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A study on soil properties of hillside work area and topographic factors

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Abstract

Soil properties were investigated in five landslide sites and in their circumferences on which hillside works had been carried out about 30 years before. These study sites were almost identical in the practical years and the kinds of hillside works and their geology, but were different in the bearings and the altitudes of hillside. The results indicated that the total carbon and total nitrogen contents and the water-holding capacity of soil increased with higher altitudes in investigated range. Furthermore, it was judged that the total carbon contents of soil on south-facing slope were more abundant than those on the north-facing slope. This was presumably due to the soil freezing in winter and due to the difference in the duration of potential solar-radiation which related to the weathering and the decomposition of the organic matter.

Key words : Soil property, Hillside work-site, Topographic factor.

I. Introduction

Forest soil property can be evaluated by water-holding capacity. This factor is related to the chemical and physical properties of soil. Total carbon content, total nitrogen content of soil and so forth are useful indexes of chemical soil properties. Grain-size distribution, pore-size distribution, water content of soil and so forth are important criterions of physical soil properties. These factors are closely related to water infiltration, storage and drainage of soil water. The soil properties will then be affected by the environmental conditions of study sites. Topographic bearings and altitudes can have profound local influences on the physical and chemical properties of surface soils.

In order to analyze the relationship between the soil properties of hillside work-sites and their topographic factors, the study sites with the same practical years of hillside works but different topography were selected. The soil samples were collected from the sites where the hillside works had been carried out about 30 years before and from the outside the circumferences of hillside work-sites.

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II. Study sites and Methods

1. Study sites

Five study sites were selected from two districts. Study sites, A, B and C, are located in Shirasaka working area of Tokyo University Forest at Seto City, about 20 km east of Nagoya City, Aichi Prefecture. Study sites, D and E, are located in a mountainous region, east of Iwamura Town, about 60 km east of Gifu City, Gifu Prefecture, Japan. Description of the general characteristics of the study sites are shown in Table 1. All of the study sites are underlain by granite. The mean annual temperatures and the mean annual precipitations are about 13 ℃ and 1800 mm at Seto (Research section of Tokyo University Forest, 1981, 1984 and 1987), about 11 ℃ and 1960 mm at Iwamura, respectively.

Table 1. General characteristics of study sites

Study sites	Lapsed years after hillside works	Bearings	Mean angles of slopes (degree)	Mean elevations (m)	Hillside works areas (m^2)	Main tree on hill-side work -sites	Main tree outside of circumferences and tree ages (year)
A	28	S20°E	40	560	1,800	Yamahannoki (*Alnus hirsuta* TURCZ. var.) *sibirica* SCHNEID.)	Hinoki(36) (*Chamaecyparis obtusa* SIEB. and ZUCC.)
B	29	N40°W	32	540	4,000	Yamahannoki (*A. hirsuta* var. *sibirica*)	Hinoki(46) (*C. obtusa*)
C	29	N50°W	35	320	300	Yamahannoki (*A. hirsuta* var. *sibirica*)	Hinoki(64) (*C. obtusa*)
D	32	N50°E	39	730	400	Yamahannoki (*A. hirsuta* var. *sibirica*)	Hinoki(56) (*C. obtusa*)
E	24	N60°E	40	720	400	Yamahannoki (*A. hirsuta* var. *sibirica*)	Hinoki(17) (*C. obtusa*)

The kinds of hillside works of the five study sites and their practical years were nearly identical, but their topographic factors were different as shown in Table 1. The hillside works were the planting of Yamahannoki (*Alnus hirsuta* TURCZ. var *sibirica* SCHNEID.) and covering the surface with straw mat. These hillside works were carried out in 1960. At sampling time, the forest floor were covered with Yamahannoki of about 15 m height and many species of bushes such as Aoki (*Aucuba japonica* THUNB.), Mizunara (*Quercus crispula* BLUME) and so on. Study site D was a hillside work-site on which wet masonry, log pilings, plantings, terracings with wood fagots and others were completed in 1957. Yamahannoki, Suzutake, and so forth were growing on this site.

Study site E was a hillside work-site on which log pilings, plantings, terracings with wood fagots, and so on were made in 1965. Yamahannoki and Harienju, black locust (*Robinia pseudoacacia* L.) were growing on the site. Vegetation was not dense, providing only about 50% cover. Coarse sand and small-size gravel covered the surface of the ground.

2. Study methods

First, two quadrates (1 m×1 m) were prepared at about the centers of the left and right halves of each hillside work-site. Five undisturbed-soil samples, using 100 cc cylindrical metal soil-samplers, were taken from the surface soils (0 to 5 cm deep from the surface) of each quadrate with the exception of A_0 horizon. Water contents of soil at sampling time and at pFs 1.8 and 2.7, porosities, and specific gravities of the samples were measured. Also disturbed-soil samples were collected from the surface soil of each quadrate for analyzing the total carbon and total nitrogen contents, grain-size distributions, and so forth. Furthermore, the thickness of each soil horizon was measured in the field, and the vegetation covers were recorded.

