SOIL AND WATER MANAGEMENT AND SOIL PHYSICAL PROPERTIES WITH SPECIAL REFERENCE TO EROSION HAZARD BY WATER

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It has become usual to refer to "soil and water management", because these two components can seldom be separated without one affecting the other. However, presently, mainly soil erosion will be discussed, except when the problems of water management arise as part of soil erosion.

Soil erosion is a natural phenomenon. Usually an equilibrium is established between the slow process of soil formation and removal of soil by erosion under natural vegetation, except on very steep land. When the vegetation is removed by agriculturists for planting purposes or by engineers undertaking construction work, erosion occurs. Bare soil promotes the detachment of the soil particles from the soil surface by the impact of raindrops. The detached soil particles are carried away into water moving over the soil surface.

Soil erosion is not simply an impact action of raindrops, it depends also on inherent properties of the soil as well as on topographic factors and man's activity.

The factors affecting soil erosion

The factors which affect the amount of erosion occurring in any given circumstances are illustrated in Fig. 1. As erosion arises basically from the effect of rainfall on the soil, these factors are very important and still other factors, i.e. soil and water management, crop management and land form affect the erosion. Thus erosion is determined by the following factors (Hudson, 1977).

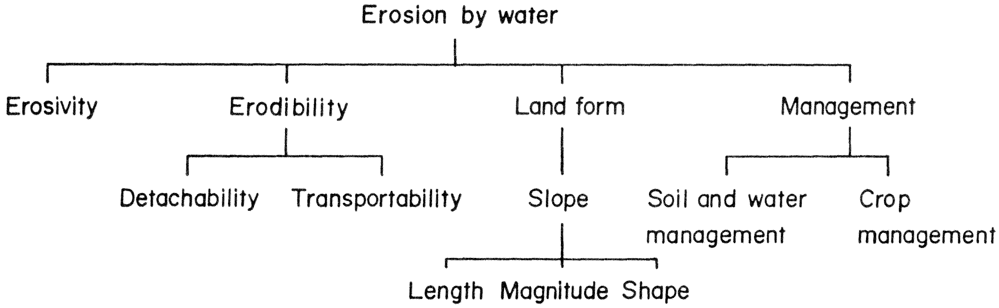

Fig. 1 Factors affecting erosion by water (after Hudson, 1979).

1 Erosivity

Erosivity of rainfall is a parameter which can be quantitatively evaluated as the ability of rain to cause erosion in any given circumstances. The value of erosivity depends on rainfall properties specifically and solely, and to that extent it is independent of the soil. But a quantitative measurement of erosivity can only be made when erosion occurs, which is connected with the erodibility of soil.

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2 Erodibility

The erodibility of a soil is defined as its vulnerability or susceptibility to erosion in any given circumstances. A soil with high erodibility will experience more erosion than a soil with low erodibility if both are exposed to the same rainfall intensity. The erodibility depends upon the actual physical properties of the soil and its assessment is often achieved by the combination of the properties of soil which affect erosion most.

3 Land form

The amount of soil erosion is very much affected by both the length and the gradient of the slope. Obviously the steeper the slope is, the greater the erosion is due to increased runoff and faster flow. Also, the longer the slope is the greater the erosion is due to the increased speed of runoff. Although the two effects have been evaluated separately in research, it is convenient to consider the two as a single topographic factor, especially for the erosion equation, USLE*. The shape of the slope (concavity or convexity) and roughness of the land surface also affect erosion. The land form factor includes all the above mentioned topographic effects.

4 Management

Management is inclusive of all the factors under man's direct control, such as land use, selection of crop and farming systems, soil amendment applied and mechanical techniques.

Of the factors affecting erosion, erosivity cannot be corrected but some improvement is possible for erodibility and land form, hence erosion control must be achieved largely through management.

Erosivity

It is generally recognized that erosivity is closely related to intensity of rainfall. The intensity is the amount of rainfall at various time intervals such as 10, 30 and 60 minutes. Ten-minute intensity has been largely used for erosion research in Japan. Choice of short time intervals such as 10 minutes may be due to the small variation in rainfall within a given time, because the amount of natural rainfall varies markedly with time. Rainfall intensity of more than 2 or 3 mm/10 min had often been adopted as the threshold of erosive rainfall in Japan. So the term "critical rainfall intensity" (the threshold of "dangerous rain") is often used. "Critical intensity" corresponds to a rate of 70% of rainfall of more than 20 mm, and rainfall of more than 20 mm is called "critical rainfall". "Critical erosion month" (dangerous month for erosion) refers to a month with more than 9 days of "critical rainfall" for the Inland Sea area in Japan. In a "critical erosion month", we should take special notice of erosion hazard. Fig. 2 illustrates the development of a "critical erosion month". According to the above mentioned method, the example of the Inland Sea area in Japan is given in Table 1. In this area, critical erosion months occur from June to September.

