil sample to height of its completely wettable sample.

The term "Water repellency" is defined in this report as relative nonwettability of water upon the soil particle surface, that is, the soil sample is completely wettable if the contact angle θ is 0°, and it is completely nonwettable if it is 180°.

Hence it becomes necessary to make the soil sample completely wettable. Heating or ignition was employed to make the soils wettable[7,8].

It is shown graphically in Fig. 1 that the heights of capillary rise of soils ascend gently from 105°C to 200°C except for Bibai soil, but ascend steeply from 200°C to 250°C and ascend gently beyond 250°C. The same phenomenon was observed in the case of humic acid as shown in Fig. 2. Especially at 250°C, the heights of capillary rise of the quartz sands coated with humic acid were the same as the noncoated quartz sands which is completely wettable. Considering the facts that the humic acids became completely wettable by ignition at 250°C and that the heights of capillary rise of soils ascended steeply from 200°C to 250°C, it was concluded that the soils changed sharply to be wettable at 250°C. It was therefore shown that not only wettable soils but also nonwettable ones became fully wettable by ignition at 250°C[8].

Consequently, from the determination of the ratio of the height of capillary rise in the sample dried at 105°C to that in the sample ignited at 250°C, the water repellency of a soil sample could be represented as a contact angle, whether the samples were very wettable or not.

The results are shown in Fig. 3 with the new conception of water repellency described in this report. It could be clearly demonstrated that the soils which had been considered to be equally hydrophilic so far showed very different wettability. For reference, the contact angle of glass or quartz sand to water is 0°, one of teflon which is very hydrophobic is 108° and polyethylene is 94°. It is concluded that a dry soil cannot be fully hydrophilic as long as organic matter is present.

Changes of water repellency of soil sample containing water

It became clear that dry soils show resistance

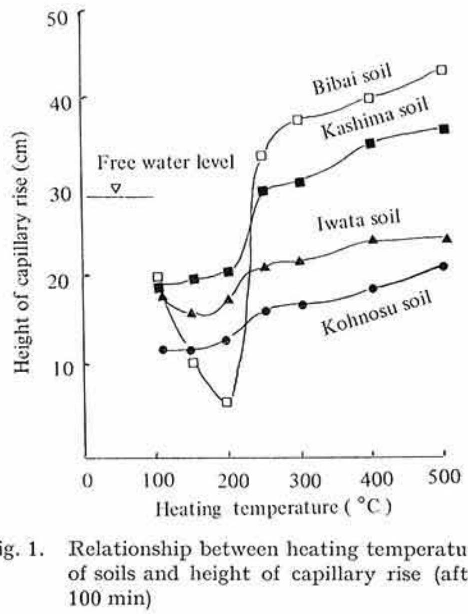

Fig. 1. Relationship between heating temperature of soils and height of capillary rise (after 100 min)

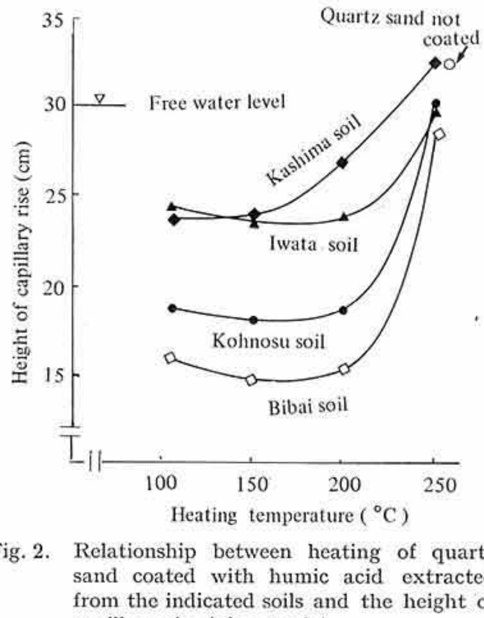

Fig. 2. Relationship between heating of quartz sand coated with humic acid extracted from the indicated soils and the height of capillary rise (after 5 min)

