is higher when clean-tilled row crops are cultivated than when cereals are planted.

17.2.4 Prediction of soil loss

There have been various efforts to quantify and predict erosion losses. Wischmeier and Smith (1965/1980) developed an equation called the **Universal Soil Loss Equation** (USLE) for predicting losses from cultivated fields by sheet and rill erosion. Soil erosion is influenced by several variables; the USLE serves to assess the effect of each of them. This information is helpful in managing land and crops so as to reduce erosion losses to permissible limits. The USLE was first tested on agricultural lands in the USA, and was later applied to a variety of soils in the USA and some European countries. The equation is represented as follows:

$$A = R \times K \times LS \times C \times P$$

where

A = soil loss in metric tonnes per hectare ($t\ ha^{-1}$).

R = rainfall and runoff factor — rainfall erosivity ($j\ ha^{-1}$).

K = soil erodability factor — soil loss per rainfall erosivity unit from a unit plot (a bare, fallow, 9 percent slope of 22.6 m length), expressed in metric tonnes per joule ($t\ j^{-1}$).

LS = slope length and steepness factor (compared to reference values of 22.6 m length and 9 percent slope), dimensionless.

C = crop management factor — a ratio which compares soil loss from an experimental field with that from a field with standard treatment, dimensionless.

P = conservation practice factor — a ratio which compares soil loss with that from a field with no conservation practices, dimensionless.

The numerical values for each variable on the right side of the equation — R (erosivity factor), K (erodability factor), LS (slope length and steepness), C (crop management), and P (conservation practice) — under a particular condition are calculated in their respective units on the basis of the climate, soil, and management practices for a given field. Multiplying the numerical values of R, K, LS, C, and P then gives the loss of soil in $t\ ha^{-1}$. The permissible limit of soil loss is stipulated as 12.5; if the product exceeds this value adjustment must be made in the LS, C, and P factors.

tures, characteristics that make the soil erodible. It will become even more erodible if the surface is mismanaged and the organic matter content declines.

The water erosion process requires a slope. Level land erodes slowly because the runoff velocity is slow. But as the slope increases, runoff velocity and erosion increase. This fact and others have been combined into a relationship (the Universal Soil Loss Equation) useful for predicting the rates of soil erosion.

Erosion prediction The **Universal Soil Loss Equation (USLE)** is widely used in the United States and other countries to predict the severity of erosion from farm fields. It is universal because the six factors are sufficient to describe the process:

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

In Equation 1

A is the long-term average annual soil loss for a field.

R is the long-term average rainfall–runoff erosivity factor.

K is a soil erodibility index.

L is a slope length factor.

S is a slope angle factor.

C is a soil cover factor.

P is an erosion control practice factor.

(For more detailed explanations, see Wischmeier and Smith, 1978, or Morgan, 1995.)

Rainfall impact and overland flow are responsible for soil erosion, but they are not easily measured. Rainfall amount (mm) and intensity (mm/hr) are easily measured, however, and these two factors are combined to estimate the long-term erosivity of rainfall and runoff for a location. The actual calculation of the R factor and other factors in the USLE is in Wischmeier and Smith (1978).

The K factor is a single number that combines the many soil properties that influence the soil's reaction to rainfall and runoff. Five properties have been combined to determine K: silt plus very fine sand, other sand, organic matter content, soil structure, and the soil permeability of the least permeable horizon. Silt and very fine sand are the most easily moved particles. Other sand (particles between 0.10 and 2.0 mm diameter) is less easily moved, and increasing organic matter decreases erodibility be[cause] it helps strengthen soil aggregation. Soil struct[ure] and permeability relate to the rapidity of ponding and runoff initiation. The least permeable horizon controls the profile's hydrology: Soils with strong structure do not detach easily and so are less erodible than are soils with weak or no structure.

Water flowing downhill accelerates to a maximum velocity based on the hill's steepness and length. The general relationship between slope length and soil loss is shown in Figure 15–3. For short slopes the rate of increase in soil loss rises rapidly, but for long slopes the rate of increase is very small. This shows that there is a limit to the length of a slope that will influence soil loss.

Slope angle also influences soil loss (Figure 15–4). Unlike slope length, as slope angle increases, soil loss rate also rises at an increasing rate, demonstrating why slope is such an important variable in soil loss.