Utilizing the data and material of five Prefectural Agricultural Experiment Stations in Japan, an attempt was made to design a prediction equation for soil loss caused by erosion (Suh *et al.*, 1977). In this attempt, monthly rainfall records were read at three intensity grades, under 2 mm/ 10 min (LE2R), 2 – 4 mm/10 min (MEDR), and above 4 mm/10 min (GT4R). Multiple regression of log-transformed soil loss for these rainfall data gave the following regression equation;

$$\text{Log (soil loss)} = -0.783 + 0.0185\ \text{GT4R} + 0.00597\ \text{LE2R} + 0.00763\ \text{MEDR}$$

with a multiple correlation coefficient (r) of 0.74**. The units of measurement were kg/ are for soil loss and mm/month for LE2R, MEDR and GT4R. This regression equation can be used

* USLE, "Universal Soil Loss Equation", as proposed by Wischmeier and Smith (1965). The equation is applicable to the greater part of the USA and reads as follows:
A = R·K·L·S·C·P, where A: soil loss in ton/acre, R: rainfall factor, K: soil-erodibility factor, L: slope-length factor, S: slope-gradient factor, C: cropping-management factor, P: erosion control practice factor.

for predicting soil loss from rainfall intensity.

Instead of intensity, the erosivity index, EI_{60} which is the product of the kinetic energy of a storm and 60-minute intensity was used by Tanada (1975). The 60-minute intensity is the greatest average intensity experienced in any 1 hour period during the storm. Experiments conducted in Kyoto have indicated a high correlation coefficient between EI_{60} and soil loss (linear correlation coefficient was more than 0.7**). EI_{60} value can be easily computed using general meteorological reports.

Table 1 Rainfall distribution by month in the Inland Sea area in Japan (Kawamura, 1966)

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Days of rainfall	84	89	96	108	113	118	123	90	117	84	71	75
Days of critical rainfall	2	1	7	11	18	35	50	37	36	13	10	8
Frequency of critical rainfall (%)	2	1	7	10	16	30	41	40	31	15	14	11
Maximum intensity of rainfall (mm/min)	2.5	2.0	4.6	7.4	6.2	17.7	20.0	12.0	20.6	5.3	4.8	3.6

For years 1951 – 1960

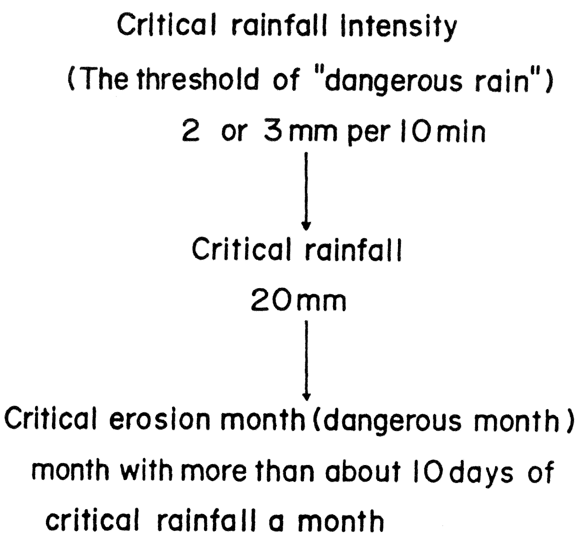

Fig. 2 Development of critical erosion month.

The ability to assess numerically the erosive power of rainfall, i.e. erosivity index, has many applications to practical soil conservation and research. So several approaches have been made to determine the rainfall erosivity index from straightforward measurement of the rain physical properties in connection with the erodibility. The above mentioned EI_{60} is also one of the indices.

At present, the erosivity index is practically used for erosion control work in the USA. Utilizing all the data from the experimental plots of 35 conservation experiment stations east of the Rocky Mountains (about 20-year records) a search was made for parameters which could be correlated with the recorded erosion. The results summarized by Wischmeier *et al.* (1958) are as follows.

The correlation of soil loss in individual storms with the amount of rainfall was poor, and it was also poor with the maximum amount of rain falling at various time intervals such as 5, 15 or 30 minutes. The momentum of rain was better, but the kinetic energy of the rain was the closest factor related to erosion. However, there was still considerable variation and so multiple regressions were also tested in which several factors were combined in various arithmetical arrangements. After testing all the reasonable possibilities, the best means to assess soil loss was found to use a compound parameter, the product of the kinetic energy of the rainfall and the 30-minute intensity. The 30-minute intensity is the highest average intensity experienced in any 30-minute period during the rainfall. It is computed from recording rain gauge charts by locating the largest amount of rain which falls in any 30 minutes, and then doubling this amount to obtain the same dimensions as intensity. This measure of erosivity is described as EI_{30} index. It can be computed for individual storms and the storm values can be summed up over periods of time to give annual values of erosivity. The annual storm value is called rain factor.

