Soil Erosion on Upland Slopes

——mainly on topographic factor——

傾斜地에서의 土壤流失

——地形因子를 中心으로——

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摘 要

土壤流失은 降雨의 性質, 土壤의 特性, 傾斜度 및 傾斜長, 栽培方法 및 土壤管理方法에 따라 달라진다. 따라서 土壤流失量을 正確하게 豫測하기 爲해서는 위의 6個 因子에 對한 究明이 必要하다. 지금까지 우리나라에서는 Wischmeier의 土壤流失量 公式(USLE)을 效率的으로 適用하기 爲하여 6個 因子中 降雨因子, 土壤浸蝕性 因子, 作物因子 및 土壤保全因子에 對해서만 硏究가 있는 實情이다.

따라서 本 硏究에서는 傾斜地에서의 傾斜長과 傾斜度가 土壤流失에 미치는 영향을 究明하여 LS 方程式을 誘導하고자 하였다.

京畿道 驪州郡 梁巨里에 있는 農業振興公社 農地保全 試驗圃에서 10個의 裸地 試驗區에 對한 土壤流失量을 測定하여 分析하였다. 10個의 試驗區中 9個는 傾斜度 10%, 20% 및 30% 各各에 對해 10m, 20m 및30m의 傾斜長으로 되어 있으며, 나머지 1個의 試驗區는 다른 試驗區와의 比較를 爲한 標準區로서 15%의 傾斜度, 20m의 傾斜長으로 되어 있다. 土壤은 禮山統에 속하며 60%의 砂質, 24%의 微砂質 및 16%의 粘土質로 구성 되어 있다.

20回의 土壤流失量 測定記錄中 12.7mm以上의 降雨에 依한 9回分의 流失量 測定資料를 回歸分析한 結果 다음과 같은 LS方程式이 誘導되었다. 即,

$$LS=\left(\frac{\lambda}{20}\right)^{0.68}\left(\frac{s}{15}\right)^{0.95}$$

그러나 傾斜度와 傾斜長因子(LS)는 다른 여러 因子들과의 相互作用(interaction)을 內包하고 있기 때문에 앞으로의 LS因子에 對한 硏究는 여러種類의 土壤에서 傾斜의 條件을 多樣하게 變化시켜 長期間 實驗을 한다면 韓國의 土壤特性에 一般的으로 適用할 수 있는 LS方程式을 誘導할 수 있으리라 思料된다.

I. Introduction

Soil erosion adversely affects upland crop productivity because of selective removal of plant nutrients, organic matter and finer soil particles leading to compaction of the soil and poor tilth. It also influences to the natural environment, especially to the water quality degradation, and water use facilities reducing water availability due to sedimentation. Therefore, the urgent need today is for an assessment of soil erosion on a large scale to provide soil erosion control measures to these problem areas.

The extent of soil erosion, however, can be predicted by applying the Universal Soil Loss Equation (USLE).

The Universal Soil Loss Equation was developed for estimating the average annual or seasonal soil loss from various conditions on upland in conservation planning. In this regard, its effective-

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ness relies on the accuracy in evaluating the six component factors, namely, rainfall-runoff factor (R), soil erodibility factor(K), slope gradient factor(S), slope length factor(L), cropping-management factor(C), and conservation practice factor(P).

Attempts to adapt the USLE to Korean upland condition different from that under which it was developed has led to the various research activities on these factors in Korea. Among these, Park (1975) calculated the rainfall erosivity factor(R) for 20 stations. Jung (1976) evaluated the soil erodibility factor(K) for 83 soil-series showing the potential of applicability of the USLE in Korean condition.

However, the topographic factor(LS) has not been studied so far. An attempt is therefore made to develop a slope length and steepness factor which is suitable to predict the soil loss. In addition, the proposed slope length and steepness factor(LS) is intended to be varified by comparing with the experimental field data.

Ⅱ. Literature Review

Soil erosion is a process of detachment of soil particles from the soil mass and transportation of these particles downslope by erosive agents (Ellison, 1947). This definition delineates the erosion processes as consisting of two steps, first, detachment and then transport.

The soil loss per unit area generally increases as the slope length increases, because the greater accumulation of runoff on the longer slope increases its detachment and transport capabilities (Wischmeier and Smith, 1978).

On the steep slopes, the increased velocity of runoff water, caused by higher gradients, allows more soil to be detached and transported. Surface detention of water becomes less as slope increases because of decreased capacity of furrows or depressions (Foster and Meyer, 1975).

