J. Fac. Agr. Hokkaido Univ., Vol. 66, Pt. 1 : 37~49 (1994)

# NUMERICAL LANDFORMS AND SOIL PHYSICAL PROPERTIES IN WESTERN TOKACHI PLATEAUS

**Masao YAZAWA, Takuya KUMAHARA* and George Kwabena KYEREME***
Laboratory of Agricultural and Forestry Land Information,
*Laboratory of Soil Amelioration,
Faculty of Agriculture, Hokkaido University
Sapporo, 060 Japan
(Received October 4, 1993)

## Introduction

The Tokachi district in Hokkaido has well-developed plateaus (terraces). The classification and naming of these plateaus were reported by Kikuchi et al.[2] and the Tokachi Research Group[7]. According to these reports, in the Tokachi district there are five plateau surfaces with different formation periods and altitudes. They qualitatively analyzed the geomorphological characteristics of these plateaus on the basis of topographic maps and concluded that the higher the altitude, the stronger is the dissection of a plateau.

The distribution, classification and properties of agricultural soils on the plateaus were reported by Seo et al.[6] and Kikuchi et al.[2]. In this district most agricultural soils are made up of different layers of volcanic ash. Seo et al.[6] classified the volcanic ash soils on the plateaus into two, dry-type and wet-type based on drainability, but the quantitative difference in geomorphological characteristics between the two soil types on the same plateau surface were not made clear.

The purpose of the present study is to quantitatively clarify geomorphological properties of some plateaus in the western part of Tokachi district and the geomorphological differences between the dry-type and the wet-type soils, and finally to show the physical difference between these soil types.

## Methods

### 1. Objective area

The area investigated, included in the topographic map "Shintoku" (scale : 1/50,000, Geographic Survey Institute), measures ca. 20×15km along N-S and E-W directions respectively. This area has five plateaus[2] with different average altitudes as shown in Fig. 1. To the west of the Tokachi River, there are two plateaus, Sahoro and Kuttari, and to the east, there are three, Nakakumaushi,

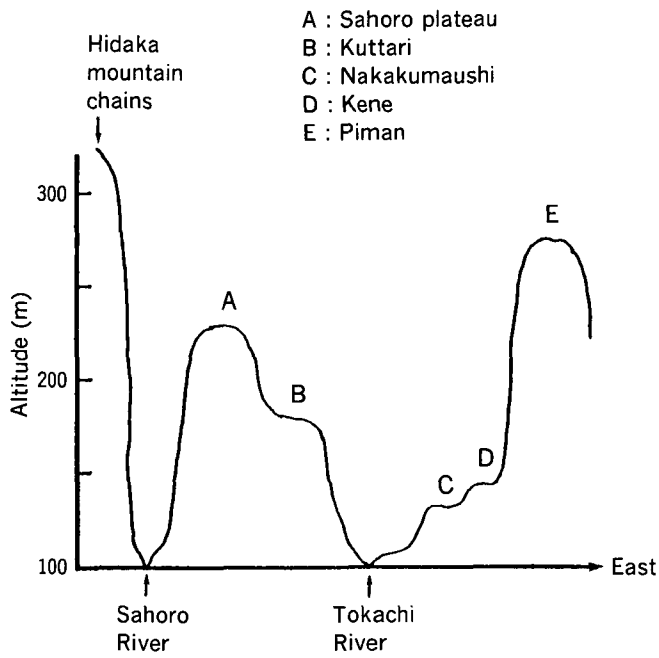


**Fig. 1** Outline of plateaus for objective area

Kene, and Piman, decreasing in average altitude in the order Piman > Sahoro > Kuttari > Kene > Nakakumaushi.

To find the areal distribution of these plateaus, a perspective image for this area is drawn by using a digital elevation file, which is part of the Digital National Land Information (Geographic Survey Institute)[5], as shown in Fig. 2. Sahoro shows a definite gap in altitude between the northern and southern parts. It can therefore be divided into two sub-plateaus[3] : the northern part, Kami-sahoro, is higher than the southern part, Shimo-sahoro. In this study, therefore, the investigation was made on the five plateaus and the two sub-plateaus. Among them, Nakakumaushi and Kene have the lowest areas compared to the others. In addition, the difference in average altitude between the two plateaus is small (about 10m). Therefore, the border between the two plateaus is not clear (Fig. 2).

The distribution of dry- and wet-type soils on each plateau was read by tracing a soil map[6].

