RELATIVE ERODIBILITY OF SOILS ON HILLY LANDS IN TAIWAN*

Part I. Properties of the soils affecting soil erosion.

by

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With increasing emphasis of the development of hilly lands for agricultural production in Taiwan, it has become more essential to evaluate the relative erodibility of major soils from the view point of conserving soil on cultivated lands.

Although some information about the erosional behavior of soils on sloped lands has become available through the time consuming runoff plot tests, no laboratory studies were carried out, which may reveal any relationship between erosivity and physico-chemical properties of the soils. This study was carried out to study the properties of soils affecting soil erosion and their relationship to soil erodibilities.

Studies on the mechanism of soil erosion[1] indicated that water erosion of soils is due to the dispersive action of the rain and the transporting power of surface runoff which are greatly affected by the properties or conditions of soils as well as other factors. Musgrave[2] found that amount of soils lost by surface runoff is closely related to both capacity and rate of the infiltration of soils. Middlelton[3] suggested the dispersion ratio as an index of the ease with which the particle would be brought into suspension. Bouyoucos[4] suggested that the clay ratio which is obtained from the ratio of $\frac{\text{sand}+\text{silt}}{\text{clay}}$ in the soil could be a possible criterion of judging the relative susceptibility of soil to erosion. Lutz[5] pointed out that soils with porous profiles, larger stable aggregates which result in greater permeability are much less susceptible to erosion.

EXPERIMENTAL PROCEDURES

Description of soils studied:

Six of main soils on hilly lands were selected for the study. In selecting the sites of soils to be studied, following assumptions were proposed to eliminate factors other than soil property itself and to unify the enviromental conditions.

1. Solum of the soil should be deeper than 70 cm.
2. Slope of the land surface is ranged from 15% to 25%.
3. Soils are cultivated to crops, but soils other than the surface are still undisturbed.

The general descriptions of the soils are provided as follows:

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Tsao-tun Soil (草屯)

This soil is a member of well drained Yellow Earth derived from soft, brownish yellow sandstones and shales. It extends on low hilly lands of Tai-chung and Nan-tou area. This soil is included in Dah-an (大安) series according to the "Soils of Tai-chung District."(6) Sheet erosion is prevailing usually on steep cultivated lands. Soils samples were collected from 25% sloped peanut field 4 km south east of Tsao-tun (南投縣草屯鎮圳寮坑)。

Profile description:

I. 0– 20 cm: Dark yellowish brown (10 YR 4/4, M.) friable loam, moderate medium subangular blocky structure, pH 4.6.

II. 20– 40 cm: Yellowish red (5 YR 5/6, M.) firm clay loam, moderate medium subangular blocky structure, pH 4.6.

III. 20–100 cm: Yellowish red (5 YR 5/6, M.), firm clay loam containing some weathered sand stones, weak medium angular blocky structure, pH 4.7.

Yen-chao Soil (燕巢)

This soil is a member of well drained Yellow Earth derived from rather hard reddish brown sandstones. The soil is included in Kuan-tze-lin series (關子嶺) reported in "Soils of Kao-hsiung Prefecture."(7) It is distributed over outer parts of low hilly lands of Kang-san (岡山) area. Sheet erosion is prevailing on the steep cultivated lands. Soil depth is usually less than 100 cm. Samples were collected from 15% sloped sugar cane field, 1.5 km north east of Yen-chao (高雄縣燕巢鄉大埔仔)。

Profile description:

I. 0–12 cm: Dark yellowish brown (10 YR 4/4, M.), friable sandy loam, moderate medium subangular blocky structure, pH 6.1.