Zingg (1940) showed the relationship which related to the effects of slope length and steepness on the soil loss. Musgrave (1947) developed a soil loss equation which includes more variables affecting the soil loss in addition to the Zingg's. Meyer and Monke (1965) studied the effects of steepness and length of slope, particle diameter and rainfall intensity on soil erosion. When the steepness of slope was 70 percent or greater, a multiple regression analysis of experimental data obtained from traials gave the equation of best fit.

Lal (1975), in Nigeria, found that erosion increases with slope to the power of 1.2 when the soil is bare, but that it is independent of the slope (1 to 15 percent) if an adequate amount of residue (4 to 6 ton/ha) is existed on the surface (Roose, 1976).

On the other hand, Hudson (1973) in Rhodesia and Roose (1975) in Ivory Coast found also the exponents larger than 2.0 for various tropical soils that are poorly covered (Roose, 1976).

Framer and Fletcher (1976) applied the USLE to the highway erosion control system. For the single uniform slope they calculate the LS value as follows;

$$LS=\left(\frac{0.45+0.3s+0.043s^2}{6.613}\right)\left(\frac{\lambda}{72.6}\right)^m \left[\cos^2\left(\tan^{-1}\frac{s}{100}\right)\right] \qquad \cdots\cdots(1)$$

where s=slope steepness in percent

λ=slope length in feet

m=an exponent (for simplicity of illustration they chose m=0.5)

McCool and others (1976) modified the USLE by replacing the rainfall factor with a rainfall, runoff erosion and adjusted length and steepness factor to meet the special climatic condition and considering steep slope of the Palouse. The length and steepness equation is

$$LS=\left(\frac{\lambda}{72.6}\right)^{0.3}\left(\frac{s}{9}\right)^{1.3} \quad (\text{for } s>9\%) \cdots\cdots(2)$$

$$LS=\left(\frac{\lambda}{72.6}\right)^{0.3}(0.43+0.3s+0.43s^2)/6.613 \quad (\text{for } s\leq 9\%) \cdots\cdots(3)$$

where λ=field slope length in feet

s=field slope steepness in percent

On the otherh and, Williams and Berndt(1976) computed the LS factor as follows;

$$LS=\left(\frac{\lambda}{22.1}\right)^m(0.065+0.045+0.0065s^2) \quad (4)$$

where m=0.5 for slopes greater than 3 percent and 0.3 for flatter slopes

λ=slope length in meters

s=slope gradient in percent

Wischmeier and Smith (1978) revised the 1995's results as follows;

$$LS=\left(\frac{\lambda}{72.6}\right)^m(65.41\ \sin^2\theta+4.56\ \sin\theta+0.065) \quad \cdots\cdots(5)$$

where λ=slope length in feet

θ=angle of slope in degree

m=0.5 if the percent slope is 5 or more, 0.4 on slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent, and 0.2 on uniform gradients of less than 1 percent.

Ⅲ. Materials and Method

Data required in this study consisted of records of measurement of soil losses in different slope length and gradients together with relevent information for evaluating other factors of the USLE at the time of each rainfall event. These were collected from 10 plots of erosion experiment under a continuous fallowed bare field at the Runoff Erosion Plots of Agricultural Development Cooperation (ADC), Yangeri, Yeojukun, Kyungki-Do in Korea. The soil used could be classified into the Yesan-series in the Typic Dystrochrept soil group. Its texture is coarse loamy, having soil components of 60% sand, 24% silt and 16% clay.

The slope gradients used in this study were 10, 20, 30 and 15 percent and there were 10m, 20m and 30m slope length in each except 15 percent plot which, with 20m slope length was selected as a standard plot for the comparison with the other plots.

Each of the plots used for this study has a collecting trough and measuring equipment located at the lower end for determining the amount of runoff and soil loss from each storm. The measuring equipment consists of a sedimentation or silting tank, and has a 10-slot Geib divisor for fractionating the overflow. Thus collecting tank collects one tenth of the sample, which is extracted and weighted.

