Research article

Determining C Factor of Universal Soil Loss Equation (USLE) Based on Remote Sensing

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Abstract Soil erosion is a serious environmental problem which causes degradation of soil and water environment. Thus, soil conservation is necessary for the areas where accelerated erosion occurs. At early stages of soil conservation, certain strategies should be implemented based on predicted soil erosion rate of the area. Soil erosion rate has been calculated using erosion models, such as Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project (WEPP), etc. However, the most common model is either Universal Soil Loss Equation (USLE) or Revised Universal Soil Loss Equation (RUSLE), as they are easy in handling by users. Attention has been paid to Cropping Management, factor C of USLE or RUSLE, since it is challenging to determine. The factor depends on the type of crop and the growing stage, however growing conditions would change locally and harvesting time are unpredictable. Also, vegetation could be changed unpredictably due to weather or farming conditions. Approaches based on remote sensing technology which has less temporal and spatial restrictions on detection of vegetation were applied to determine C factor using vegetation indices. However, it is not always successful in field application. Therefore, the objective of the study is to improve determination of C factor using vegetation indices. For clarification, experiments for identifying the relationship between C factor and vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI) were carried out under several types of soil. Furthermore, the accuracy of determination of C factor using vegetation indices was discussed through an erosion model experiment. The results showed SAVI is more strongly correlated with C factor than NDVI. Estimation of C factor based on NDVI and SAVI have 30% and 36% of relative error in field application. Therefore, it was concluded that vegetation indices have high potential to determine C factor of USLE or RUSLE. Also, estimation of field C factor based on SAVI is more recommendable for determination of C factor in the field where there are several types of soil.

Keywords soil erosion, soil conservation, USLE, C factor, remote sensing, NDVI, SAVI

INTRODUCTION

It is well known that accelerated erosion results in serious form of soil degradation, and pollutes the water environment with component of nitrogen and phosphorous. Thus, soil conservation is necessary for protecting soil and water areas, where accelerated soil erosion happens. At the early stage of soil conservation planning, soil erosion predicting model is employed for evaluating condition of local soil erosion rate, before and after soil conservation strategies are applied. Many models have been developed for predicting water-induced soil erosion rate. Especially, Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) have been used to calculate annual soil erosion rate (Wischmeier and Smith, 1978; Renard, 1997). USLE is empirical model, originally developed to predict soil erosion rate, mainly in agricultural land. RUSLE is an advanced version with less limitation on application area. However, more details about field are required. Both USLE and RUSLE have the same mathematic structure which can be written as follows:

$$A = RKLSCP \quad (1)$$

Where A is soil erosion rate (ton/ha yr.), R is rainfall and runoff erosivity factor (MJ mm/ha h yr.), K is soil erodibility factor (t ha h/ha MJ mm), LS is topographic factor comprised of slope length and slope gradient-slope steepness, C is Cropping Management factor, P is soil conservation practice factor. (Revised) Universal Soil Loss Equation is most common model for soil conservation planning. Determining LS factor and C factor is always challenging when applying (Revised) Universal Soil Loss Equation in field. Complicated topographic feature causes difficulties in initial field data collection for computing LS factor. Several proposed ideas indicate remote sensing has high potential in estimating LS factor, in terms of high speed of execution and computing in topographic complex (Desmet, et al., 1996; Winchell, et al., 2008). Efforts linking LS factor and remote sensing have been successfully carried out by processing topographic function in Geographic Information system (GIS) with raster database of Digital Elevation Model (DEM). However, determining C factor still remains a challenge. C factor is defined as relative impact of vegetation reducing on soil erosion rate. Determining C factor requires one to know about vegetation which is difficult to identify manually. Remote sensing technology which has less temporal and spatial restrictions on detection of vegetation were widely applied to determine field C factor using vegetation indices such as Normalize Difference Vegetation Index (NDVI) (Van der Knijfff et al., 2000; Lin et al., 2002). However, it is not always successful in field application (Alejandro, et al., 2007).

OBJECTIVE

Accordingly, the objective of the study is to improve determination of C factor using vegetation indices.