II. 12–35 cm: Dark yellowish brown (10 YR 4/4, M.), firm sandy loam, weak moderate subangular blocky structure, pH 5.8.

III. 35–65 cm: Dark brown (7.5 YR 4/4, M.), very firm sandy loam, compact massive structure, pH 5.8.

Ah-kung-tien Soil (阿公店)

This soil is a member of Lithosol derived from soft grey calcareous mudstones. The soil is included in Tso-chen series (左鎮) reported in "Soils of Kao-hsiung Prefecture."(7) It is distributed on the low hilly lands of southern Taiwan ranging from Yu-chin, Tainan (臺南玉井) to Chi-san, Kao-hsiung (高雄旗山). In this area, being subjected to extremely severe erosion and land slides, a vast area of the lands has been destroyed to bad lands. Soils deeper than 70 cm are seldom found on steep lands. Soil samples were collected from 15% sloped cassaba field located at 2 km north east of Yen-chao (高雄縣燕巢鄉千秋寮)。

Profile description:

I. 0–15 cm: Olive brown (2.5 YR 4/4, M.), hard silty clay, moderate medium angular blocky structure, with excessive cracking, pH 6.1.

II. 15–30 cm. Olive (5 Y 4/3, M.), silty clay with common grey (5 Y 5/1) mottling, very sticky when wet and very hard when dry, weak medium angular blocky structure, pH 6.9.

III. 30–60 cm: Grey (5 Y 5/1, M.), very hard silty clay with common olive grey (5 Y 5/2) mottlings along ped surfaces, coarse angular blocky structure containing great portion of partly weathered mud-stones, pH 7.3.

Feng-san Soil (鳳山)

This soil is a red earth derived from old dilluvium of sand stones. It is scattered on gently sloping low hills of Feng-san (鳳山) area. This soil is much similar to the soils of Heng-chun (恒春) series reported in "Soils of Kao-hsiung Prefecture."[7] Moderate erosion is prevailing on the soils and shallow gravelly soils are frequently found on steeper lands. Soil samples were collected from 20% sloped pineapple field near the runoff test plots of Feng-san Tropical Agricultural Experiment Station (鳳山熱帶園藝試驗所)。

Profile description:

I. 0– 18 cm: Yellowish brown (10 YR 5/4. M.), soft clay loam, weak medium subangular blocky structure, pH 4.2.

II. 18– 39 cm: Dark brown (5 YR 4/4. M.), slightly firm clay loam, weak coarse subangular blocky structure, pH 4.9.

III. 39– 60 cm: Reddish brown (5 YR 4.5/4, M.), slightly firm clay loam massive structure, pH 5.1.

IV. 60–100 cm: Yellowish red (5 YR 5/7) firm clay loam with massive structure, pH 4.9.

Tai-tung Soil (臺東)

This soil is a young soil derived from soft calcareous grey shales. It is occupying the east side of low gently sloping foothills of Tai-tung coastal mountains. The soil samples were collected from 15% sloped sugar cane field near the runoff test plots of Taiwan Sugar Company's farm at Chia-lu-lan, Taitung (臺東縣加路蘭)。

Profile description:

I. 0– 14 cm: Very dark greyish brown (2.5 Y 3/2, M.), very firm clay, moderate coarse angular blocky structure with excessive cracking, pH 6.5.

II. 14– 20 cm: Very dark grey (10 YR 3/1, M.), very firm clay, rich in organic matter, very coarse angular blocky structure, pH 6.2.

III. 20– 45 cm: Olive (5 Y 5/4, M.), clay with very dark grey (10 YR 3/1) streaks, very firm massive to weak very coarse angular blocky structure, very sticky when wet, pH 7.2.

IV. 45–100 cm: Olive (5 Y 5/3, M.). clay with common yellowish brown partly weathered shale fragments. Very firm massive to weak, very coarse angular blocky structure, pH. 8.0.