Next, two more quadrates of the same size were set outside of the left and right sides of the circumferences where were 2~3 m away from the boundaries of hillside work-sites. The measurements and samplings were done in the same manner as for the quadrates on the sites. Collected soil-samples from the surface soil were corresponding to the AB horizon on the hillside work-sites, and to the A horizon outside their circumferences (Fig. 1).

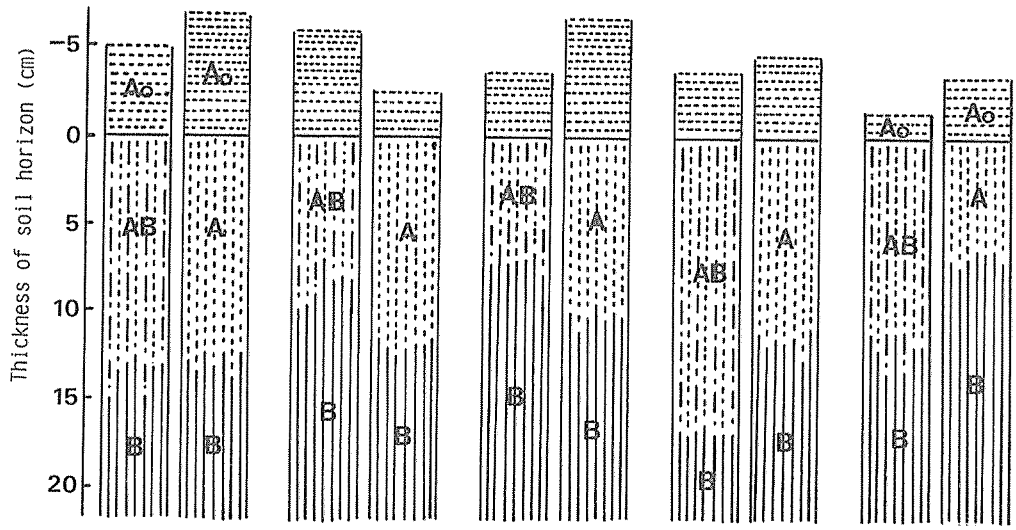

Fig. 1. Soil profiles of the study sites : left side, profiles on the hillside work-sites, right side, profiles outside their circumferences.

The soil samples were taken on study site A on November 9, 1988, on study site B on March 10, 1989, on study site C on September 26, 1989, on study site D on June 1, 1989, and on study site E on October 30, 1989.

Total carbon and total nitrogen contents, grain-size distributions, water contents of soils at sampling time and at pFs 1.8 and 2.7, porosities and specific gravities of the collected soil-samples were tested in accordance with Japanese Industrial Standard (JIS) and Japanese Society of Soil Mechanics and Foundation Engineering (JSF).

The total carbon and total nitrogen contents of soil were analyzed by using a C-N recorder, Yanaco MT 500. The method for analyzing the grain-size distribution was the sieving and hydrometer procedures. Sieving was used for segregating grains coarser than 0.074 mm, and the hydrometer method was applied for grain finer than 0.074 mm. The weight percentage of each grain size, corresponding to the meshes of the sieves and to the values of the hydrometer, was calculated and classified into coarse sand, fine sand, silt and clay.

The physical properties of 100 cc undisturbed-soil samples were analyzed as follows: after measuring the weight of 100 cc undisturbed-soil at each sampling time, the soil samples were saturated with water. In order to weigh soil samples at pF 1.0, a column of 7.5 cm high was made by a fine quartz sand on the free-water surface. The free-water surface was raised slowly to the surface of the column until it was saturated with water. Next, each saturated soil-sample was put on the saturated column, and the moisture in the sample was equilibrated to that of the column. The free-water surface was reduced to a level at which the soil-moisture tension was equivalent to pF 1.0. After keeping each soil sample on the column for one day, the weight of soil sample at pF 1.0 was measured. At pFs 1.8 and 2.7, the weights of soil samples were measured when the water contained in the pores was expelled under a pressure equivalent to pFs 1.8 or 2.7 in a closed chamber (Multi-Fold pF meter, DIK-9210). After keeping the soil samples in the chamber for two days at pF 1.8 (for three days at pF 2.7), the weights of the soil samples were thus measured. Dry weights were obtained after drying the soil samples in an oven at 105 ℃ for 24 hours. The weights of soil samples saturated with water were calculated by the weights of the soil samples at pF 1.0 and by their porosities. The porosities of undisturbed-soil samples were to represent the differences between the saturated and dried weights of the soil samples. Specific gravity in this paper is the oven-dried weight divided by the volume of dried soil.

III. Relations of soil properties

The vegetation of the hillside works supplies organic matter to the soils on the ground. The fallen leaves are decomposed by microorganism. Thus, the carbon has gradually accumulated in the soil with the lapsed years after hillside works. Changes in total carbon and total nitrogen contents of soil are to indicate typical chemical properties with respect to the forest soil. In the following, the total carbon as related to the other soil properties were discussed.