METHODOLOGY

Estimation of C Factor Based on Vegetation Indices

Required materials such as experimental plots, soil samples, canopies, portable spectroradiometer (MS-720E), and white panel were prepared. Soil physical properties were analyzed and classified based on IUSS method (Table 1). For each plot, same amount of soil samples was used and were randomly planted canopies with coverage approximately ranging from 0% to 70%. In total, there were three different kinds of treatments; (a) *Andosol* (1) + *Ophiopogon japonicus* (b) *Ultisol* + *Ophiopogon japonicus* (c) *Andosol* (2) + *Lolium perenne*. At the beginning, white panel was used for calibrating effect of shadow and spectra reflectance of red light and near-infrared red were measured in each plot by spectroradiometer outdoor (Fig.1). After reflectance spectra data of each plot was acquired, vegetation index was calculated as in Eq. (2) proposed by Deer (1978).

$$NDVI = (NIR - Red) / (NIR + Red) \quad (2)$$

Where NDVI is Normalized Difference Vegetation Index calculated with function of reflectance differences between red and near infrared red (NIR), Red is reflectance of red light (630 nm - 690 nm) and NIR is reflectance of near-infrared red (775 nm - 900 nm). Secondly, experiment of soil erosion was conducted under artificial rainfall simulator for evaluating C factor (Fig. 2). Plots were placed on slope of 8 degree under rainfall simulator. At each trial of rainfall simulation, rainfall intensity was varied from 36 to 120 mm/hr. for 30 minutes. Soil loss was collected after rainfall-simulation and measured by oven-drying for 24 hours. The weight of soil loss was used for computing C factor based on the ratio of soil loss between the plots with bare soil and vegetation cover. Finally, the graph of the relationship between C factor and vegetation index was drawn. Besides, equation of C factor based on vegetation index was established by statistical regression analysis.

Table 1 Soil physical properties

Soil	Specific gravity	Pacticle size distribution (%)					Ignition loss (%)	Soil texture
		Gravel	Coarse sand	Fine sand	Silt	Clay		
a. Andosol (1)	2.64	1.2	17.9	16.7	31.8	32.4	15	Sandy Clay Loam
b. Ultisol	2.73	0.1	0.9	15.5	49.6	34.0	8	Clay Loam
c. Andosol (2)	1.53	2.4	4.2	9.9	27.0	56.5	64	Clay

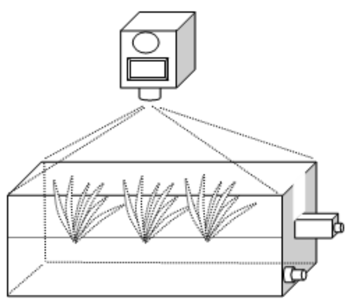

Fig. 1 Experiment for evaluating vegetation index

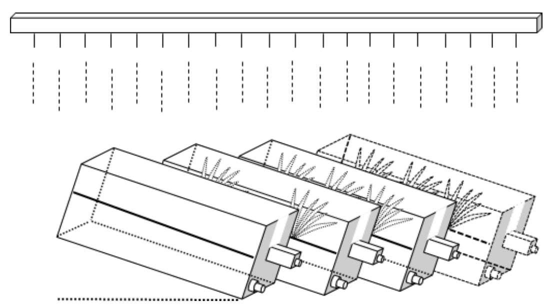

Fig. 2 Slope model experiment for evaluating C factor

Field Measured C Factor

In this procedure, field C factor was measured in study area. Study area is located in Linkou distinct, north part of Taiwan. It lies in 25°3′ to 25°9′ N latitude 121°17′ to 121°25′ E longitude (Fig. 3). Total area of study is 54.15 km^2. Forest and agriculture are main dominant land use pattern in Linkou distinct. Annual average rainfall is about 2500 mm. Degree of soil erosion is influenced by changes of vegetation and land use pattern. Main species of canopy in the field is *Eremochloa ophiuroides* (*Munro*).