## 2. Geomorphometry

For the analysis of numerical landforms, the digital elevation model[5] of the Digital National Land Information (Geographic Survey Institute) was used. The grid aperture of this model is about 231.4m in N-S direction and about 254.8m in E-W direction for the surveyed area, which has about 4,300 grid points given each

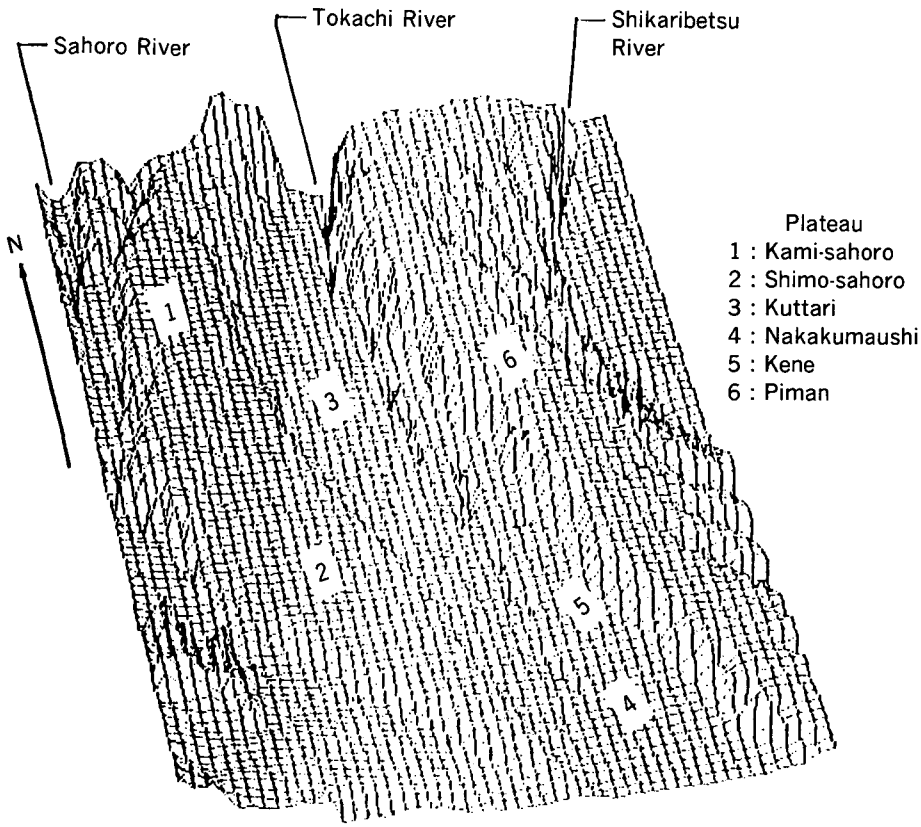


**Fig. 2** Perspective image of plateaus

elevation value. Calculated numerical landforms are, average altitude, relief, slope (degree of inclination), and Laplacian. Apart from altitude, the other three landforms are determined from the relations between one grid point, (p), and its eight surrounding points as shown in Fig. 3. The calculations adopted are as follows[4] :

(1) Altitude : Averaged elevation value for nine grid points.

(2) Relief : Difference between the maximum elevation and the minimum elevation among nine grid points.

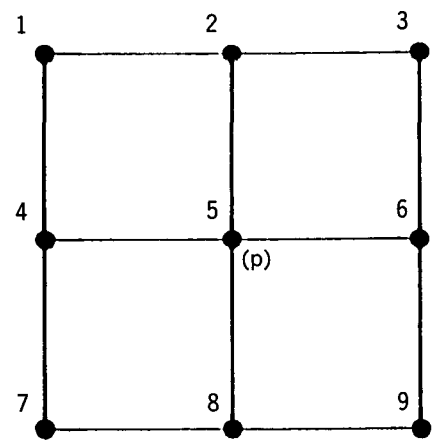


**Fig. 3** Configuration of grid points for geomorphometry

(3) Slope (degree of inclination, $\theta$) :

$$\theta = \tan^{-1}(\sqrt{A^2+B^2}/243)$$

where A stands for the elavation difference between grid points 5 and 2, and B for that between grid points 5 and 6 ; and 243 is average grid aperture.