Cover is the principal erosion control practice. If a soil is completely covered with vegetation, raindrops and overland flow will not be able to detach particles. In the USLE, the cover factor (C) is the ratio (from 0 to 1) of soil loss from a plot with some level of cover to soil loss from a bare plot. The C value is determined by experience rather than by an equation and includes the kind of cover and the amount of the soil surface covered. (See Section 15.4 for more on erosion control.)

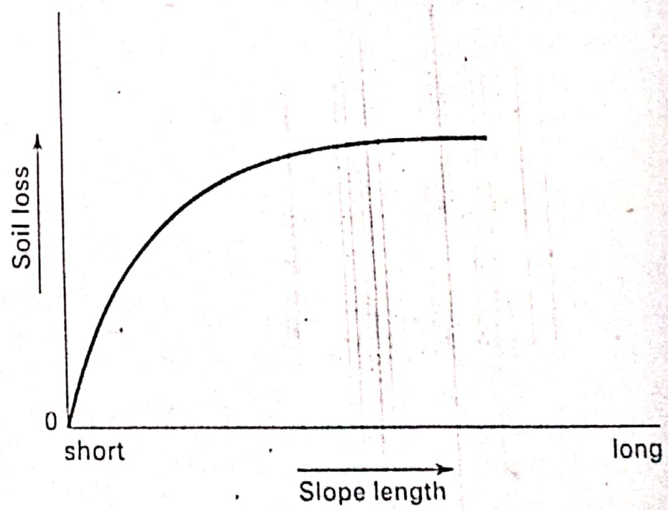

FIGURE 15–3 Soil loss increases as slope length increases, up to some maximum length depending on the slope angle. Most agricultural field lengths are in the steep portion of the curve.

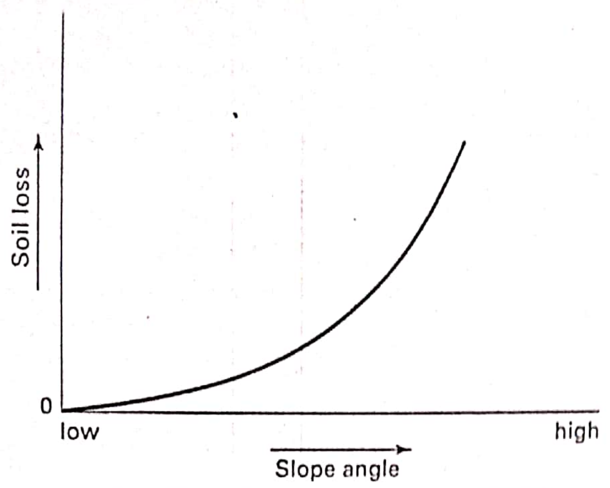

FIGURE 15–4 Steep slopes are susceptible to severe soil erosion because soil loss increases exponentially as the slope angle increases.

The final factor in the USLE is the conservation practices (P) factor. Like the L, S, and C factors, it compares the soil loss from a soil with conservation practices with that of one plowed up and down the hill with no erosion control practices. Conservation practices include contour tillage, terraces, and grass waterways. The no-practice condition gives a P factor of 1.

Once all of the factors have been determined, they are multiplied together to yield the predicted average annual soil loss from the field or construction site. This number can be used to determine whether conservation practices are required and what level of C or P factor is necessary to reduce the soil loss to the desired level. The equation is not designed to predict erosion from watersheds or individual storms.

The USLE has served the erosion community well since its inception, but it had limitations, particularly in the western United States. The USDA has developed two new erosion models in recent years. Both are products of the USDA Agricultural Research Service and the USDA National Soil Erosion Research Laboratory. One, the revised USLE (RUSLE), modifies each of the six factors in the USLE but does not change the basic structure of the equation. Each of the changes was made to improve the accuracy of predictions and to extend the usefulness of the equation to the entire United States.

The RUSLE expands on the original USLE and includes changes that make it more widely applicable in the United States. It continues to rely on field plot and rainfall simulation data and is thus an empirical equation much like the original USLE. The factors are defined in much the same way as in the USLE. The A factor continues to be defined as a long-term average annual soil loss over a field slope, and losses at various points on the slope may differ greatly from one another.

R The R factor, with a few exceptions, is calculated for the RUSLE just as it is calculated for the USLE. The changes that have been made are in how rainfall energy is calculated. The formula that is now recommended is as follows:

$$e = 1099[1 - 0.72\, e^{(-1.27i)}] \qquad (2)$$

i has units of inches per hour, and e has units of foot-tones (ft) per acre per inch.