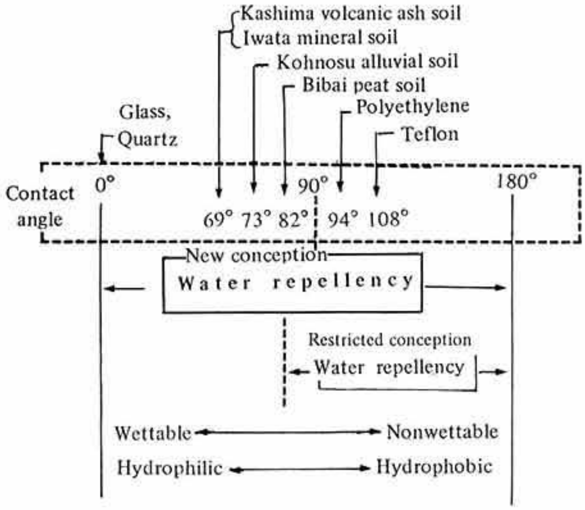

Fig. 3. New conception of water repellency as expressed by contact angles of soils

to wetting with water as mentioned above. But soils in field condition contain water more or less. So, to clarify whether soils containing water show resistance to wetting or not is of use for elucidation of mechanism of water repellency based upon physical properties of moist soils. Soils in field condition, differing from glass or plastic products, contain moisture in their structure.

The water repellency of moist soils was studied by infiltrating water into soils. The length of time that one water drop (0.01 m*l*) could remain on the soil surface was used as an index of water repellency of soil[9].

As shown in Fig. 4, infiltration of water into soils which contain organic matter became slower at above pF 3.0. At pF 4.2 the infiltration was slowest. In the case of kaolin which does not contain organic matter (Fig. 4) and in the soils ignited at 250°C (Fig. 5) which are hydrophilic, infiltration slowdown at pF 4.2 was not recognized, but as shown in Fig. 6 infiltration at pF 4.2 of a mixture of kaolin and humic acid which is very hydrophobic after drying became slower with the increase in humic acid content. Thus it is clear that the presence of organic matter in the moist soil decreases infiltration rate, in other words, it resists to wet.

The infiltration of soils at pF 4.2 was clearly slower in the wetting process where dry samples were wetted than in the drying process where wet samples were dried, whereas in the case of