(4) Laplacian (L) : If a, b, c, d, and e are the elevation values at the grid points 2, 4, 6, 8, and 5, respectively,

$$L = (a+b+c+d-4e)/243^2$$

### 3. Measurement of soil physical properties

To clarify the physical differences between the dry- and the wet-type soils on each plateau, dry density, degree of saturation, saturated hydraulic conductivity, organic matter content, and particle-size distribution were measured. A representative soil profile for each soil type on each plateau was selected (twelve profiles in all), surveyd and sampled in August, 1991. Dry density, degree of saturation, and saturated hydraulic conductivity were measured by using three undisturbed soil samples (100cm$^3$ cylindrical sampler) for each soil layer. Organic matter content was measured by the carbon ignition method, and in the measurement of particle-size distribution, the acid dispersion method[8] for volcanic ash soils and the hydrometer method were used.

## Results and Discussion

### 1. Numerical landforms of plateaus

Averaged numerical landforms of each plateau are shown in Table 1. The altitude was obtained by averaging all grid points included in each plateau. But the adoption of the same method for the relief, slope and Laplacian resulted in a serious noise effect due to the outside grid points that are included in the terrace cliff or intrusive ravine. Therefore the upper limit value of relief for each plateau was set, and the grid points whose relief are within the upper limit were used for the calculation of the average relief, slope and Laplacian. These upper limit values of relief were determined by reading the maximum change of contour line per unit length for each plateau on the topographic map. These upper limit

**Table 1.** Numerical landforms of plateaus

| Plateau | Altitude (m) | Relief (m) | Slope (degree) | Laplacian ($\times 10^{-5}$) |
|---|---|---|---|---|
| Kami-sahoro | 263 | 13 | 1.3 | −2.9 |
| Shimo-sahoro | 194 | 7 | 0.6 | 0.2 |
| Kuttari | 180 | 4 | 0.4 | −0.2 |
| Nakakumaushi | 132 | 5 | 0.5 | 1.3 |
| Kene | 143 | 10 | 0.8 | 1.7 |
| Piman | 275 | 19 | 2.0 | −4.2 |

values are 30, 20, 10, 10, 20 and 40m for Kami-sahoro, Shimo-sahoro, Kuttari, Nakakumaushi, Kene and Piman, respectively. The effect of outside grid points on the averaged altitude was negligible.

The altitude in the survey area usually increases from south to north, as is evident from Fig. 2. Therefore, the difference in altitude between Kami-sahoro and Shimo-sahoro is large. This tendency is apparent in a box and whisker chart (Fig. 4) giving statistical values of altitude. As shown in Fig. 4, Piman and Kuttari have larger standard deviations and ranges, compared to the others. This can be explained by the fact that the two plateaus are more extensive in N-S direction than the others.

The relief and slope are indices of the flatness of a plateau, and are nearly in a straightline relation (Fig. 5). The plateaus with large relief and slope are Piman and Kami-sahoro, which are the highest, being over 200m in altitude. On the other hand, the plateaus with small relief and slope are Kuttari and Nakakumaushi, which are located along the shores of the Tokachi River. Therefore, it is confirmed that, as the altitude of a plateau increases, flatness is lost and the dissection is more pronounced.

Laplacian is regarded as an index of slope form. A positive sign corresponds to a concave slope, negative sign to a convex slope, and zero to a straightline slope. The plateaus with clear convex slope are Piman, Kami-sahoro and