Experiments conducted in the tropics have indicated a lower correlation coefficient between EI_{30} and soil loss than was obtained for the original experiments in the USA. Therefore, in humid tropical countries an alternative method was developed, i.e. $KE > 1$ and AI_m indices. $KE > 1$ index is the total kinetic energy of the rain falling at intensities of more than 1 inch/hr (Hudson, 1971). AI_m index is the product of the total rainfall amount (A) and peak storm intensity (I_m). A better correlation with AI_m than either EI_{30} or $KE > 1$ in an experiment conducted in Nigeria is shown in Table 2 (Lal, 1977).

Various indices have been proposed in different countries with different climates. This is mainly due to the differences in average intensity, total quantity and frequency of erosive rain in each country. For the purpose of erosion control we need to determine the properties of rain, i.e. maximum intensity, intensity – duration relationships and frequencies of severe storms and to establish the best erosivity index for individual countries.

Table 2 Correlation coefficient (r) for runoff and soil loss (Lal, 1977)

Rain factor	Runoff	Soil loss
$KE > 1$	0.81	0.64
EI_{30}	0.85	0.65
AI_m	0.91	0.80

Weighted mean average correlation coefficient (r) of various erosivity indices with runoff and soil loss for standard bare runoff plots at International Institute of Tropical Agriculture, Ibadan, Nigeria, with slopes of 1, 5, 10 and 15% during the period 1971 – 1975.

Erodibility

There are many studies which have attempted to relate the amount of soil erosion as measured in the arable land to the characteristics of soil which can be measured. But the assessment of erodibility is very complicated because it depends upon many physical properties of soil. Almost every physical property can be measured quantitatively and has been used for such purpose either singly or in combination.

However a single correlation between individual soil properties and soil loss in many kinds of soils is practically impossible and it is thus necessary to clarify to what extent each property of soil relates to erosion and reexamine the validity and limitation of the erodibility index used so far. At present our studies are focussed on identifying a good erodibility index relating to soil physical properties such as texture, dispersion ratio, organic matter content, permeability, structure, etc. Meanwhile, the results obtained up to now will be outlined.

In this study, a nozzle type rain simulator with rotating disk (Tokudome *et al.*, 1981) of which particle size distribution and kinetic energy are similar to those of natural rainfall was used. The artificial rainfall adopted for the plot was 29 mm per hour. Plot size was 0.3 m^2 (0.3 x 1.0 m) and slope gradient was 10°. During the test, soil loss, runoff, and infiltration were determined. On the other hand, soil physical properties were determined for soils used in the experiment.

1 Soil texture and soil erosion

Soil particle size distribution is an important property which influences the detachability of the particles from the surface by impact of the rain drops and transportability of the detached particles by moving water over the surface. In this experiment, clay ratio was introduced as a parameter which indicates the particle size distribution namely the ratio of the sum of silt and sand to clay. The relationship between clay ratio and soil loss is shown in Fig. 3, suggesting that soil loss is inversely proportional to the ratio. Also in Fig. 4, particle size distributions for original and lost soils are shown for various soils. Lost soils are rich in fine particles compared with original soils. It is considered that soil loss may be largely influenced by transportability of the detached soil particles on the basis of this experiment.

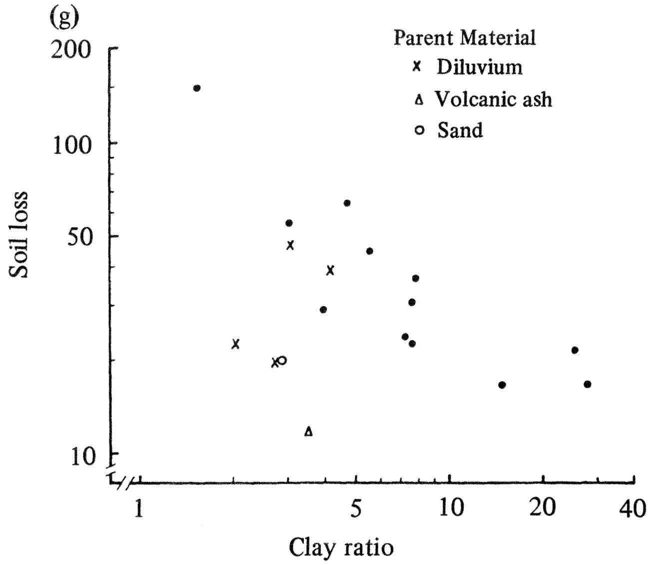

Fig. 3 Soil loss-clay ratio relationship.