The metric equivalent is

$$e_m = 0.29[1 - 0.72\, e^{(-0.05 i_m)}] \qquad (3)$$

Units of e_m are megajoules per hectare per millimeter rain, and i_m has units of millimeters per hour. One can calculate the R value for an area by taking the average sum of EI values for all storms over all years. The original R value was calculated for storms that had more than 0.5 in. of rain. The R value in the RUSLE includes all storm records for the western states. This recognizes that in the western United States, any storm, not just those producing over 1/2 in. of rain, may have the potential to produce erosion.

Two other changes in the RUSLE are the inclusion of the effect of ponded water on the soil surface and an R equivalent for cropland in the northwestern wheat and range region. The R equivalent is used where rain on frozen ground and snowmelt have been shown to be very important in soil loss prediction.

K The definition of K remains the same in the RUSLE as in the USLE, but calculation methods have changed. For example, surface rock fragments are now incorporated into the RUSLE; surface rock fragments protect the surface from direct raindrop impact and influence interrill flow on the soil surface. Subsurface rocks influence infiltration by reducing the volume of soil available to transmit water. In the RUSLE, surface rock fragments are considered within the C factor and subsurface rock fragments in sand- and loamy-sand–textured soils. The effect is considered within the permeability portion of the K factor calculation.

Seasonal variation in K values is considered in the RUSLE. Variations in K values appear to be due to soil freezing, soil texture, and soil water content. It is thought that freezing and thawing increase soil erodibility through the effect on soil structure, hydraulic conductivity, bulk density, aggregate stability, and soil strength. In areas that do not have many freeze thaw cycles, it has been proposed that the K value declines to a minimum over the growing season and then increases to its maximum some 6 months after the end of the growing season.

L and S The LS factor represents the ratio of soil loss on a given slope length and steepness to soil loss from a slope that has a standard length and steepness. The equations were first developed for uniform slopes and then extended to include nonuniform slopes. The slope length factor, L, is calculated, as it was in the USLE, from the following equation:

$$L = \left(\frac{\lambda}{72.6}\right)^{m} \quad (4)$$

where λ is the actual slope length and m is a variable slope length exponent based on slope steepness. All units are feet. A major change in the RUSLE is the way in which the slope steepness factor, m, is calculated. It is now related to rill and interrill erosion processes through a factor termed β, which is the ratio of rill to interrill erosion. If a soil is highly susceptible to rill erosion, the exponent m should be increased. In some cases the value of β needs to be doubled to adequately predict m. Similarly, if slopes are known to resist rill erosion, β should be decreased. In the RUSLE manual, tables are given to assist in the selection of values for β and m.

The slope steepness factor, S, is calculated using equations for different conditions as follows. Implicit in all of these equations is the concept that runoff is not a function of slope steepness.

$$S = 10.8 \sin\theta + 0.03 \text{ for } s < 9 \text{ percent} \quad (5)$$

$$S = 16.8 \sin\theta - 0.50 \text{ for } s > 9 \text{ percent} \quad (6)$$

$$S = 3.0 (\sin\theta)^{0.8} + 0.56 \text{ for slopes shorter than 15 ft} \quad (7)$$

Under the special conditions of the Pacific Northwest, where recently tilled soil is thawing, in a weakened state, and subjected primarily to surface flow, use

$$S = 10.8 \sin\theta + 0.03 \text{ for } s < 9 \text{ percent} \quad (8)$$

$$S = (\sin\theta/0.0896)^{0.6} \text{ for } s > 9 \text{ percen}$$

Both the USLE and RUSLE have a systematic me[...] for calculating LS for nonuniform slopes.

C and P The C and P factors are used in the RUSLE as they were used in the USLE, but some new twists have been added. For cultivated crops, the C factor is calculated for time periods. In forestland and rangeland situations, the C factor may not change appreciably over the season and a single C factor may be used.

The terminology in the RUSLE changes a bit in that the soil loss ratio (SLR) for each crop stage is calculated and then multiplied by the fraction of rainfall and runoff erosivity (EI) for the period. These EI weighted values are summed for the year to obtain an overall C value. The time step for calculating the C factor, like the EI factor, was chosen as 15 days. The first half of the month consists of 15 days always, and the second half has a variable number of days depending on the length of the month. This provides 24 periods during the year for which SLRs are calculated. These periods may be subdivided if needed.