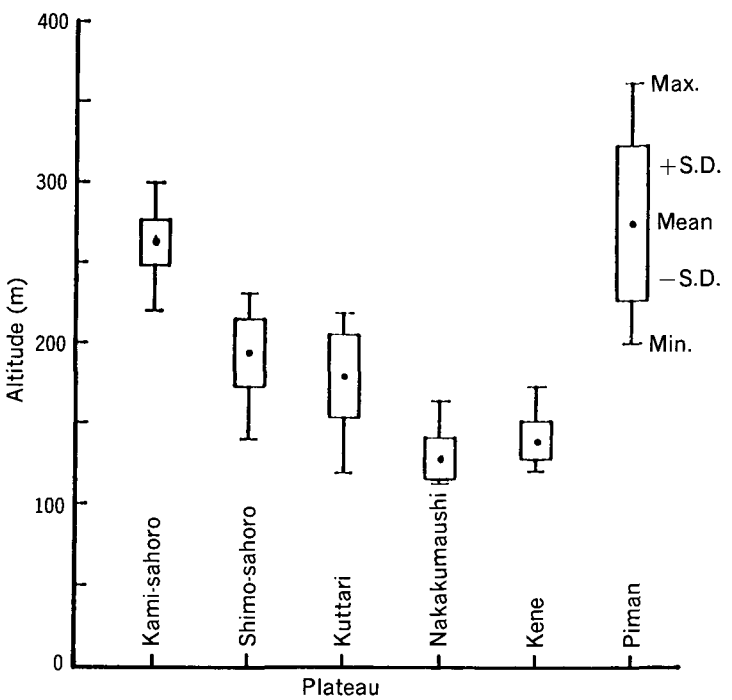


**Fig. 4** Box and whisker chart for statistical values of altitude (S.D. : standard deviation)

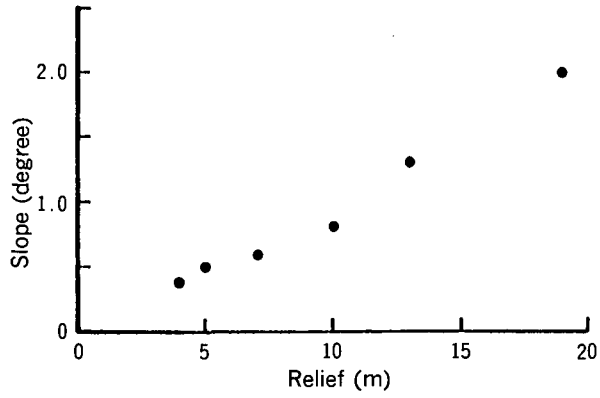


**Fig. 5** Relations between relief and slope

Kene. Apart from Kene, the other plateaus are high and have no neighboring upper plateaus. Nakakumaushi has a clear concave slope, and it is the lowest plateau. On the other hand, Shimo-sahoro and Kuttari show a nearly straight-line slope, and are intermediate in altitude. It is therefore obvious that the slope form has a close connection with the altitude of plateaus.

## 2. Distribution and numerical landforms of dry- and wet-type soils

The distribution of dry-type and wet-type soils on each plateau is shown in Fig. 6 as a mesh map. A symbol in the figure represents a mesh with the size of 231.4×254.8m along N-S and E-W directions, respectively. Table 2 shows the distribution rate of each soil type per total mesh numbers on each plateau.

First, let us look at the outline of distribution of the soil types. On Kami-sahoro, the wet-type (34%) is distributed in a lump to the north, and the dry-type usually surrounds the wet-type.

The wet-type of Shimo-sahoro shows the greatest distribution rate (44%) among the plateaus, and mostly distributed along the boundary line with the upper plateau Kami-sahoro. The dry-type is usually distributed at the edge of the plateau.

The wet-type on Kuttari (36%) is distributed as on Shimo-sahoro, that is, along the boundary line with Kami-sahoro and Shimo-sahoro which are the

**Table 2.** Distribution rate of dry-type and wet-type soils

| Plateau | Numbers of total mesh | Dry-type (%) | wet-type (%) |
|---|---|---|---|
| Kami-sahoro | 235 | 66.0 | 34.0 |
| Shimo-sahoro | 487 | 55.9 | 44.1 |
| Kuttari | 504 | 63.9 | 36.1 |
| Nakakumaushi | 175 | 84.6 | 15.4 |
| Kene | 143 | 67.1 | 32.9 |
| Piman | 793 | 63.3 | 36.7 |