Rainfall erosivity factor(R) was computed by dividing each rainfall event into successive increments of essentially uniform intensity and using the following equations;

$$KE=210.3+89\ \log_{10}I \quad \cdots\cdots(6)$$

$$E=KE\cdot t\cdot I \quad \cdots\cdots(7)$$

$$R=\frac{(\sum E).I_{30}}{100} \quad \cdots\cdots(8)$$

where I=rainfall intensity for each increment in cm/hr

KE=kinetic energy in ton-m/ha/cm of rainfall

t=rainfall duration for each increment in hr

I_{30}=maximum 30-min rainfall intensity in cm/hr

From the USLE (A=RKLSCP), K, C and P factors are assumed the same all over the plots. Consequently the LS factor may have the following relationship;

$$LS\propto\frac{A}{R} \quad \cdots\cdots(9)$$

If the value of LS factor is unity under standard plot condition defined previously, the observed LS value may be obtained by just dividing the amount of soil losses in each plot by that of the standard plot; the LS value is the ratio of soil loss in other plots to the standard plot.

For the derivation of the LS equation it is necessary to evaluate the relationships between soil loss and each L and S. Under the consideration of interaction between L and S, the influences of each L and S to the amount of soil losses are assumed to be of the relationship as follows;

$$L\propto\frac{A}{RS}, \quad S\propto\frac{A}{RL} \quad \cdots\cdots(10)$$

Then, since slope length factor(L) is the ratio of field soil loss to corresponding loss from 20m slope-length plot (standard plot), its value may be expressed as (Wischmeier and Smith, 1978; Musgrave, 1947; Zingg, 1940);