Pin-chen Soil (平鎮)

This soil is a member of well drained reddish brown latosols derived from old diluvium. The soil is grouped in Pin-chen series reported in "Soils of Tao-yuen Prefecture."[8] It occupies the higher table lands and the surrounding low hilly lands of Tao-yuen and Shin-chu area. Soil samples were collected from 15% sloped tea plant field of Pin-chen Tea Experiment Station (平鎭茶業試驗所) 。

Profile description:

I. 0– 14 cm: Yellowish red (5 YR 4/4 M.), clay, friable fine granular structure, pH 4.4.

II. 14– 32 cm: Yellowish red (5 YR 4/8 M.), clay, slightly firm moderate fine subangular blocky structure, pH 4.5.

III. 32– 49 cm: Red (2.5 YR 4/5 M.), clay, firm moderate to weak medium subangular blocky structure, pH 4.6.

IV. 49–100 cm: Red (2.5 YR 4/5, M.), clay, firm massive to weak medium subangular blocky structure, pH 5.1.

Methods:

Before soil samples were taken, infiltration capacities of the soils were determined in situ under constant water head of 1 cm by double cylinder method modifying the method proposed by Musgrave.[2] The inner cylinder was driven into the soil to a depth of 25 cm which is deep enough to reach the subsoils to prevent lateral movement of water to minimum during the infiltration. Amounts of infiltrated water were recorded at the intervals of 5 minutes during the first 30 minutes and 10–15 minutes during the next succeeding period. Triplicated determination were made and the average values were adopted as results.

Soil samples collected by horizon of each soil were subjected to physical and chemical analyses. Properties included in the physical analyses were bulk density, particle density, porosity, dispersion ratio, clay ratio, aggregate stability and particle size distribution.

Chemical analyses were made to determine soil reaction, organic matter and free iron contents in the soils.

Triplicated determination of bulk density, particle density and porosity were made by the methods provided in "Agricultural Handbook No. 60 of USDA"[9], except bulk density was determined by paraffin method. The method used for determining soil dispersion ratio was that outlined by Middleton.[3] With this method, the despersion ratio is expressed in percentage of the silt and clay determined under suspension of a 20 times end over end inversion to the total silt and clay obtained by mechanical analysis. Method for aggregate stabilities of particles less than 50 microns was that proposed by Lee.[10] The value was obtained from the sum of positive difference between mechanical and aggregate analysis.

Particle size distribution was determined by the Hydrometer method.[11]

The clay ratio was obtained from the ratio $\frac{\text{sand}+\text{silt}}{\text{clay}}$ in the soil as suggested by Bouyoucos.[4]

Soil reaction was determined by glass electrode method using 1:1 soil-water ratio.

Free iron and organic matter contents were determined by $Na_2S_2O_4$-EDTA method[12] and Walkey's rapid method[13] respectively.

RESULTS AND DISCUSSION

As well recognized, field soil erosion is influenced by a great number of factors. The results shown here aim to take into account only the soil factor and to indicate to what relative degree the various soils would be susceptible to erosion under the same condition.

Infiltration capacity and rate:

Both capacities and rates of the infiltration for the soils obtained by this methed aim to show the relative ones of the soils under the same conditions rather than to show the actual ones that take place on the sloping lands. Amounts of infiltrated water should be much less than those obtained by this method because of less opportunity for water to infiltrate into soils on sloping surfaces.

Figure 1 shows the infiltration capacities of the soils determined for 2 hours at field. The amounts of water infiltrated into soil were expressed in cumulative surface centimeters against time. The result shows that highest capacity was obtained for Tai-tung soil at first 90 minutes but the total capacity remained pretty low after all. Total infiltration capacities for Feng-san and Tsao-tun soils were highest although their capacities in early period were lower than that of Tai-tung soil. The capacities of Yen-chao and Ah-kung-tien soils were always lowest through the whole infiltration period.