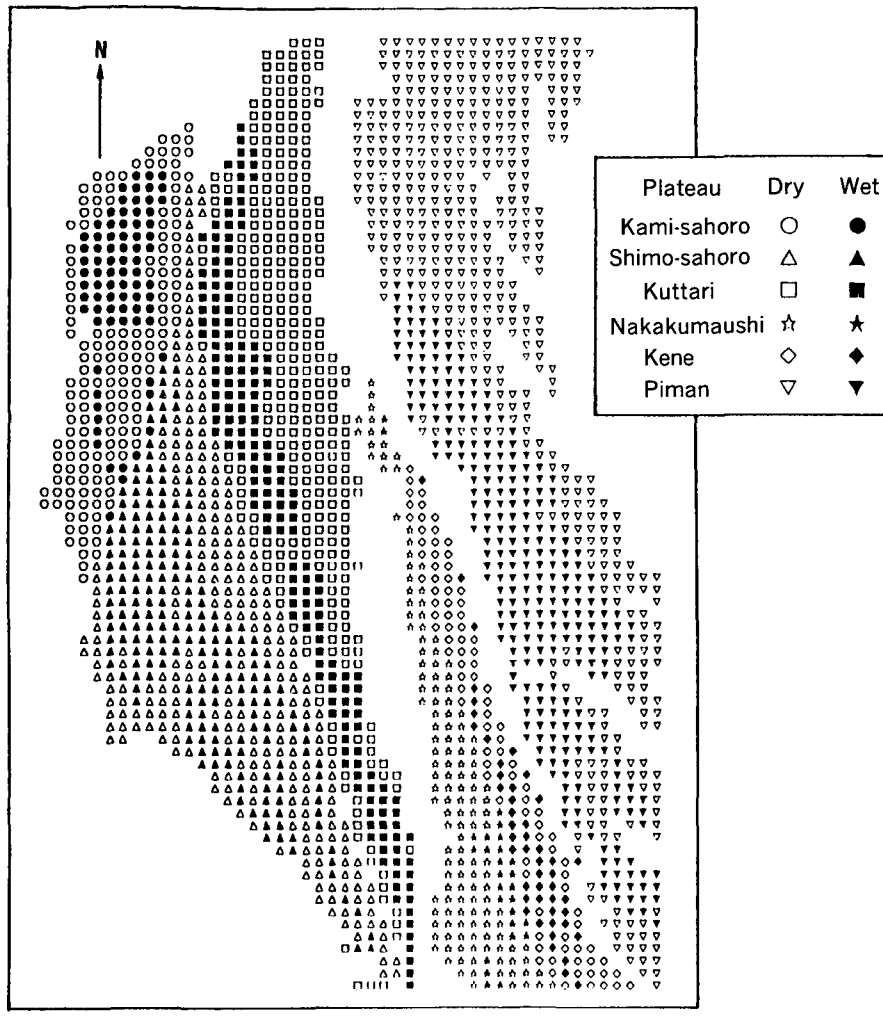


**Fig. 6** Mesh map for the distribution of dry- and wet-type soils

neighboring upper plateaus. In contrast to this, the dry-type is distributed along the shore of the Tokachi River.

The wet-type on Nakakumaushi shows the least distribution rate (15%), and the greater part is along the boundary line with the upper plateau Kene. The dry-type is distributed along the Tokachi River as on Kuttari.

On the plareau Kene, the wet-type is not necessarily distributed at the east side along the upper plateau Piman. This seems due to the presence of sharp terrace cliffs and some small wet fans[6] between Kene and Piman, the two plateaus being not continuous.

In case of Piman, the greater part of dry-type is distributed to the north with higher altitude, the wet-type soils (37%) being distributed from the center towards

the south.

All this shows that the distribution of dry-type or wet-type depends on the situation of each plateau ; however, for plateaus that have a neighboring upper plateau, the wet-type soils tend to be distributed along the boundary line with the upper plateau.

Next, the numerical landforms in the two soil types are compared (Table 3). It can be seen that the difference in altitude between the soil types is due to

**Table 3.** Numerical landforms of dry-type and wet-type soils

| Plateau | Altitude (m) | | Relief (m) | | Slope (degree) | | Laplacian ($\times 10^{-5}$) | |
|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| Kami-sahoro | 261 | 268 | 15 | 12 | 1.4 | 1.3 | −7.5 | 1.7 |
| Shimo-sahoro | 193 | 196 | 6 | 7 | 0.5 | 0.6 | −1.7 | 1.5 |
| Kuttari | 184 | 172 | 4 | 4 | 0.4 | 0.4 | −0.8 | 0.7 |
| Nakakumaushi | 133 | 127 | 5 | 6 | 0.5 | 0.6 | 1.1 | 2.4 |
| Kene | 146 | 137 | 11 | 9 | 0.8 | 0.7 | −3.1 | 0.3 |
| Piman | 291 | 247 | 22 | 14 | 2.4 | 1.4 | −3.6 | −4.9 |

the soil locations on each plateau.

Piman, Kami-sahoro and Kene show a clear difference in relief between the soil types, the relief of their dry-types are larger than that of the wet-types. This shows that, at least in the cases of these plateaus, the dry-types are distributed at the places that received larger dissection than the wet-types. As for the slope, on the other hand, only the dry-type of Piman is clearly larger than the wet-type.