To determine field C factor , parameters such as amount of annual soil erosion (A), rainfall and runoff erosivity factor (R), soil erodibility factor (K), topographic factor (LS), Soil conservation practice factor (P) were measured in the field. In addition, field measured C factor are computed based on Eq. (3).

$$C = A / RKLSP \tag{3}$$

As the arrangement for measuring annual soil erosion (A) was illustrated in Fig.4, two poles were inserted into ground surface tightly and deeply in the field. Initial difference of height for both sides of the pole was 17.5 cm. Both side of the pole was connected with a baseline of 14.9 m long and was given a mark at every 10 cm interval. After equipment was installed in the field, the height from baseline to the ground was measured and recorded at interval of 10 cm. Experiment was conducted from 13 September, 2014 to 5 September, 2015. Changes of soil surface and dried density of soil was measured to calculate total amount of soil erosion (A) in the field. Data of hourly rainfall from 2004 to 2013 was collected from local weather station for calculating rainfall and runoff erosivity factor (R). Soil erodibility factor (K) and topographic factor (LS) was computed based on field measurements and experimental analysis. Soil conservation practice factor (P) was assumed as 1.

Fig. 3 Study area

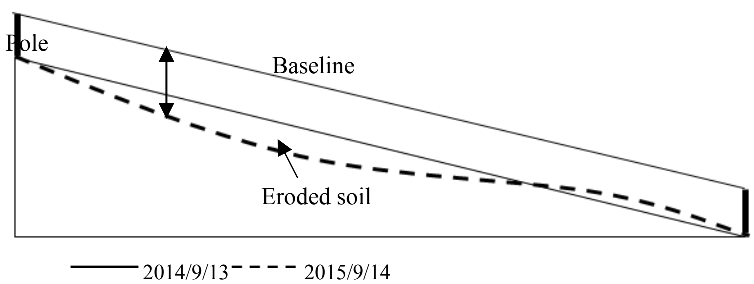

Fig. 4 Observation of soil erosion in the field

Validation of Determination of C Factor Using Vegetation Indices

By comparing with field measured C factor, estimated C factor based on vegetation indices could be validated. Estimated C factor was derived by substituting monthly field vegetation index into C factor equation based on NDVI. Moreover, monthly vegetation index was calculated as in equation (2) with data of satellite-image of Landsat 7 from 2014 to 2015. The satellite-image was first downloaded from website of NASA and calibration of atmospheric effect was done by following instruction of Landsat 7 Handbook.

RESULTS AND DISCUSSION

Estimation of C Factor Based on Vegetation Indices

The estimation of C factor of USLE or RUSLE becomes challenging as land use pattern and vegetation change (Alejandro, et al., 2007). It was thought that determining C factor using vegetation indices is promising technology for responding to fast land use and vegetation changes. Lin (2002) stated that there is linear correlation between C factor and NDVI. Moreover, Van der Knijfff (2000) presented exponential C factor equation based on NDVI, which is applicable for environmental condition in Europe. As results of experiments shown in figure 5, it shows linear correlation ($R^2 = 0.69$) between C factor and NDVI. The result is similar to approach of Lin (2002). Nevertheless, it was observed that NDVI is highly variable as C factor equals to 1. It would decrease accuracy of estimation of C factor. Therefore, Soil-Adjusted Vegetation Index (SAVI) presented by Huete (1988) was applied to improve estimation of C factor. Equation of Soil-Adjusted Vegetation Index (SAVI) can be expressed as follows.

$$SAVI = (NIR - Red)(1 + L) / (NIR + Red + L) \quad (4)$$

Where L is an adjustment length and it was assumed as 0.5. In Fig. 6, the relationship between SAVI and C factor was shown. The results indicated SAVI is more strongly correlated with C factor than NDVI. Correlation R^2 increases from 0.69 to 0.73. Huete (1988) indicated estimation of vegetation based on SAVI is less affected by soil background. It means estimation of C factor based on SAVI is more accurate than NDVI in the field where there are several types of soil. Besides, it was observed that there is less variation in SAVI than NDVI under bare soil (Table 2). Moreover, it was observed that equation established by statistical regression analysis (Figs. 5 and 6) has similar mathematic structure which could be defined as follows:

$$C = -a\, VI + 1;\ VI < 0,\ C = 0 \quad (5)$$

Where C is cropping management factor, VI is vegetation indices which represents vegetation signal response of canopy, and *a* is defined as efficiency of vegetation in reducing soil erosion rate. The *a* is equal to 0.82 when VI is NDVI, and *a* is equal to 1.18 when VI is SAVI. It was considered that the value of *a* may decrease as height of vegetation increases because higher vegetation has lower efficiency in reducing soil erosion rate (Wischmeier and Smith, 1978; Renard, 1997). In the case of study, heights of vegetation were about 5 cm to 15 cm.