Fig. 2 indicates a relationship between the total carbon contents *versus* the total nitrogen contents of soil inside hillside work-sites and outside their circumferences. This result showed that the nitrogen contents of soil had positive correlation with the carbon

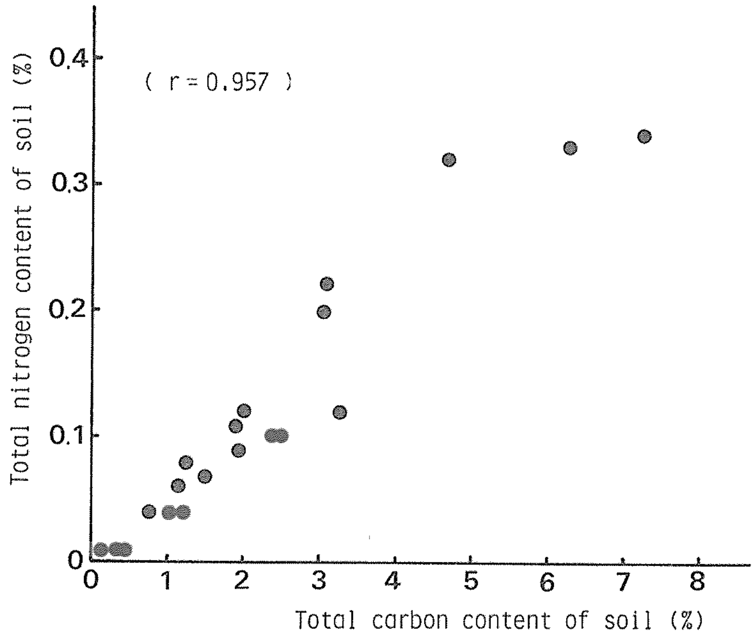

Fig. 2. Relationships between the total carbon contents and the total nitrogen contents of soil.

contents. On the other hand, the total carbon contents of soil indicated a converse relationship with the specific gravities of soil (Fig. 3).

Water-holding capacity is an important factor which is related to porosity, pore-size distribution, and other properties of soil. ARMSON (1977) states that the net effect of formative process of soil showed an increase in porosity. Fig. 4 indicates a positive correlation between the total carbon contents and the porosities of soil. Furthermore, the relative proportion of particles in soil smaller than 0.074 mm in diameter increased with the time after the hillside works because of weathering process. Fig. 5 indicates a relationship between the porosities and the fine fraction of soil. Judging from this figure, the fine particles contained in soil increased as the porosities of soil increased.

The water contained in soil can be of three kinds. First, is the hygroscopic water which is absorbed forming thin films on the surfaces of soil particles at pFs 4.5~7. Second, is capillary water which is held at pFs 1.8~4.5 in capillary pores and is available for plant growth. Third, is gravitational water held at less than pF 1.8 and which moves gravitationally in the coarse pores of soils. Among them, one part of capillary water in term of gravitational capillary water (pF 1.8~2.7) and gravitational water (pF 0~1.8) volumes are useful to evaluate the water-holding capacity.

The precipitation which had affected the water contents of soil at sampling time was 10 mm in the study site A for four days before sampling, 30 mm in the study site B for

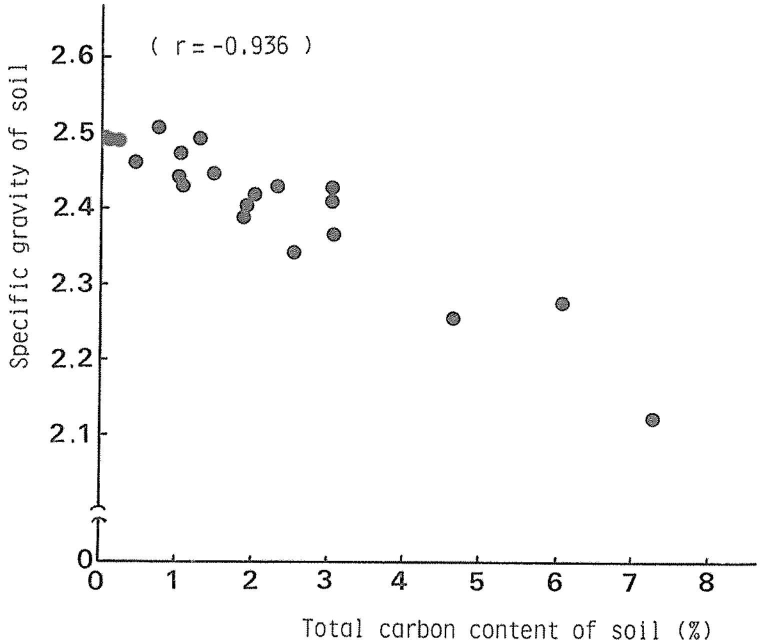

Fig. 3. Relationships between the total carbon contents and the specific gravities of soil.