The Laplacian shows most clearly the difference between the soil types. In the cases of Kami-sahoro, Shimo-sahoro, Kuttari and Kene, all the dry-types have the negative signs (convex slope), and all the wet-types have the positive signs (concave slope).

### 3. Soil physical properties

The basic difference between the soil types is drainability. Therefore, a few physical properties related to drainability are compared and discussed. However, because only one soil profile for each soil type on a plateau is used, the comparison is restricted to obtain the general tendency.

The profiles of dry density ($\rho_d$) is shown in Fig. 7. In order to facilitate the comparison, two broken lines are drawn in the figure, one corresponding to $\rho_d = 0.6$ and the other to $\rho_d = 1.0$. The relations between soil types and three dry density zones formed by the broken lines are as follows :

(1) $\rho_d < 0.6$ : All symbols are for the wet type.

(2) $0.6 \leqq \rho_d < 1.0$ : The wet types tend to be distributed close to $\rho_d = 0.6$ and the dry types close to $\rho_d = 1.0$.

(3) $\rho_d \geqq 1.0$ : At deeper layers, there are a few wet type symbols which clearly exceed $\rho_d = 1.0$.

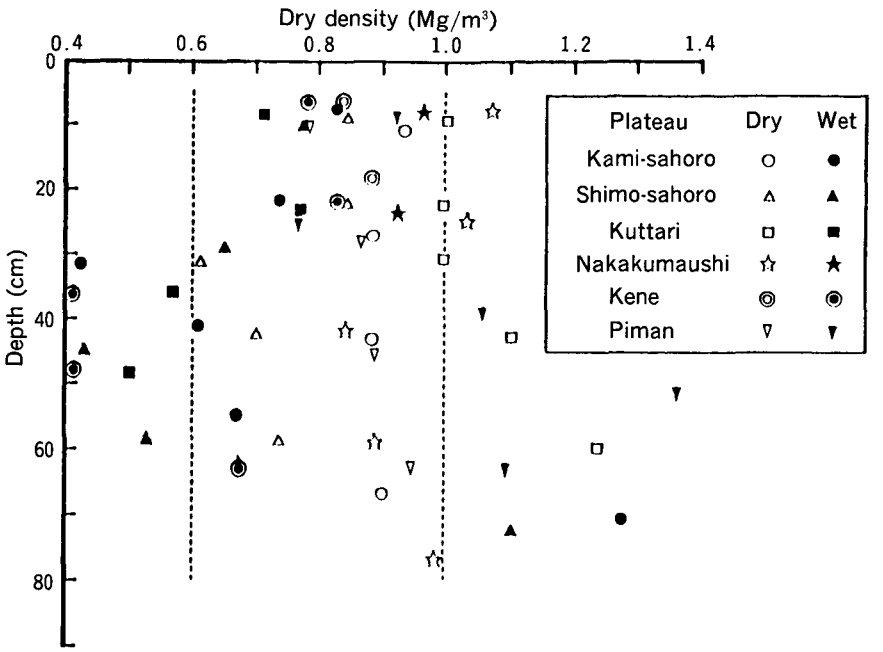


**Fig. 7** Profiles of dry density ($\rho_d$)

These results show that the wet types generally have a smaller dry density than the dry types. However, some deep layers of the wet types may show very large dry densities- possibly the cause of poor drainage.

Fig. 8 shows the profiles of saturation degree ($S_r$). The soil was sampled twice at an interval of about two weeks, therefore no strict comparison of $S_r$ has been possible. However, since the sampling for the two soil types on the same plateau were done on the same day, it is possible to obtain a general tendency. In the figure, two broken lines are also drawn, this time at $S_r=70\%$ and $S_r=90\%$.

(1) $S_r<70\%$ : The symbols for the dry types are clearly more than for the wet types.

(2) $70\leqq S_r<90\%$ : Rather similar to (1).

(3) $S_r\geqq 90\%$ : Mostly the the wet types.

Clearly the wet types have higher $S_r$ than the dry types, but a higher $S_r$ is a result of poor drainage, not a cause.

Fig. 9 shows the profiles of saturated hydraulic conductivity ($K_{15}$). If the soil layers with $K_{15}$ under $10^{-4}$ cm/s (broken line) are regarded as poorly permeable, then these wet type soils exist because of their poor permeable layers. This is because majority of the symbols located at the left side of the broken line are the wet type soils. On the other hand, for wet types where $K_{15}$ is over $10^{-4}$ cm/s, it may be concluded that their poor drainage is due perhaps to concave slope, a geomorphologacal factor.