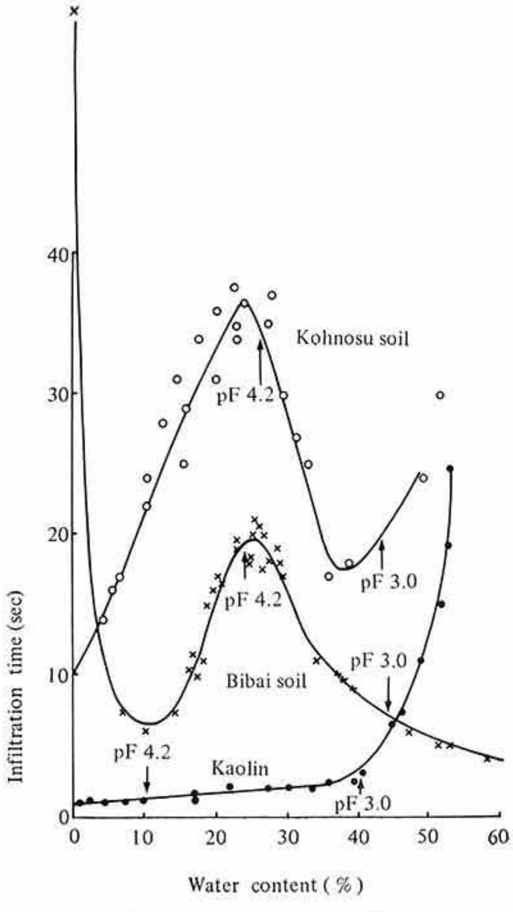

Fig. 4. Relation between infiltration time and water content

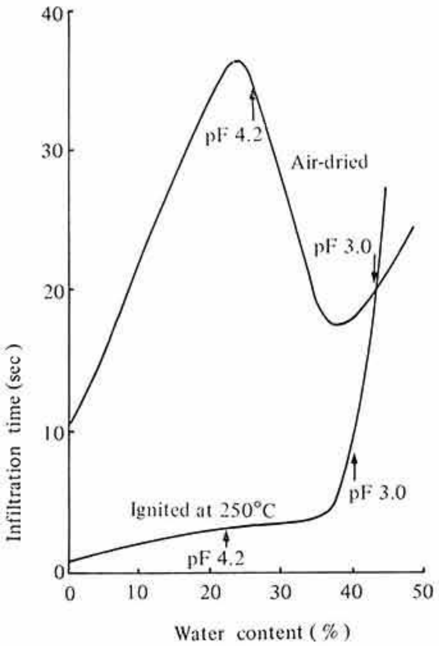

Fig. 5. Infiltration time of Kohnosu soil ignited at 250°C

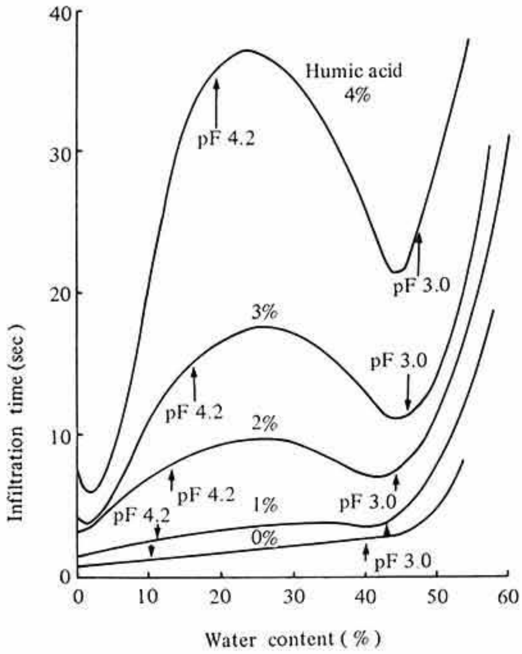

Fig. 6. Infiltration time of the mixtures of kaolin and humic acid

kaolin the slowdown infiltration at pF 4.2 was not recognized in either process. From these facts it is considered that the entrapped air resulting from the presence of organic matter disturbs infiltration.

It is concluded that soil organic matter shows hydrophobic property above pF 3.0 and that it becomes most hydrophobic at pF 4.2.

Discussion

Soils, regardless of drying or wetting, is not completely hydrophilic mainly by the presence of organic matter, and soils are thought to be relatively hydrophobic. Especially, soils containing moisture corresponding to pF 4.2 exhibited slowest infiltration for the reason of water repellency of soils. For plants, moisture content with the value of pF 4.2 is referred to as permanent wilting point, and it was suggested in this report that such moisture content could extremely prevent soils from water movement.

The fact that soils are resistant to wetting with water gives new suggestion to researches on soil physical properties. Insomuch as water repellency influences water movement in soil, it must be taken into consideration in a hydrological study.

In Japan, moisture content of surface soils sometimes becomes to pF 4.2 or more in drought or in summer. In arid or semi arid zones, soils are thought to be often dried above pF 4.2. In these cases it is considered to be necessary to take into consideration the water repellency for efficiency of utilization of soil moisture and irrigated or rain water.

It is consequently evolved that water repellency of soils gives new idea to water management in field condition and also that it controls the moisture regime of the soils.

Conclusion

The contact angles of dry soils which had been considered to be hydrophilic were appreciably greater than zero. Moist soil as well as dry soil was resistant to wetting mainly by the presence of organic matter. In moist soils the infiltration was slowest at pF 4.2 for the reason of hydro-

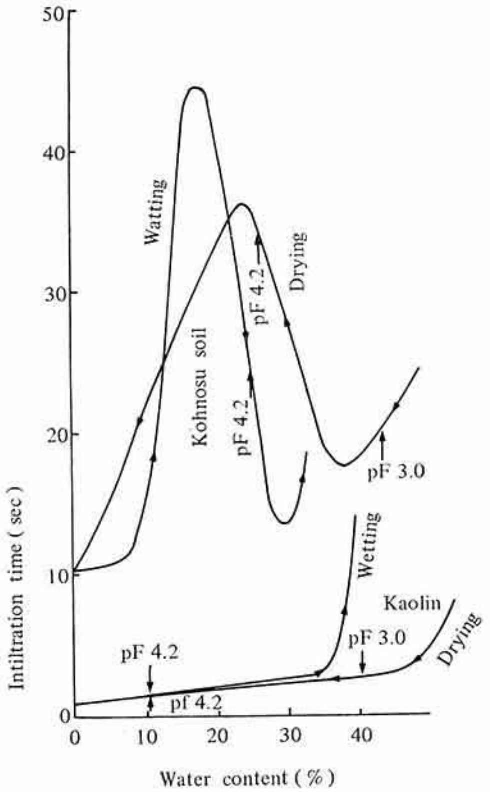

Fig. 7. Hysteresis of infiltration time vs. water content curve

phobic property of soil organic matter.

It was suggested that generalization of conception of water repellency which had restricted to the extremely hydrophobic soils gave the new view point to soil physics, especially soil water movement.

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