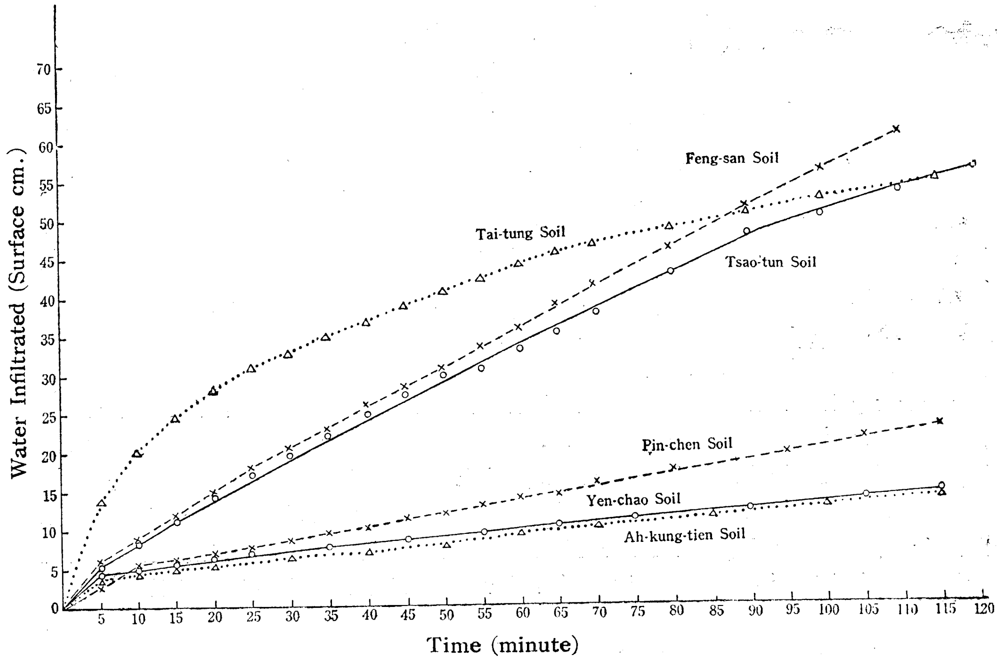

Fig. 1. Cumulative Infiltration (Surface cm.)

Figure 2 shows the infiltration rates of the soils calcultated from water infiltrated in succesive unit time. The rates are expressed in surface millimeters of water infiltrated per 10 minutes. The results show that the infiltration rates of all soils were decreased rapidly in first 30 minutes-period and turned to the stable minimum rates in about 100 minutes. As the result shows, the minimum infiltration rate of Feng-san soil is the highest of all soils, it exceeds that of Yen-chao soil by almost 5 times. In general, the minimum infiltration rates of the soils mav be grouped into three groups.