Table 2 Comparison of NDVI and SAVI under bare soil

	NDVI			SAVI		
	Max.	Min.	Sd.	Max.	Min.	Sd.
Bare soil	0.30	0.06	0.07	0.16	0.03	0.03

Sd. is standard deviation

Field Measured C Factor

About 72 ton/ha/yr. of soil loss (A) was observed in the field (Fig. 8). Moreover, field measured C is equal to 0.56 which is calculated by following parameters summarized in Table 3.

Validation of Determination of C Factor Using Vegetation Indices

The results of monthly NDVI and SAVI (Fig. 7) are shown. Moreover, estimated C factor based on different approaches were summurized in table 4. It was observed that estimated C factor based on both

NDVI and SAVI are higher than field C factor. Moreover, although SAVI is more strongly correlated with C factor than NDVI (Figs. 5 and 6), estimation of C factor based on NDVI is most accurate with 30 % of relative error. It was considered that estimation of C factor based on SAVI becomes accurate as different types of soil is existed in the field. However, only single type of soil (Ultisol) was found in the field. Furthermore, it was observed that both estimated C factor based on NDVI and SAVI are more accurate than appoach of Lin (2002).

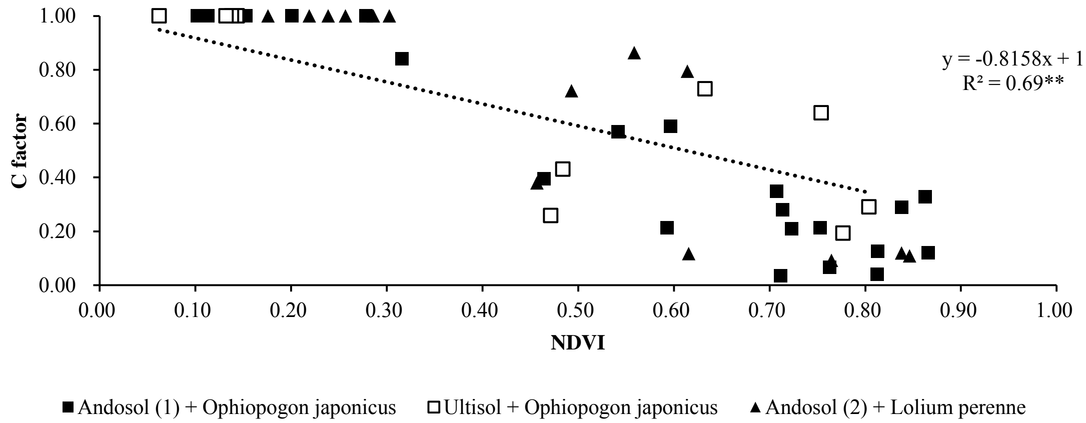

Fig. 5 Relationship between C factor and NDVI