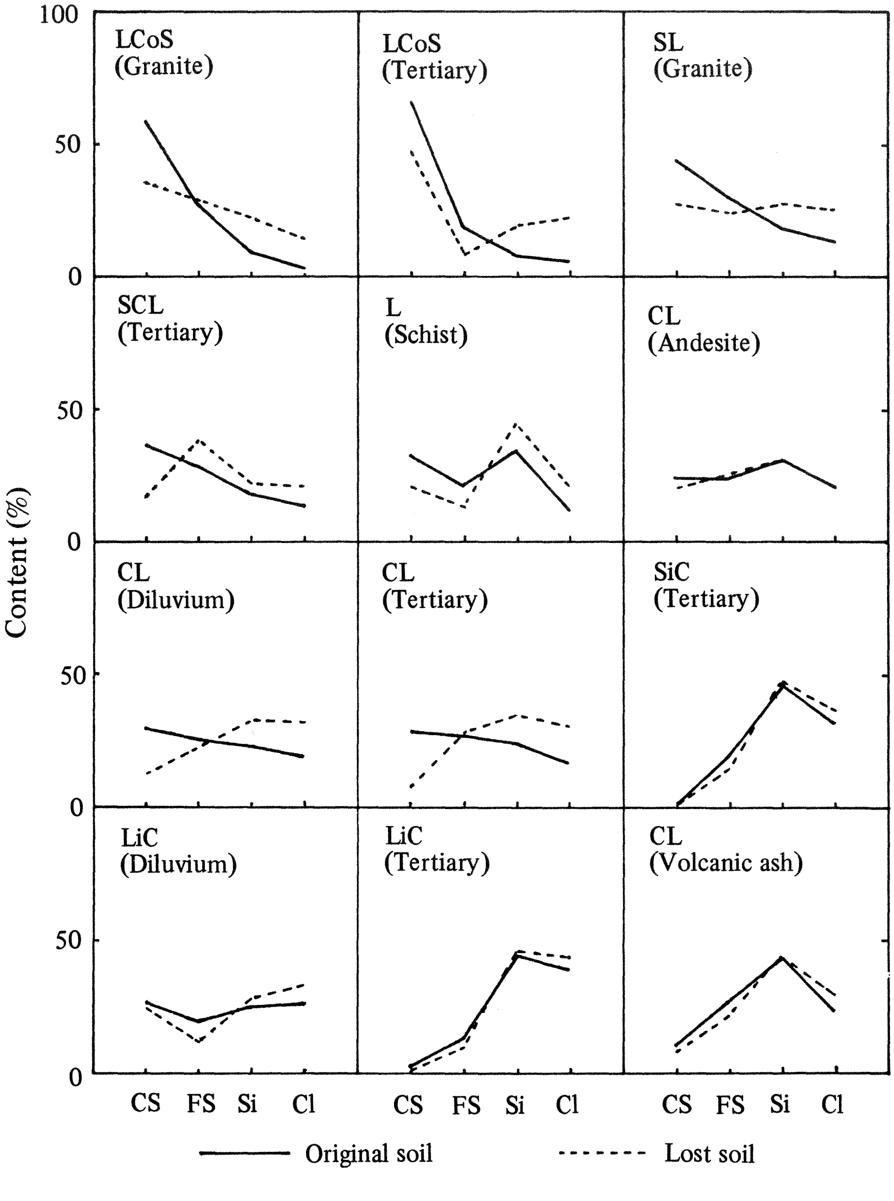

Fig. 4 Particle size distributions for original and lost soils.

2 Dispersion ratio and erosion

Dispersion ratio (ratio of the amount of soil particles less than 0.05 mm in diameter dispersed only with distilled water to that of the corresponding size under complete dispersion) was determined to measure the stability of an aggregate to the impact of rain and transportability of runoff. In order to estimate the effect of the dispersion ratio on soil loss the relationship between soil loss and dispersion ratio is shown in Figure 5. Obviously soil loss per unit surface flow (g/mm) increases with the increase in the dispersion ratio. It is suggested that soil loss per unit surface flow of fine and medium textured soil is higher than that of coarse textured soil if both have the same dispersion ratio. Correlation coefficient of log transformed soil loss per unit surface flow to the dispersion ratio is 0.63**. When soils are classified by textural grade such as fine and medium textured soils and coarse textured soils, the correlation coefficient rises markedly.