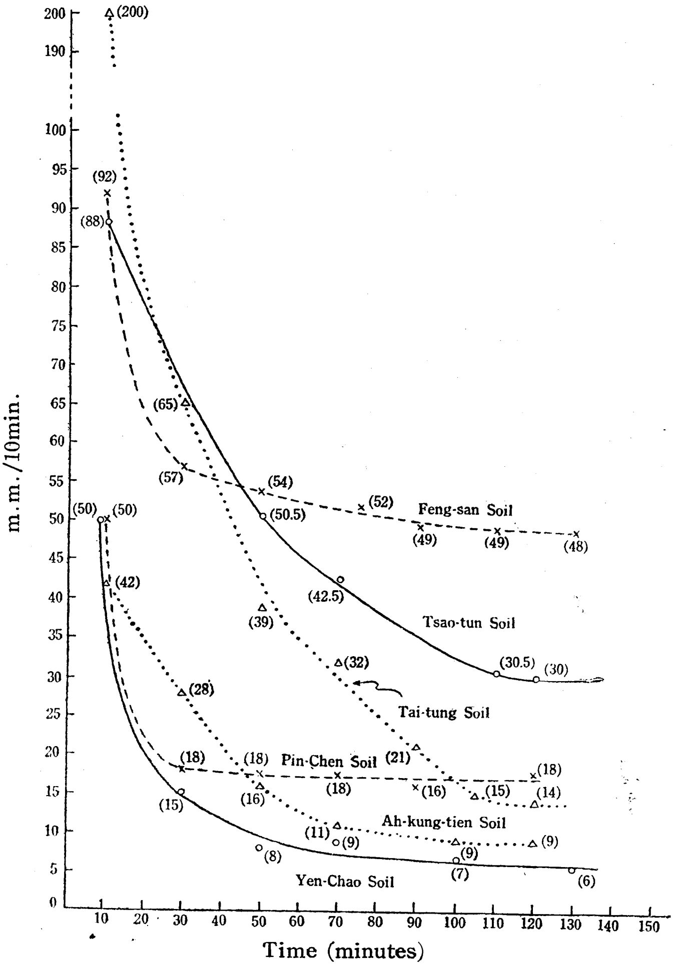

Fig. 2. Infiltration rate (Surface m.m./10 min.)

Extremely high infiltration group includes Feng-san and Tsao-tun soils which have minimum infiltration rates of more than 30 mm per 10 minutes. Pin-chen and Tai-tung soils are included in moderately high infiltration group ranging from 14 mm to 19 mm per 10 minutes. Ah-kung-tien and Yen-chao soils are included in low infiltration group having the rates of less than 10 mm per 10 minutes. The rates of minimun infiltration and their ratios for the soils are listed as follows:

Soils	Tsau-tun	Yen-chao	Ah-kung-tien	Feng-san	Tai-tung	Pin-chen
Minimum infiltration rate (mm/10 minutes)	30	6	9	48	14	18
Ratio of minimum infiltration rate	5	1	1.5	8	2.3	3

Since soil moisture and other conditions of land surfaces were not able to be controlled under the same levels at field, the minimum infiltration rates of the soils would provide more meaningful information in considering their contribution to surface runoff than the total infiltration capacities.

In refering to characteristics of the soil profiles, no evident relationship between infiltration rate and texture profile of the soils, but close relationship was found between porosity distribution of the profile. Higher infiltration rates of Tsau-tun and Feng-san soils are related to the uniform higher porosity of around 40% through the profiles and lower infiltration rates of other soils are resulted from the less porous layers of around 30% porosity in the profiles. Less porous lower subsoil of around 27% in porosity of Tai-tung soil resulted in low infiltration rate at latter period. As Baver[14] found that percolation rate, which is approximately the same as the minimum infiltration rate, increased directly with non-capillary porosity. Further study on the non-capillary porosity of the soils will reveal closer relationship between porosity and infiltration rate.

The extremely high infiltration rate (200 mm/10 minu.) of Tai-tung soil at first period is due to the consumption of infiltrated water by filling spaces of excessive cracking of surface soils, the rate was decreased rapidly after the cracking was saturated.

Dispersion Ratio and Aggregate Stability:

As shown on table 1., the dispersion ratios of the soils are all high. According to the classification proposed by Middleton[3], all of the soils studied are included in erosive group if based on this property alone.

Among the soils tested, Tsao-tun soil has the lowest dispersion ratios ranging from 20 to 30 through the profile and Feng-san soil has the highest ranging from 40 to 50. Soils of Ah-kung-tien, Yen-chao, Tai-tung and Pin-chen have the intermediated dispersion ratios ranging from 30 to 40 through the profiles.

In a soil, the dispersion ratio of different horizon is increased with the depth, with a exception of Pin-chen soil. This fact implies subsoils will be more masily eroded once they are exposed and plowed.

In considering the relationship between dispersion ratio and other single properties, contents of organic matter and clay in soils contributed to the soil's resistance to dispersion. In a given soil, content of organic matter takes more important part in increasing soil's resistance to disporsion than that of clay does. This fact was seen in the results showing that the dispersion ratios of surface soils with higher organic matter but lower clay contents are usually lower than those of subsoils with lower organic matter but higher clay contents.