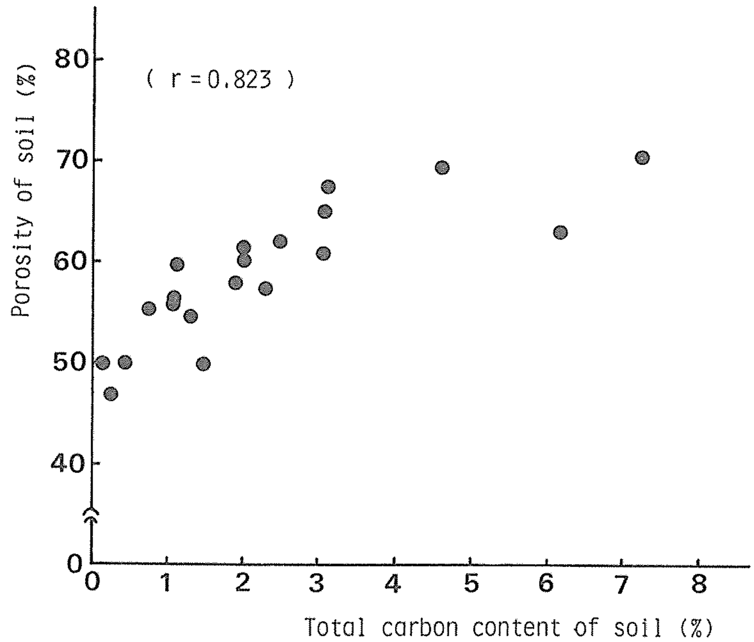

Fig. 4. Relationships between the total carbon contents and the porosities of soil.

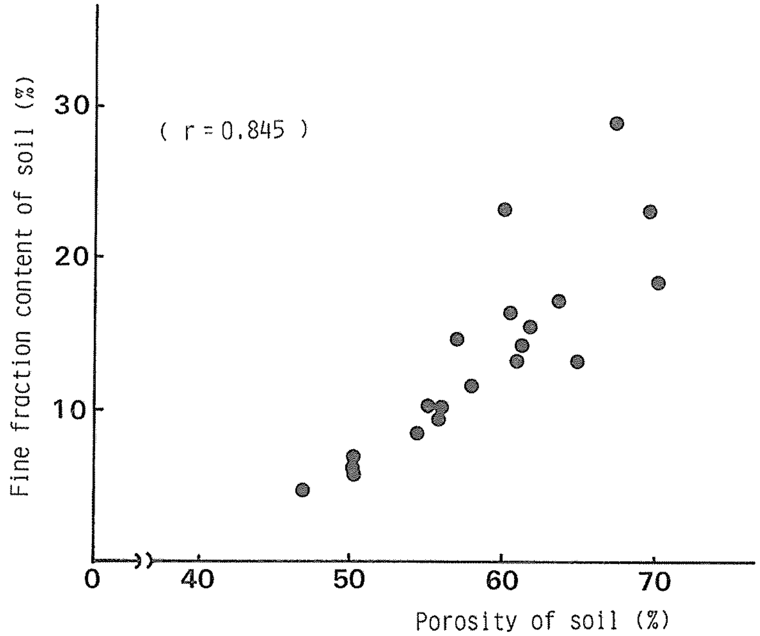

Fig. 5. Relationships between the porosities and the fine fraction contents of soil.

five days before sampling, 42.5 mm in the study site C for four days before sampling, 18.5 mm in the study sites D for four to five days before sampling, and 19.0 mm in the study sites E for ten days before sampling.

Field capacity of soil is one of the important factors which relate to water holding-capacity. This index has been defined as the moisture status of a soil two to three days after it has been saturated and free drainage has virtually ceased (ARMSON, 1977). It was supposed that the gravitational water of the study sites might have drained away from the surface soil. Therefore, water-holding capacity in this study can be estimated by the water contents of soil at sampling time. Fig. 6 indicates a relationship between the porosities of soil and the water contents at sampling time. This result indicates that water contents of soil at sampling time increased with enlarged pore space.

Figs. 7 and 8 indicate relationships between the degree of saturation of soil at pF 1.8 and non-capillary and capillary pore volume of soil. The degree of saturation at pF 1.8 had a negative relation with the non-capillary pore volume and a positive relation with the capillary pore volume of soil. It is suggested that the fine pore has increased as the fine fraction (silt and clay) contents of soil got abundant, that means, the weathering has advanced. There are many factors to evaluate the chemical and physical properties of soil as above-mentioned. Correlation coefficients of these factors were given in Table 2. Many factors in Table 2 had close relations with each other. Among them, the total carbon contents of soil and the degree of saturation of soil at pF 1.8 were the most effective factors related to the other properties of soil. These factors represented the soil properties related to the topographic factors as discussed in the following.