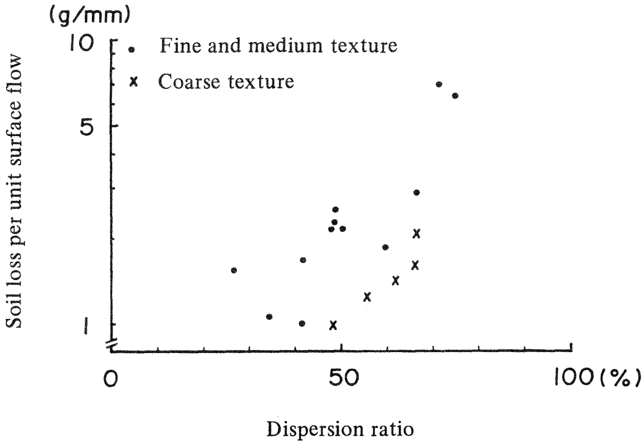

Fig. 5 Soil loss – dispersion ratio relationship for mineral soils.

When it rains on dry soil, some of the aggregates break down due to quick infiltration of water into the capillary pores of soil (slaking effect) and formation of a crust resulting in a decrease of soil permeability. The stability of the aggregates is also affected by soil moisture content and reduction of aggregate by slaking effect increases surface runoff. Kawamura (1966) recognized that the erodibility of mineral soils is markedly dependent on the air-dry ratio which is the ratio of the amount of aggregates in air dried soil to that in soil saturated with capillary water. Thus air-dry ratio is useful for the determination of the erodibility index i.e. soils with low air-dry ratio are more prone to erosion than soils with high air-dry ratio for the above mentioned reason. Correlation coefficient between the dispersion ratio and air-dry ratio is –0.74** as shown in Fig. 6. It is suggested that we can estimate the value of the air-dry ratio from the value of the dispersion ratio.

3 Organic matter and erosion

It is generally recognized that a soil rich in organic matter is more resistant to erosion because organic agents promote the development and stability of aggregates and then improve the water-holding and infiltration capacities. The role of organic matter in stability ranges from entanglement by fungal hyphae and roots to binding by the decomposition products and secretions of roots, microorganisms and soil animals. The dispersion ratio, i.e. the reciprocal of stability of aggregates decreases with the content of organic matter in the soils as represented in Fig. 7. The above mentioned relationship seems to deviate from a regression equation with the influence of soil history and kind of organic matter applied, in a few cases.

Development of water stable aggregates of more than 1 mm in the soil tends to be promoted by the addition of fresh and easily decomposable organic matter or immature compost compared with well humified compost. An example is shown in Table 3.

Organic matter also contributes to the improvement of infiltration resulting in the development of aggregates, but infiltration may be reduced by hydrophobic properties (repellency) that increase the angle of contact between water and soil under dry conditions (Nakaya, 1981).

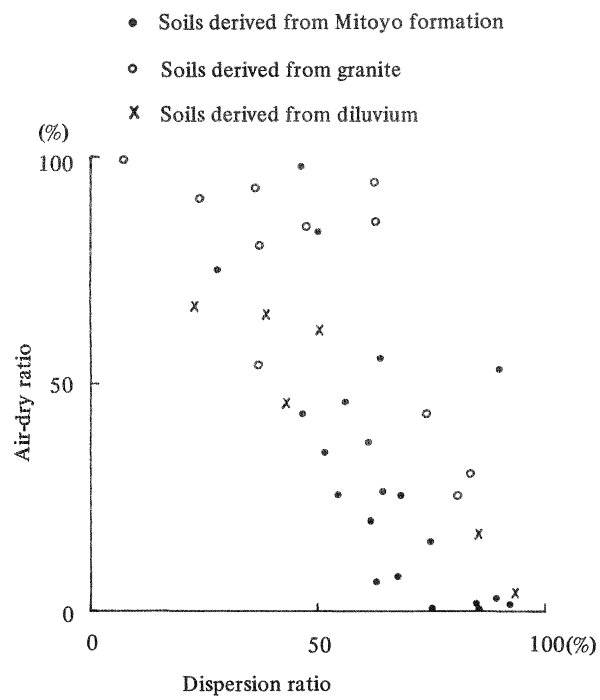

Fig. 6 Air-dry ratio – dispersion ratio relationship.