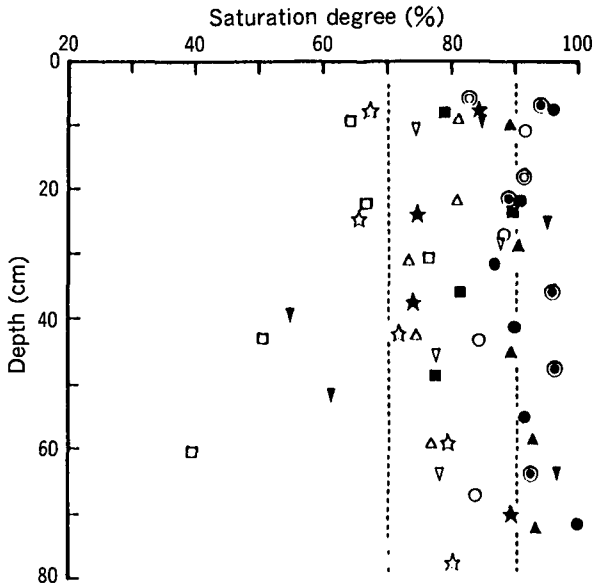


**Fig. 8** Profiles of saturation degree ($S_r$) (Symbols are the same as Fig. 7)

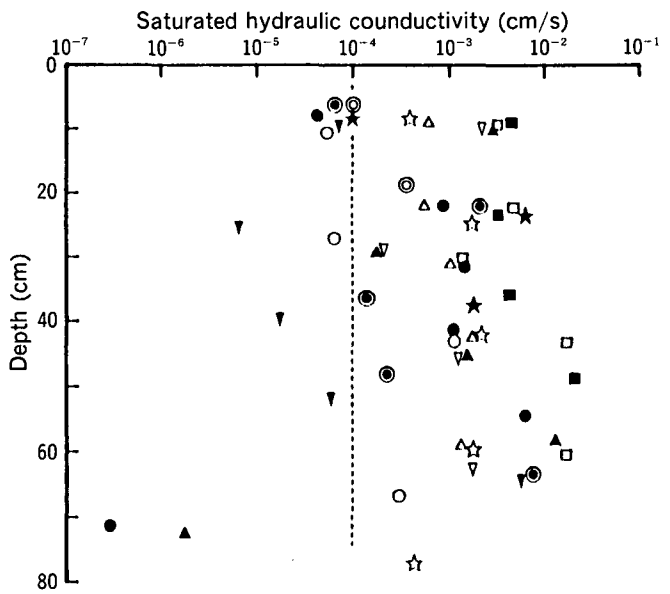


**Fig. 9** Profiles of saturated hydraulic conductivity ($K_{15}$) (Symbols are the same as Fig. 7)

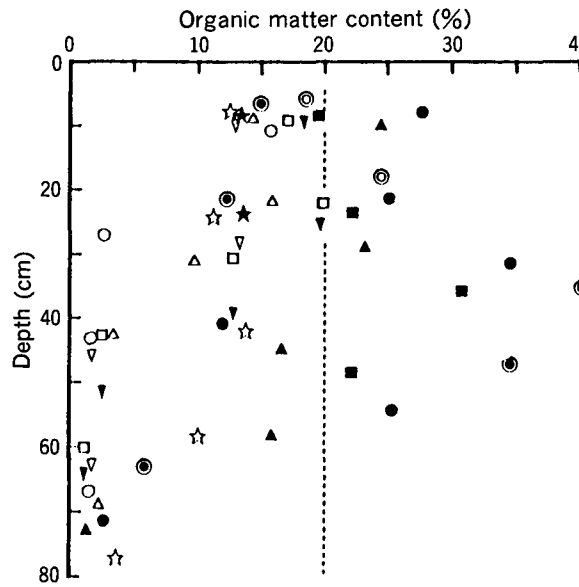


**Fig. 10** Profiles of organic matter content (Symbols are the same as Fig. 7)

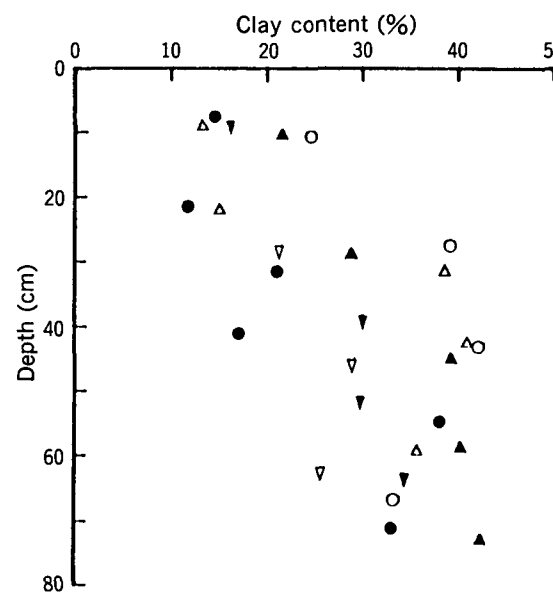


**Fig. 11** Profiles of clay content (Symbols are the same as Fig. 7)

The profiles of organic matter content and clay content are shown in Fig. 10 and 11, respectively. As is evident from Fig. 10, the difference in organic matter content between the soil types is clear. For some wet types, the soil layers with over 20% organic matter content (broken line) extend from the soil surface to a depth of 40 or 50cm. These wet-type soils correspond to the typic Gleyic Cumulic Andosols[1]. On the other hand, in the dry types, the layers with over 20% organic matter content are limited to a depth within about 20cm. This difference arises from the difference in drainage between the soil types.

Compared to organic matter content, the difference in clay content is small (Fig. 11). Therefore, it can be concluded that there is no effect of clay content on the poor drainage of the wet-types.

## Summary

Numerical landforms of the five plateaus in western Tokachi district were calculated from the elevation file of the Digital National Land Information. The plateaus are different in formation period and average altitude. From the relief and slope, it was recognized that the dissection of plateaus usually become stronger with increasig altitude.

Agricultural soils on each plateau are classified into the dry-type and wet-type based on drainability. In case of plateaus that have a neighboring upper plateau, the wet-type soils tend to be distributed along the boundary line with the upper plateau. The dry-type soils have convex slope and the wet-type soils have concave slope.