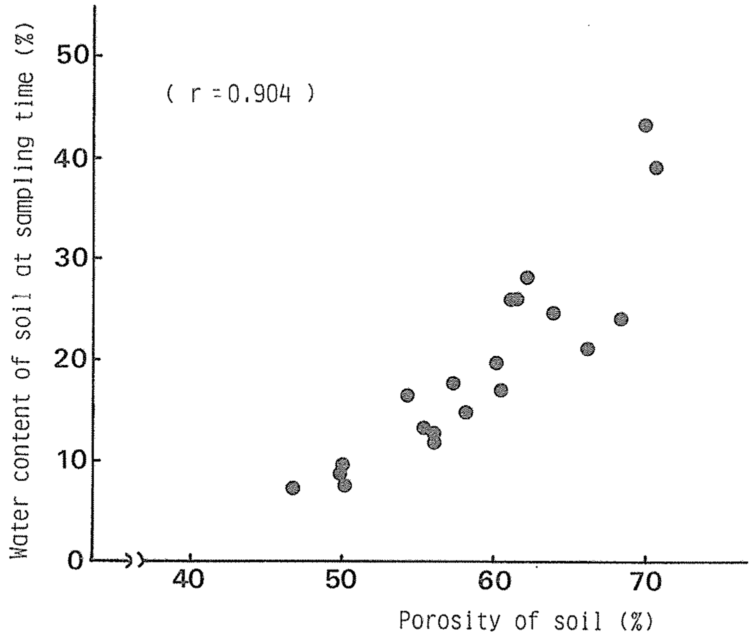

Fig. 6. Relationships between the porosities and the water contents of soil at sampling time.

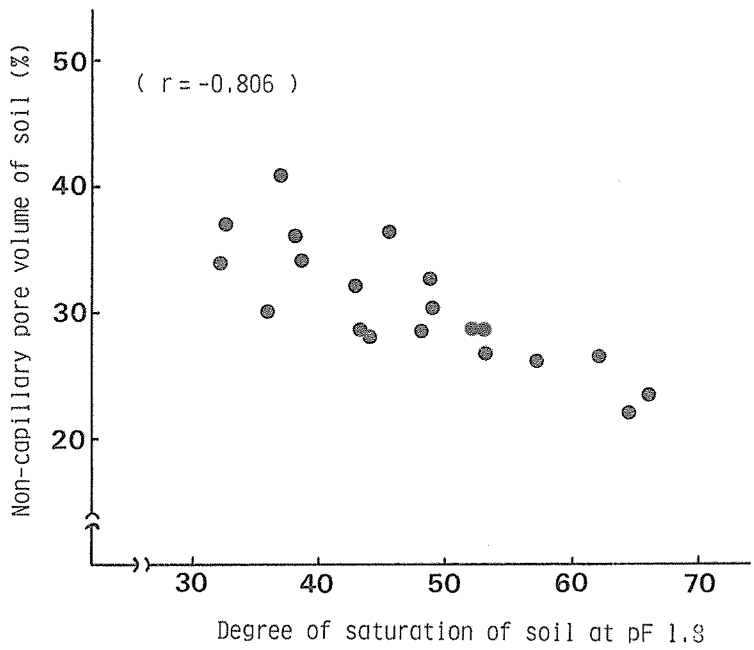

Fig. 7. Relationships between the degree of saturation at pF 1.8 and the non-capillary pore volume of soil.

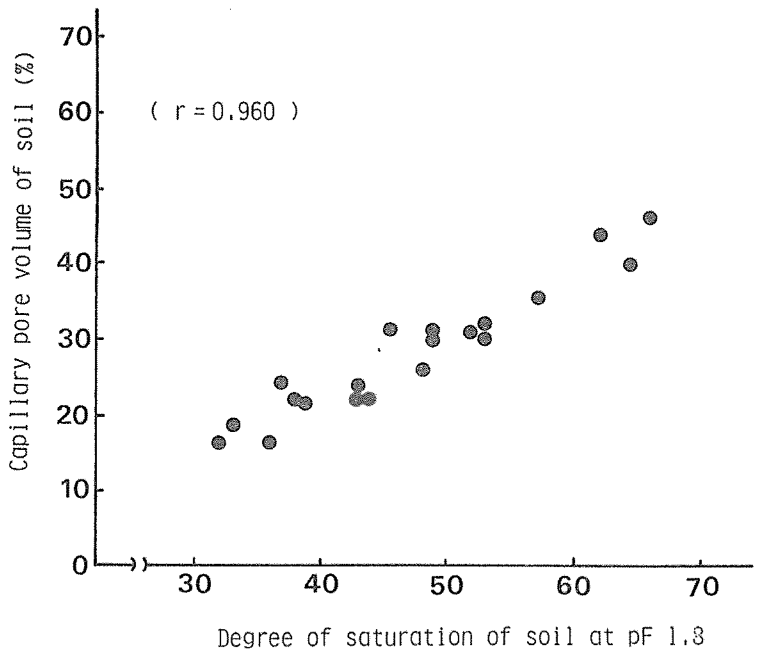

Fig. 8. Relationships between the degree of saturation at pF 1.8 and the capillary pore volume of soil.