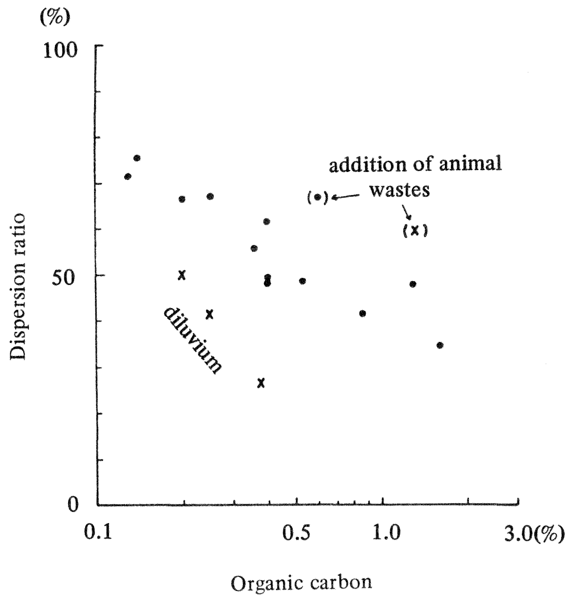

Fig. 7 Dispersion ratio – organic carbon relationship for mineral soils.

Table 3 **Amount of water stable aggregates formed by the addition of different types of organic matter in a soil (Kawamura, 1966)**

Organic matter	Water stable aggregates (%)			
	> 18 mesh	18 – 30 mesh	30 – 50 mesh	50 – 100 mesh
No addition	11.1	14.0	12.5	11.5
Compost	17.1	18.1	14.0	10.9
Rice straw	22.9	19.2	12.2	9.3

Survey was conducted after the second soybean-wheat cropping rotation. Compost (2.25 ton/ha) was applied each year and straw was applied with corresponding amount of dried compost. The soil had a fine texture and was mainly derived from andesite.

4 Soil chemical properties and erosion

Soil chemical properties which influence soil physical properties are thus related to erodibility. For example, application of lime increases the pH of soil and the activity of some fungi and entanglement by their hyphae is weakened. When Na ion constitutes a sufficient portion of the exchange complex, aggregates may become unstable. Iron and aluminum oxides can act alone or possibly in combination with organic matter to stabilize the aggregates.

5 Assessment of erodibility by soil physical properties

Assessment of erodibility has been attempted by the determination of various physical characteristics of the soil in the laboratory as follows:

Wischmeier *et al.* (1969, 1971) showed a good correlation between erodibility and an index grouping 15 physical properties of the soil. Subsequently this determination was refined and simplified to a practical nomographic method using only 5 properties, i.e. sum of silt and very fine sand, sand content, organic matter content, soil structure and permeability.

On the basis of regression analysis of soil physical parameters which are related to erodibility such as "clay ratio" [clay/(silt + sand)] and increment of soil loss (determined by the subsoil permeability) it became possible to predict soil erodibility (Uchida, 1979).

The estimation of the infiltration capacity and permeability of the soil which influence runoff of rainfall and the amount of runoff could be classified into three grades. Also the determination of physical properties such as dispersion ratio, air-dry ratio and clay ratio [(silt + sand)/clay] which influence detachability and transportability of soil particles could be classified into three grades. Depending upon the combination of the grades, erodibility was estimated and a map for the prediction of water erosion was prepared in Japan (Motomura, 1979).

According to Wischmeier's method, soil erodibility factor 'K' was experimentally determined in Japan. For a particular soil, factor 'K' is the rate of erosion per unit of erosivity index (EI_{60}) from unit plot. The unit plot is 20 m long, 2 m wide, with a uniform slope of 10°, in continuous fallow. On diluvium soil, Kuroboku, andesitic soil and Kunigami maji in southwestern Japan, the 'K' values were 0.48, 0.10, 0.70 and 0.72 respectively (Taneda, 1980).

It is considered that each method has particular features and advantages. It is important to devise a new method to improve the erodibility index.

Land form

Among the topographical factors both the degree and length of slope are important factors which influence soil erosion. With the increase in slope, erosion generally increases exponentially. Length of slope has an effect on soil loss similar to that of the extent of the slope. The increase in the amount of surface runoff, its velocity and depth on longer slopes increase erosion hazard. However, the relationship between slope length and soil loss depends on the shape of the slope, i.e. convex or concave.