Among the different soils, clay content in the soil apparently contributed to the resistance to the dispersion with exception of Fen-san soil. This implies that sandy soil is more susceptive to disperse than clayey soil. This tendency is even more apparent in aggregate stability of particles less than 50 microns in the soils, The stability was decreased with increase of clay ratio of the soil.

Contents of free iron in the soils did not affected the dispersion ratios or

Table 1. Physical and Chemical Properties of the Soils

Soils	Horison	Depth (cm)	Texture	Sand %	Silt %	Clay %	Porosity %	Clay ratio $\frac{Sand+Silt}{Clay}$	Dispersion ratio	Aggregate stability	Organic matter %	Free Iron (Fe_2O_3%)
Tsao-tun	I.	0-20	L	36.92	36.76	36.32	47.21	2.80	18.39	51.48	1.49	2.92
	II.	20-40	CL	30.92	31.76	37.32	41.51	1.68	22.58	53.48	0.86	4.80
	III.	40-100	CL	36.92	38.76	39.32	40.15	1.67	26.82	53.48	0.77	3.56
Yen-chao	I,	0-12	SL	62.34	29.16	8.50	46.30	10.76	32.82	25.30	1.45	2.86
	II.	12-35	SL	60.34	25.16	14.50	31.37	5.90	36.21	25.30	0.30	2.21
	III.	35-65	SL	60.34	31.16	18.50	40.66	4.41	41.26	23.30	0.28	0.50
Ah-Kung-tien	I.	0-15	SiC	8.00	50.00	42.00	41.04	1.38	36.96	58.00	1.48	3.08
	II.	15-30	SiC	8.00	46.00	46.00	31.50	1.17	34.78	60.00	1.07	3.23
	III.	30-60	SiC	2.00	51.00	47.00	32.73	1.13	51.02	48.00	0.95	3.78
Feng-san	I.	0-18	CL	36.22	35.00	28.78	33.96	2.47	46.69	34.00	1.02	2.65
	II,	18-39	CL	38.22	28.00	33.78	40.74	1.96	43.35	35.00	0.96	2.70
	III.	39-60	CL	38.22	27.00	34.78	41.48	1.88	59.53	35.00	0.76	2.75
	IV.	60-100	CL	39.22	27.00	33.78	38.52	1.96	52.29	29.00	0.65	2.95
Tai-tung	I,	0-14	C	10.22	37.00	52.78	36.92	0.89	24.26	68.00	2.65	3.17
	II.	14-20	C	0.22	37.00	62.78	36.57	0.59	19.82	80.00	3.51	2.81
	III.	20-45	C	9.22	32.00	58.78	27.01	0.70	35.01	59.00	1.18	2.58
	IV,	45-100	C	21.22	26.00	52.78	27.84	0.89	40.34	47.00	0.79	2.12
Pin-chen	I.	0-14	C	21.30	35.70	42.00	48.51	1.38	30.11	54.00	1.86	4.53
	II.	14-23	C	20.30	34.70	45.00	32.56	1.22	24.73	61.00	1.82	4.29
	III.	23-49	C	16.30	30.70	53.00	36.30	0.87	30.70	57.00	0.97	4.92
	IV.	49-100	C	14.30	32.70	53.00	40.11	0.87	21.70	67.00	0.91	5.03

aggregate stabilities of the soils.

CONCLUSION

Based on the capacity of reducing surface runoff and soil's resistance to dispersion, Tsao-tun soil is regarded as the most non-erosive among the soils because of its higher infiltration rate, lower dispersion ratio and higher aggregate stability. Based on its highly dispersible property, Feng-san soil is regarded to be easily eroded if it is subjected to the lasting heavy rainfall which the intencity usually exceeds the infiltration rate in rainy season.

Soils of Ah-kung-tien and Yen-chao are regarded as the easily erosive because of their higher dispersible properties and low infiltration capacities and rates.