Table 2. Correlation coefficients of soil properties

	Carbon	Nitrogen	Porosity	Non-capillary pore	Coarse pore	Capillary pore	Degree of saturation at pF 1.8	Degree of saturation at pF 2.7	Water content at sampling time
Carbon	+1.000	+0.957	+0.823	−0.177	+0.745	+0.806	+0.601	+0.725	+0.828
Nitrogen		+1.000	+0.812	−0.141	+0.717	+0.780	+0.565	+0.697	+0.839
Porosity			+1.000	−0.067	+0.820	+0.846	+0.636	+0.747	+0.904
Non-capillary pore				+1.000	−0.626	−0.486	−0.806	−0.559	−0.401
Coarse pore					+1.000	+0.940	+0.960	+0.906	+0.936
Capillary pore						+1.000	+0.874	+0.982	+0.960
Degree of saturation at pF 1.8							+1.000	+0.861	+0.817
Degree of saturation at pF 2.7								+1.000	+0.900
Water content at sampling time									+1.000

IV. Soil properties and topographic factors

The chemical and physical properties of forest soils have been developed through a long term after the hillside works depending on the environmental conditions of each site. The soils on the hillside work-sites is expected to develop towards the forest soils outside their circumferences with time. Therefore, the relationships between the topographic factors of study sites *versus* the chemical and physical properties of surface soil in the hillside work-sites and outside their circumferences were discussed.

1. Relations of altitudes and soil properties

The effects of altitude on soil properties were rather clear in Fig. 9 that showed some positive relationships between the altitudes of the study sites and the total carbon contents of soil in the hillside work-sites and outside their circumferences. It is supposed that the soil at high altitude area is affected by the weathering action due to the soil freezing in investigated range of altitude. This action might be due to the low temperature on the study sites. According to COOPER (1960) who cited HOCKENSMITH and TUCKER (1933) that they showed soil nitrogen increased with altitudes where temperatures were cooler.

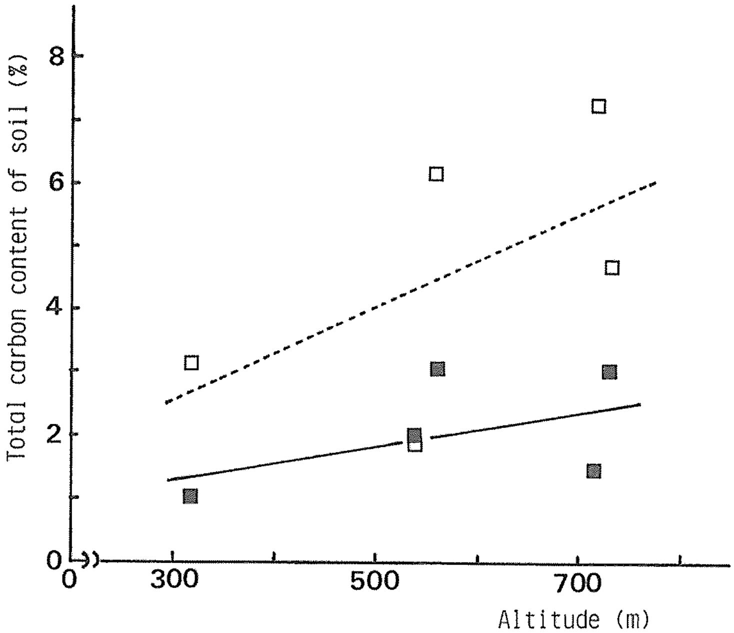

Fig. 9. Relationships between the total carbon contents of soil and the altitudes
Legend : ■, Hillside work-sites,
□, Outside their circumferences.

Fig. 10 indicates the mean values of air, soil and minimum air temperatures in fifteen years (1966-1980) at gauging station of Tokyo University Forest at Seto (Research section of Tokyo University Forest, 1981, 1984 and 1987). This station is located at about 300 m above sea level. According to this figure, mean air temperature on the ground surface and mean soil temperature showed almost the same sequence of change. These temperatures are applied to the study site C which located at about 320 m above sea level. It can be estimated that the air temperature decreases 0.6 ℃ in every 100 m of altitude above sea level. It is sure that the air temperature and soil temperature in winter reached degrees below zero in higher altitudes of the study site, and the surface soil has been weathered by freezing and thawing with attendant hydration, dehydration and particle breakdown. Therefore, fine particle of soil and fine pore volume increased and total carbon and total nitrogen of soil were accumulated in the soil.

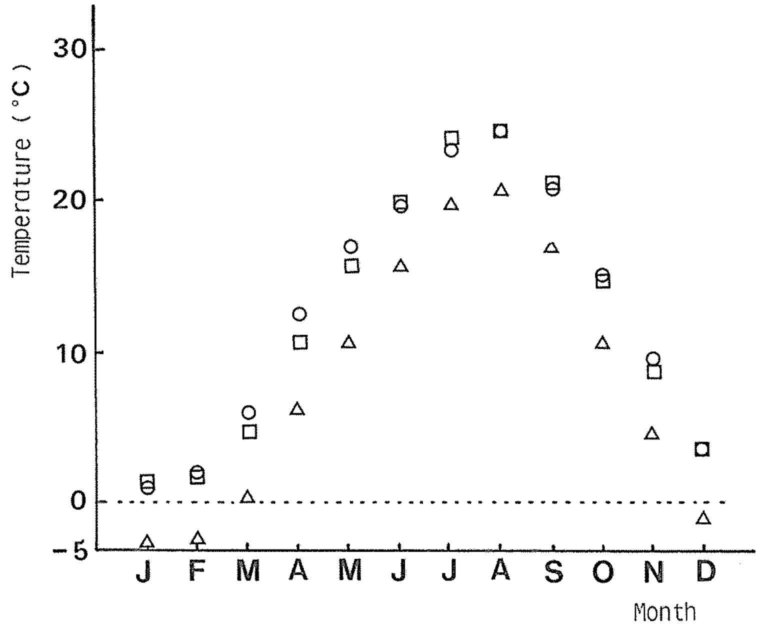

Fig. 10. Monthly mean temperatures
Legend : ○, Air temperature,
□, Soil temperature (at 10 cm depth from surface ground),
△, Minimum air temperature.