In the USA, the LS factor in USLE is the expected rate of soil loss per unit area on a field slope to the corresponding loss from a typical 9 per cent slope, 72.6 feet long. An empirical equation has been introduced:

$$LS = \sqrt{\lambda}\,(0.0076 + 0.0053S + 0.00076S^2)$$

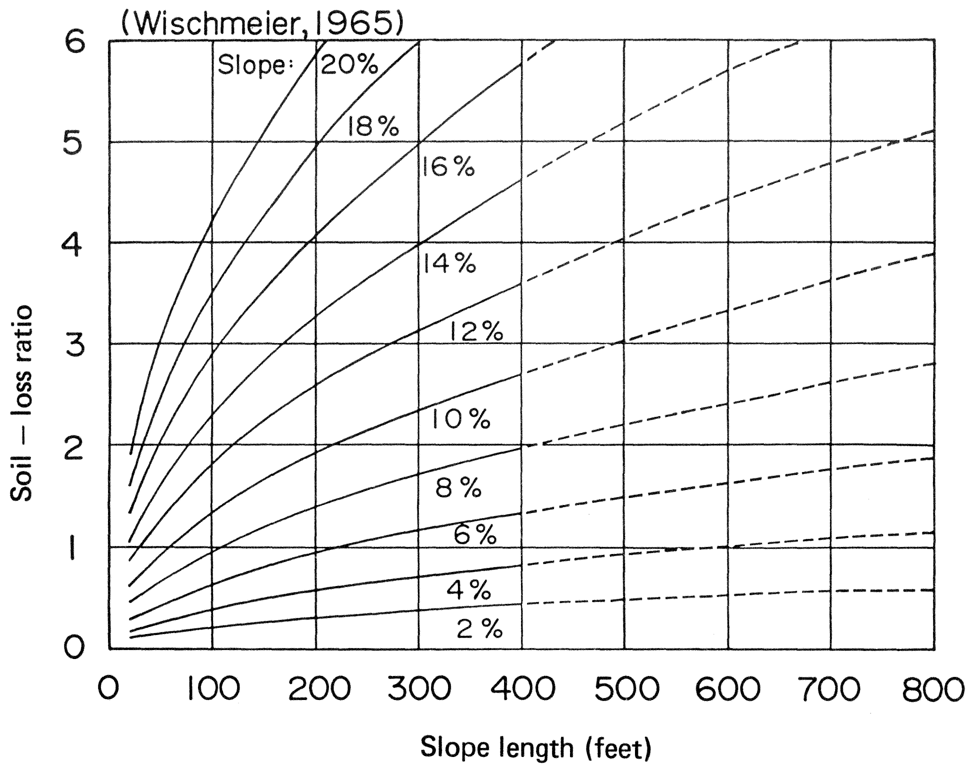

Fig. 8 Slope-effect chart (topographic factor, LS).

where λ is the field slope length in feet, and S is the gradient expressed as slope %. This ratio, for specific combinations of slope length and gradient, may usually be estimated directly from the slope-effect chart as shown in Fig. 8, computed from the equation. This equation is valid up to 70 or 130 m of maximum slope length and up to 11° of maximum slope gradient (Wischmeier and Smith, 1965).

From the observation of erosion on a granitic soil by artificial rainfall, the following equation was obtained:

$$LS = \sqrt{L}\,(0.0067S + 0.952S^2)$$

where L is the slope length in meter and S is the gradient expressed as the tangent of slope degree θ ($\theta < 30^\circ$) (Taneda, 1975).

These equations are not considered to be influenced by the slope shape nor soil type, and thus more research on slope factors will be necessary.

Control of erosion on agricultural land

The first important step towards erosion control is the correct use of land based on a scientific land use classification or land capability classification. Correct use of land is the first step towards both good agronomy and good erosion control.

There are many land capability classifications in the world, for in every country or geographical region there are different factors which should be taken into consideration.

In Japan, a kind of land capability classification has been made according to possible productivity for crops through the Soil Fertility Conservation Project organized by the Ministry of Agriculture, Forestry and Fisheries. In this system agricultural land is allocated into four classes mainly according to soil properties which influence fertility and productivity.

General soil conservation practices for arable land are illustrated in Fig. 9. Agronomical control is the management of crop to control the factors that cause erosion. For example, the farming methods utilizing mixed cropping and suitable crop rotation system which minimizes soil exposure to direct erosive rainfall are common features in the prevention of erosion. Maintenance of soil fertility and good farming result in decreased erosion due to excellent growth of vegetation on the land. Grass and straw mulch prevent direct raindrop impact on the soil and lead to the development of macropores in the soil by promoting biological activity.

Control of erosion by agronomic management	Mechanical protection from erosion
1. Protection from raindrop impact	1. Increasing infiltration of rainfall
Suitable crop rotation	Subsoil improvement
Keeping fertility of soil and good farming	Terrace building
Grass and straw mulch	
2. Increasing infiltration of rainfall	2. Reducing speed of runoff and introducing it to river safely
Dressing with organic matter	Modification of land form
Mulch tillage	Catchment drain and collecting channel
Deep plowing and subsoiling	Terrace outlet channel
Contour cropping	Stabilization and flood retardation structure (silt trap and regulating dams)
Strip cropping and vegetative zone	

Fig. 9 An illustration of general soil conservation practices.