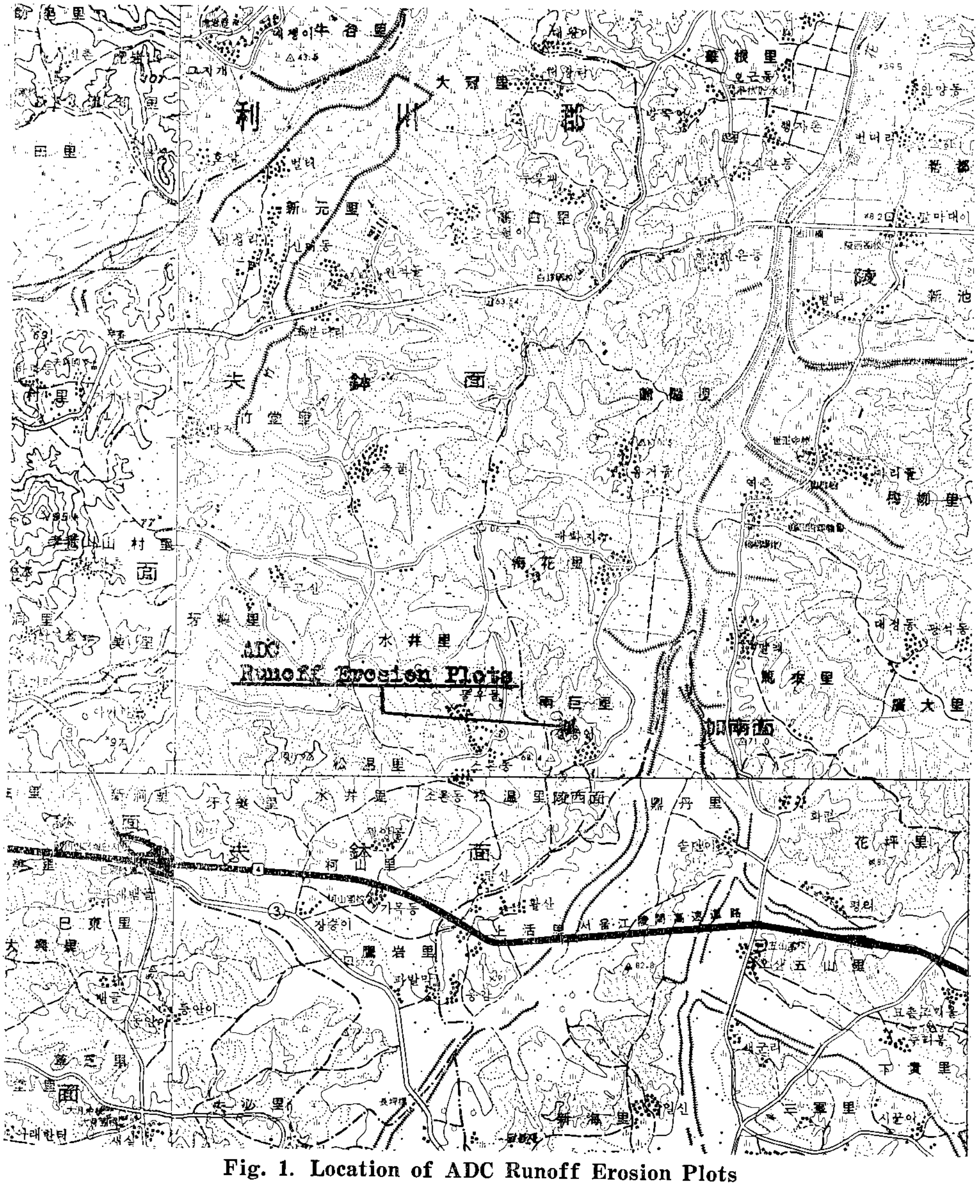

Fig. 1. Location of ADC Runoff Erosion Plots

$$L=c\left(\frac{\lambda}{20}\right)^{m} \quad \cdots\cdots(11)$$

where λ is slope length in meters.

Similarly, slope gradient factor(S) can be expersssed as exponential or polynomial form of slope gradient as follow;

$$S=c\left(\frac{s}{15}\right)^{n}$$

$$S=p+q\cdot\sin\theta+r\cdot\sin^{2}\theta \quad \cdots\cdots(12)$$

where θ= angle of slope gradient in degree

s=slope steepness in percent

Therefore, the effect of slope length and steepness to the soil loss may be assumed in two cases.

case 1.

$$\frac{A}{RS}=a\left(\frac{\lambda}{20}\right)^{m} \quad \cdots\cdots(13)$$

$$\frac{A}{RL}=b\left(\frac{s}{15}\right)^{n} \quad \cdots\cdots(14)$$

case 2.

$$\frac{A}{RS}=c\left(\frac{\lambda}{20}\right)^{m} \quad \cdots\cdots(15)$$

$$\frac{A}{RL}=p+q\cdot\sin\theta+r\cdot\sin^{2}\theta \quad \cdots\cdots(16)$$

where A=soil loss for each rainfall event

R=rainfall erosivity factor

L=slope length factor

λ=slope length in meters

S=slope gradient factor

s=slope steepness in percent

m,n=exponents

a,b,c,p,q,r=coefficients

θ=angle of slope gradient in degree

The coefficients and exponents in eq. (13), (14), (15) and (16) were evaluated using scientific subroutine package LISA/3,000 (regression analysis). Thus, eq. (17) and (18) can be obtained by rearranging the case 1 and case 2 in terms of combination of the slope length (L) and slope steepness (S).

$$\text{case1.}\quad LS=c\left(\frac{\lambda}{20}\right)^m\left(\frac{s}{15}\right)^n \cdots\cdots\cdots\cdots(17)$$

$$\text{case2.}\quad LS=c\left(\frac{\lambda}{20}\right)^m(p+q\cdot\sin\theta+r\cdot\sin^2\theta) \cdots\cdots\cdots\cdots(18)$$

Also, the constant c in eq. (17) and (18) can be easily obtained by adjusting each LS value to be unity under the condition of standard plot.

Ⅳ. Results and Discussion

From the 20 rainfall events recorded in 1980, only 9 records were available for the analysis of LS factor. In the regression analysis the number of input data were 90, which were the combination of 9 records of R and ten kinds of polt conditions in S and λ in each eqs. (13)—(16). Two LS equations were obtained using the result of statistical analysis;

$$\text{case 1.}\quad LS=\left(\frac{\lambda}{20}\right)^{0.68}\left(\frac{s}{15}\right)^{0.95} \cdots(19)$$

$$\text{case 2.}\quad LS=\left(\frac{\lambda}{20}\right)^{0.68}(-0.1922+3.635\sin\theta-5.116\sin^2\theta) \cdots\cdots\cdots\cdots(20)$$

In terms of correlation coefficients and F values, the case 1 showed more preferable result than the case 2. In addition, with the x^2 test between estimated and calculated LS value for the case 1 and case 2, the case 1 showed better fitting with the observed values as shown in Table 2.

Therefore the eq. (19) was adopted as a model of slope length and steepness factor in this study.

The relationship between slope length and LS value according to slope steepness 10%, 20% and 30% was shown in Fig. 2. The extention of the curve would not be recommended because the input data were not much enough to estimate the soil loss in all of the conditions.

This research was intended primarily to derive a LS model providing a normalized value of slope and length effect on soil erosion in the conservation and hillside development.

The exponent of the proposed slope-length equation showed a little greater than that of the other researchers', which were smaller than 0.5.