Having compared physical properties of the dry- and wet-type soils, it is concluded that the poor drainage of wet-type soils is due to high dry density in deeper layers, poor permeability, and geomorphological factors, for example the concave slope.

## Acknowledgement

The authors are greatly indebted to the staff of Soil Conservation and Amelioration Section, Civil Engineering Research Institute, Hokkaido Development Bureau, for their kind assistance in the measurement of organic matter content.

In this study, the Digital National Land Information (Geographic Survey Institute, Ministry of Construction) was used, and the calculations were done at Hokkaido University Computing Center.

## Literature cited

1. Hokkaido Soil Classification Committee : Soil classification of agricultural land in Hok-

kaido -2nd approximation-. Misc. Pub. Hokkaido Prefect. Agric. Exp. Stn., 10 : 78-89. 1979 (in Japanese with English abstract)

2. Kikuchi, K. et al. : The survey and study on the characteristics of soil in Tokachi district -1. The studies on topograph and volcanic ashes as the soil genetic factors-. Bull. Hokkaido Prefect. Exp. Stn., 31 : 14-27. 1975 (in Japanese with English abstract)
3. Kokufuya, M. et al. : Explanatory text of the geological map of Japan (scale 1 : 50,000) -SHINTOKU-. Hokkaido Development Bureau, 1969 (in Japanese)
4. Nogami, M. : A processing system for digital terrain analysis. Trans. Japan. Geomorph. Union 6(3) : 245-264. 1985 (in Japanese with English abstract)
5. Nogami, M. : Numerical land information in Japan. Trans. Japan. Geomorp. Union 10-A : 147-156. 1989
6. Seo, H. et al. : Soil survey report of the western part of Tokachi subprefec, Hokkaido. Soil Survey Report, Hokkaido Nation. Agric. Exp. Stn. Fascicle 3 : 1-124. 1954 (in Japanese)
7. Tokachi Research Group : Tokachi plain 105-245. The Association for the Geological Collaboration in Japan, Tokyo, 1978 (in Japanese with English abstract)
8. Yazawa, M. : Studies on the dispersion and flocculation properties of volcanic ash subsoils. Soil Phys. Cond. Plant Growth, Jpn. 38 : 9-15. 1978 (in Japanese with English abstract)