When organic matter is added to the soil, the surface soil has a higher infiltration rate and the hydraulic conductivity is also high due to the development of stable aggregates. When the subsoil is compact enough to prevent percolation, deep plowing and subsoiling are effective for infiltration of rain water. For example, effect of subsoil breaking and vertical straw mulch on surface runoff coefficient in coarse textured granitic soil is shown in Table 4. In this case straw mulch was most effective in reducing the surface runoff.

Table 4 Improvement of soil physical properties and runoff control by agronomic management

Plot	Soil	Bulk density	Porosity (%)	Organic matter (%)	Surface runoff coefficient (%)
Bare	Top	1.30	51.1	0.69	35
	Sub	1.45	45.2	0.52	
Contour cropping	Top	1.25	52.0	0.52	27
	Sub	1.46	44.9	0.31	
Subsoil breaking	Top	1.15	56.6	1.10	22
	Sub	1.37	48.5	0.86	
Vertical straw mulch	Top	1.24	53.4	0.83	28
	Sub	1.23	53.7	0.52	
Straw mulch	Top	1.21	54.5	1.24	12
	Sub	1.35	48.8	0.76	

Survey was conducted in 1978. Subsoil breaking and vertical straw mulch application (straw was buried in the soil vertically) were performed in 1975. Straw mulch was applied at the rate of 3 ton/ha per year. Soybean-wheat rotation was carried out from 1975. Runoff coefficients were determined in soybean cultivation from June to October in 1978. The soil had a coarse texture and was derived from granite (Ichon, Korea). The plot size was 0.2 a (10 x 2 m) with a gradient of 10 degrees.

Contour cropping and settlement of vegetative zone contain water and reduce the velocity of the runoff, thus tending to prevent concentration of runoff water and increasing infiltration time. The effect of crop row direction on runoff and soil loss is shown in Table 5. The experiment shows that contour cropping was much more useful than vertical row cropping in the control of erosion. When grasses or legumes were seeded between the strips of cultivated crops to form a buffer belt (2 – 4 m wide), soil loss was markedly reduced (Nishikata, 1963).

Table 5 Effect of crop row direction on runoff and soil loss (Kawamura, 1966)

Plot	Crop	Crop-stage period	Rainfall (mm)	Runoff (mm)	Soil loss (kg/a)
Contour cropping	Sweet potato	Early (Jun. – Aug.)	357.6	8.5	8.6
		Later (Sep. – Oct.)	296.2	2.5	0.5
	Wheat	Early (Dec. – Feb.)	157.2	2.4	2.1
		Later (Mar. – May)	235.3	4.7	4.0
Vertical row cropping	Sweet potato	Early (Jun. – Aug.)	357.6	87.1	322.0
		Later (Sep. – Oct.)	296.2	42.0	7.3
	Wheat	Early (Dec. – Feb.)	157.2	10.6	21.2
		Later (Mar. – May)	253.3	32.4	30.2

The results are the mean average values of a two-year trial. The plot size was 0.2 a (10 x 2 m) with a gradient of 14 degrees. The soil had a coarse texture and was derived from granite.

The methods to be considered for mechanical erosion control are subsoil improvement, terrace building, modification of land form, catchment drain, collecting channels, terrace outlet channel and stabilization and flood retardation structures. Subsoil improvement and terraces are mainly effective in increasing the infiltration of rainfall. The other methods are mainly effective in slowing down the runoff. The methods used should be adapted to the soil, topography and climate of the area.

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Discussion

Benckiser, G. (IRRI): You defined erosion susceptible soils by the air-dry ratio and dispersion ratio. What is the advantage compared with field determinations?

Answer: This method provides a better evaluation of erosion.

Kubota, T. (Japan): How vigorously do you shake the soil suspension when you determine the dispersion ratio of a soil? Is the method you describe reproducible?

Answer: The soil suspension consists of 10 gram of air-dried soil to which distilled water is being added. The suspension must be shaken by hand 20 times. Using the pipette method, particles less than 0.05 mm in diameter are then aspirated. The dispersion ratio is a relative value which is reproducible if the method is followed completely and this value can be used for the evaluation of soil erodibility.

Somasiri, S. (Sri Lanka): In one of the figures you presented, you indicated that 2 – 3 mm rainfall/10 min (intensity of 12 – 18 mm/h) caused erosion, whereas at IITA a rainfall intensity of 25 mm/h was found to cause erosion. Can you explain the reason for such differences?

Answer: I cannot provide you with a satisfactory explanation.