The relationship between the altitudes of study sites and the degree of saturation of soil at pF 1.8 in Fig. 11 followed the same trend as in Fig. 9. It means that the water-holding capacity was excellent in accordance with high altitude. It is considered important that the altitude on microtopography may affect weathering process of soil.

2. Relations of bearings and soil properties

The higher soil temperatures and cycles of freezing and thawing and of wetting and

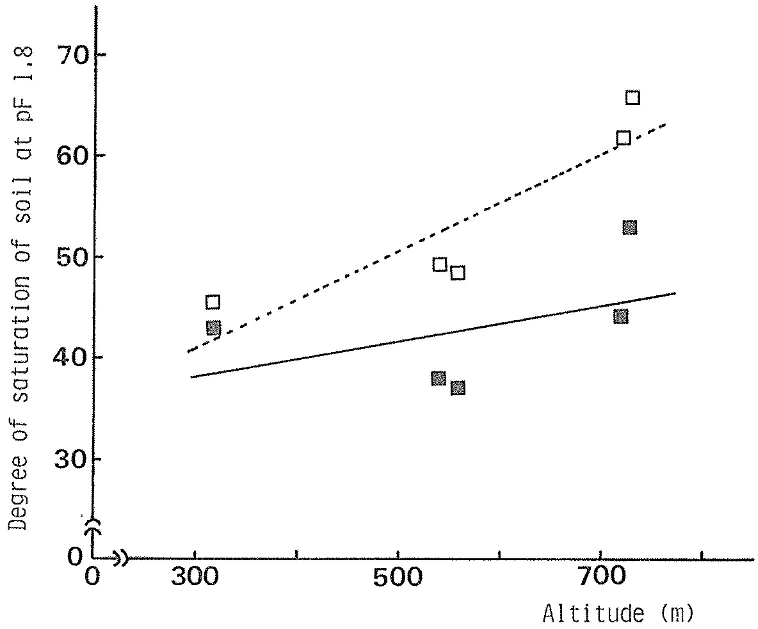

Fig. 11. Relationships between the degree of saturation of soil at pF 1.8 and the altitudes
Legend : ■, Hillside work-sites,
□, Outside their circumferences.

drying that occur on south slopes promote greater chemical and biotic weathering (COOPER, 1960). FINNEY *et al.* (1962) also reported that organic matter were apparently decomposed more rapidly in the comparatively extreme climate of southwest-facing slope. Figs. 12 and 13 show relationships between the deflection angles from north and the total carbon contents of soil, and the degree of saturation of soil at pF 1.8.

The duration of potential solar-radiation from sunrise to sunset on the north-facing and the south-facing slope with slope angle 30° was calculated by an equation which OZAWA (1962) reported. The values in Fig. 14 are to indicate the duration of potential solar-radiation from sunrise to sunset on the fifteenth day of every month in latitude 35 degrees north. According to Fig. 14, the annual duration of potential solar-radiation on the north-facing slope is about 90 % of the south, but it is about 50 % in winter. It is judged therefore that organic matter on the south-facing slope was better decomposed than the north, and the total carbon contents of soil on the south-facing slope were more abundant than those on the north.

Fig. 13 means that the degree of saturation of soil on the south-facing slope is lower than that on the north. It is supposed that the surface soil on the south-facing slope was too soft to retain the water depending on the frequent repetition of the freezing and thawing.

In studying chemical and physical properties of soils, almost all of the results in the hillside works sites were rather poor than those in their circumferences (Figs. 9, 11~13). It indicates that about the 30 years of hillside works are not enough for the soil genesis.

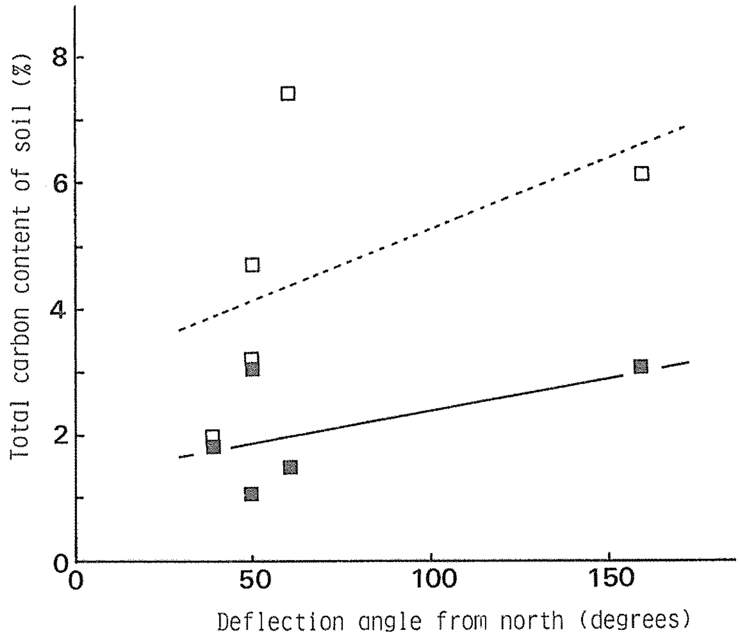

Fig. 12. Relationships between the total carbon contents of soil and the deflection angles from north