SUMMARY

To evaluate their relative erodibility, six soils from cultivated lands on the slopes ranging from 15% to 25% were subjected to the field study on their soil profile characteristics and infiltration capacity. Analyses on their physical and chemical properties including porosity, particle size distribution, dispersion ratio, aggregate stability, clay ratio and contents of organic matter and free iron in the soils were carried out.

The results revealed that:

1) Highly porous profile of the soil resulted in higher infiltration capacity of the soil. The infiltration rates of all soils were decreased rapidly in first 30 minutes and then gradually decreased to the stable minimum values in 100 minutes. Higher infiltration rates were found for Tsao-tun (草屯) soil and Feng-san (鳳山) soil, but lower rates for Ah-kung-tien (阿公店) and Yen-chao (燕巢) soils.
2) All of the soils tested are highly dispersible according to their dispersion ratios and aggregate stabilities. Lower dispersion ratios were found for Tsao-tun (草屯), Tai-tung (臺東) and Pin-chen (平鎮) soils and higher ratios for Feng-san (鳳山), Yen-chao (燕巢) and Ah-kung-tien (阿公店) soils.
3) According to the result of higher dispersion ratios of subsoils, it is expected that soils will be easily eroded once the subsoils are exposed and cultivated.
4) The resistance to dispersion of the soils were increased directly with the contents of organic matter and clay in the soils and no evident relationships were found for free iron content.
5) Based on the infiltration rate and dispersion ratio of the soils, Tsao-tun (草屯) soil is regarded as the least erosive and soils of Ah-kung-tien (阿公店) and Yen-chao (燕巢) as easily erosive.

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臺灣坡地主要土壤之冲蝕性研究

1. 影響土壤冲蝕之性質

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中 文 摘 要

爲探究丘陵地區坡地主要土壤之相對冲蝕性，選擇坡度在15～25%土壤深度70公分以上之耕地土壤，在現地作剖面性狀觀察與水分滲浸率測定，並就土層別採取土壤在室內測定與土壤冲蝕有關之各種土壤理化性質。

本試驗選擇的土壤共有六種卽 (1)平鎭洪積臺地上紅壤 (2)草屯砂頁岩風化黃壤 (3)燕巢砂岩風化黃壤 (4)阿公店泥岩風化石質土 (5)鳳山洪積層紅壤 與(6)臺東頁岩風化石質土。

室內分析項目有 (1)機械分析 (2)孔隙度 (3)分散率 (4)團粒安定度 (5)土壤反應 (6)有機質含量 與(7)粘土率。

其結果簡述如下：

1. 土壤剖面之孔隙度較高的土壤（如草屯土壤），其現地水分滲浸率較高，所有土壤之滲浸率在最初30分內均急速減低，以後卽緩慢減低，至100分時達到安定的最低滲浸率。其最低滲浸率以草屯、鳳山，土壤較高，阿公店及燕巢土壤較低，其差異多至5倍左右。
2. 土壤分散率與團粒安定度之測定結果顯示，所有土壤均頗易分散其分散率大多在20以上。草屯、臺東及平鎭等土壤之分散率較低（20～30）而鳳山、燕巢及阿公店等土壤之分散率均高（30～50）。
3. 所有土壤之底土分散率均高於表土，由此可推測現有表土流失底土露出而被開墾呈膨鬆狀態時更易引起冲蝕。
4 土壤之有機物及粘土含量對土壤分散率及團粒安定度有直接關係。有機物與粘土含量愈高，分散率愈低，而團粒安定度卽愈高。但游離鐵含量則未發見有相關關係。
5. 由土壤分散率與水分滲浸率測定之綜合結果，因其分散率低（18～27）滲浸率高（30公糎/10分），草屯土壤被認爲最難被冲蝕。阿公店及燕巢土壤因分散率高（30～50）滲浸率低（6～9公糎/10分）被認爲最易被冲蝕之土壤。