It was found that in rainy season, the rill erosion was severe at steeper slop owing to the heavy storm. Since the slope of all plots was steeper than 9%, LS equation was expressed in the form of exponential function as similar form of equation as McCool's work (1976). Each of six erosion factors in the USLE is a function of numerous secondary variables and interaction effects must be considered when computing local values of the factors (Wischmeier, 1976).

From the scientific point of view, this topographic factor is surely the weak point of the USLE because the influence of slope is not independent of vegetal cover, cultural techique, soil, surface condition and probably of climate (Roose, 1973, 1975; Wischmeier, 1976).

For the general application of slope-length factor to Korean conditions, it might be necessary to expand the further researches for the various soil types and slope conditions. Also it is considered that for accurate soil loss estimates using the USLE, cooperative works among agronomists, agricultural engineerers, soil scientists, and hydrologist may be needed in the development of the proposed LS model.

Ⅴ. Summary and Conclusion

This study was conducted to evaluate the val-

Table-1. Results of Regression Analysis

case	Equation	F-value	Corr. Coeff.
1	$\frac{A}{RS}=0.1564\left(\frac{\lambda}{20}\right)^{0.68}$	7.24**	0.276**
	$\frac{A}{RL}=0.1248\left(\frac{s}{15}\right)^{0.95}$	14.11**	0.372**
2	$\frac{A}{RS}=15.975\left(\frac{\lambda}{20}\right)^{0.68}$	7.23**	0.276**
	$\frac{A}{RL}=-0.1922+3.635\sin\theta-5.116\sin^2\theta$	3.00$^{N.S.}$	0.254*

* significant at 5% level test
** significant at 1% level test
N.S. non-significant

Table-2. The Results of x^2 Test

plot		Case1.				Case2.			
(%)	(m)	O_i	E_i	$(O_i-E_i)^2$	X^2	O_i	E_i	$(O_i-E_i)^2$	X^2
10	10	0.798	0.423	0.141	0.332	0.798	0.316	0.232	0.735
10	20	0.427	0.679	0.063	0.093	0.427	0.507	0.006	0.013
10	30	1·064	0.895	0.029	0.032	1.064	0.668	0.157	0.235
20	10	0.808	0.820	0.0001	0.0002	0.808	0.861	0.003	0.003
20	20	1.401	1.316	0.007	0.005	1.401	0.182	0.0004	0.0003
20	30	2.606	1.736	0.757	0.436	2.606	1.822	0.615	0.337
30	10	1.144	1.208	0.004	0.003	1.144	1.143	0.000	0.000
30	20	1.988	1.938	0.003	0.001	1.988	1.834	0.024	0.013
30	30	3.312	2.556	0.571	0.224	3.312	2.418	0.799	0.330
15	20	1.000	1.000	0.000	0.000	1.000	1.000	0.000	0.000
				$\sum x^2=1.128$					$\sum x^2=1.667$

ues of slope length and steepness factor in the Universal Soil Loss Equation (USLE).

The experimental plots are located at the ADC Runoff Erosion Plots in Yangeori, Yeojukun, Kyungki-Do, which belongs to the Yesan-series in the Typic Dystrochrept soil group. Its texture is coarse loamy, having soil components of 60% sand, 24% silt and 16% clay.

Using the statistical analysis for the data collected from the experimental plots, a LS equation has been developed for prediction of soil loss from a field as follows;

$$LS=\left(\frac{\lambda}{20}\right)^{0.68}\left(\frac{s}{15}\right)^{0.95}$$

Since slope length and steepness factor which

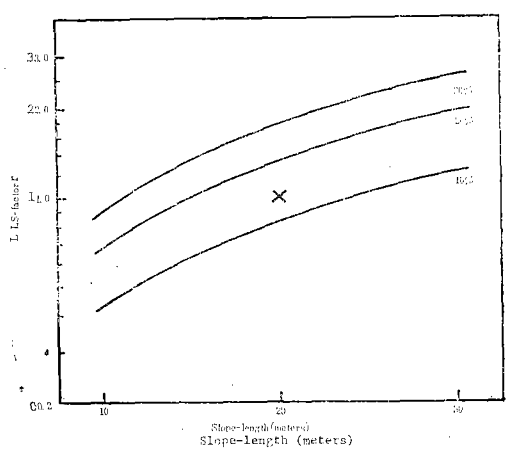

Fig. 2. Slope-effect chart

vary with soil types contains an interaction with other factors in the USLE, the derived equation in this study may not represent sufficiently the LS factor of Korean upland condition. If the LS factor could be investigated in the various slope condition with different soil types, the LS equation representing the general condition in Korea may be derived.

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