Legend : ■, Hillside work-sites,
□, Outside their circumferences.

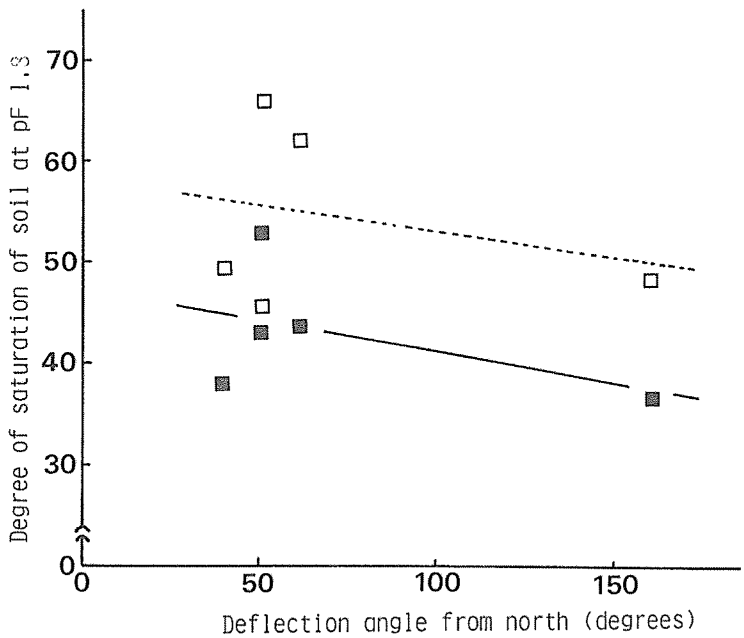

Fig. 13. Relationships between the degree of saturation of soil at pF 1.8 and the deflection angles from north

Legend : ■, Hillside work-sites,
□, Outside their circumferences.

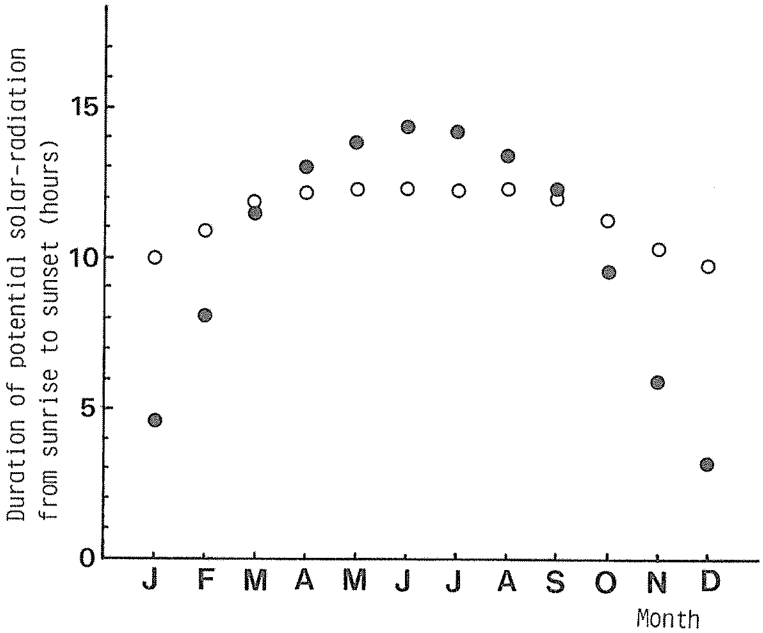

Fig. 14. Duration of potential solar-radiation from sunrise to sunset on a slope.
Legend : ●, North-facing slope,
○, South-facing slope.

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山腹工事施工地における土壌の性質と地形要因

アルンシリ　カムラン・竹田泰雄・戸松　修・田中隆文・桜井清人

約30年前に山腹工事が施工された山腹斜面およびその周辺部の土壌について，土壌の物理的および化学的性質について調査した。これらの施工地は施工年および施工種はほぼ同一であるが，斜面の方位や標高など地形的要因は異なる。そこで，斜面の方位や標高と施工地の土壌化について検討した。土壌化における標高の影響については，調査範囲内では高標高地域での炭素含有量が多く，また水分保持容量も高いことが示された。また，南向きに近い斜面の表層土壌の方が北面よりも炭素含有量が多く，これらの原因として冬期における土壌の凍結の影響や有機物の分解に関係する可能日照時間の違いが考えられた。