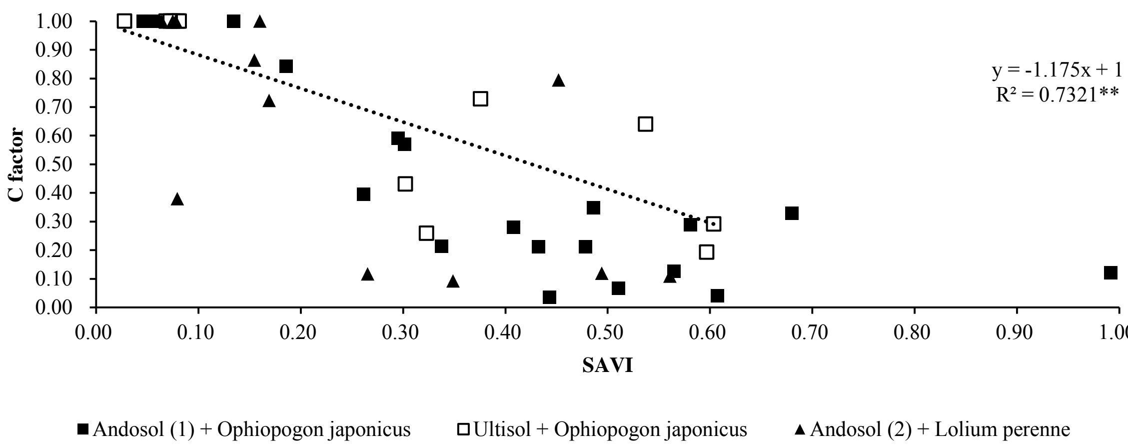

Fig. 6 Relationship between C factor and SAVI

Table 3 Parameters for calculating C factor in the field

A	R	K	L	S	P	Field measured C factor
72	8135	0.02	0.82	0.96	1	0.56

Table 4 Comparison of field C factor with different C factor approaches

C factor (Field)	C factor (NDVI)	Relative error %	C factor (SAVI)	Relative error %	C factor (Lin, 2001)	Relative error %
0.56	0.73	30%	0.76	36%	0.33	45%

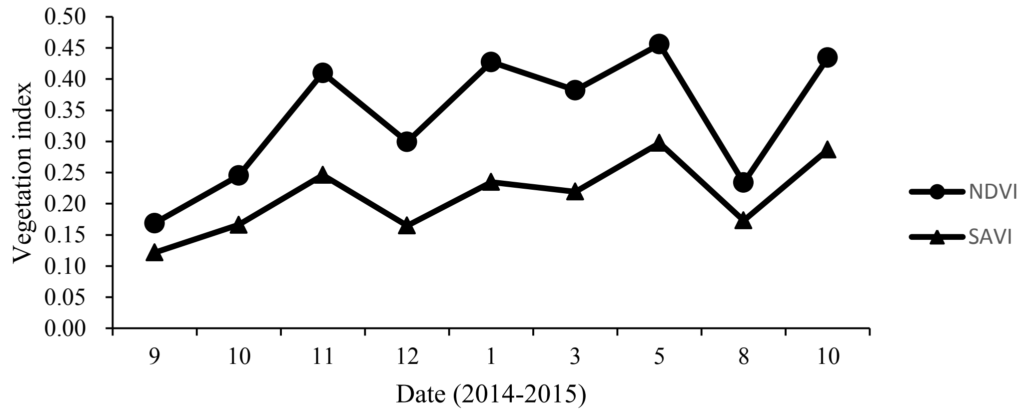

Fig. 7 Variation of vegetation indices from 2014 to 2015

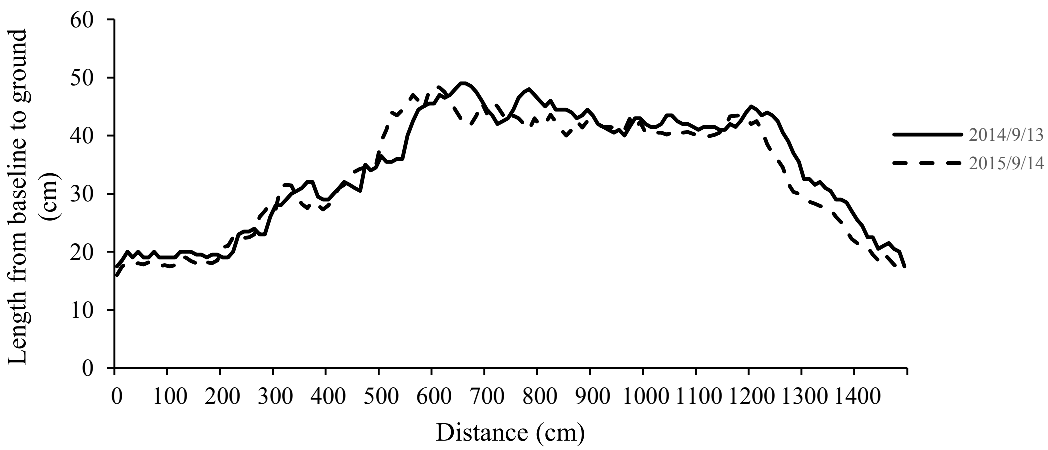

Fig. 8 Changes in heights from baseline for evaluating annual soil loss in the field

CONCLUSION

Therefore, it was concluded that (1) vegetation indices have high potential to determine C factor of USLE or RUSLE, (2) estimation of field C factor based on SAVI is more recommendable for determination of C factor in the field where there are several types of soil. For the future research plan, the experiment for evaluating the relationship between C factor and vegetation indices will be conducted in other different kinds of vegetation and soil. Also, more field erosion model experiments will be conducted for validating determination of C factor using vegetation indices.

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