The calculation of the soil loss ratios (SLR) is based on five subfactors ($PLU*CC*SC*SR*SM$). Each is calculated separately, then multiplied together to equal the SLR for the given conditions. These subfactors are as follows:

PLU is the prior land use subfactor

CC is the canopy cover subfactor

SC is the surface cover subfactor

SR is the surface roughness subfactor

SM is the soil moisture subfactor

The RUSLE uses a crop database to store values required to calculate the variables that go into the subfactors. These values include growth characteristics of vegetation, amount of residue produced, and residue characteristics. Another database within the RUSLE has temperature and rainfall data for locations so that residue decomposition rates can be calculated.

PLU considers the influence on soil erosion of subsurface residual effects from previous crops and the effect of previous tillage practices on soil consolidation. *Bu* accounts for the effect on erosion rates of live and dead roots and incorporated residue. Subfactor *CC* accounts for interception of raindrops and

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reduction in the energy of raindrops that reach the soil surface. The *SC* subfactor accounts for the reduction in area of the soil surface that can be directly impacted by raindrops, thus reducing detachment. It also accounts for reduced capacity for transport by overland flow due to slowing of the overland flow rate and increased tortuosity of the flow path produced by the cover. Finally, cover produces ponding behind the cover elements, which results in deposition, and, if deep enough, it also reduces the effect of raindrop impact. This is perhaps the most important of the subfactors.

The surface roughness subfactor, *SR*, accounts for the effects of the random depressions and barriers that trap water and sediment on a rough surface. Surface roughness also reduces the velocity of overland flow, thus reducing its transport capacity and detachment. The soil moisture subfactor (*SM*) accounts for antecedent soil moisture and its effect on infiltration and runoff and their influence on soil erosion.

The support practice factor, *P*, has been defined for common practices including contouring, cross-slope strip-cropping, buffer strips, filter strips, terracing subsurface drains, diversions, and windrows. As with the other factors, *P* is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage. An overall *P* factor is calculated as a product of *P* subfactors for individual practices when practices are used in combination. These practices are considered in Section 15.4.1.

A second new USDA erosion model is the Water Erosion Prediction Project (WEPP). The WEPP model is a process-based computer model that uses fundamental physical principles and basic understanding of water erosion processes to predict soil loss. Erosion is a complex process, and the WEPP models the complex interactions among raindrops, overland flow, topography, soil properties, and surface cover to predict amounts of soil loss. Because of the approach taken by the designers of the WEPP, it includes deposition, ephemeral gully erosion, sediment yield, and spatial and temporal variability. The hillslope profile version of the model estimates when and where on the hillslope erosion is occurring. The goal is to use the model to better design soil erosion control measures and reduce sediment yield from watersheds. To be used, the WEPP will require much more data and more computer resources than the RUSLE.

Universal Soil loss equation :-

"It is an equation which predicts the average soil loss over time."

Several methods are available for measuring soil loss from different land units. Several equations are also available to estimate soil erosion. The Universal Soil Loss Equation (USLE) developed by Wischmeier & Smith (1978) is most useful.

"The USLE, an empirical equation, estimates average annual soil loss per unit area as a function of major factorss affecting sheet & rill erosion."

It enables determination of land management erosion rate relationship for a wide range of rainfall, soil slope, crop & management conditions & to select alternative cropping & management combinations that limits erosion rates to acceptable limits.

$$A = R \times K \times LS \times C \times P$$

where

A : Soil loss in t/ha/yr (metric)

R : Rainfall erosivity factor (J ha⁻¹) } Rain related factors

K : Soil erodibility factor (m t J⁻¹) }

L : slope length factor } (dimensionless) soil related factor

S : slope steepness factor }

C : Soil cover & management factor (dimensionless) } land management factor

P = Erosion control factor (dimensionless) }

R :- This takes into account the erosive effects of the storms.
It is the rainfall & runoff factor. R depends on local weather conditions.

K :- Factor K is related to rate at which different soils erode under the conditions of equal slope, rainfall, vegetative cover & soil management practices.
Some soils erode more easily due to inherent ability of soil.
Its value is low for soil with high infiltration rate.

→ Soil erodibility factor is the only factor in USLE with dimentions.
K depends on Texture, structure, organic matter content.

LS or topographic factor or slope factor :-
The LS is the expected ratio of soil loss percent area from field slope to that from 22.13 m length of 9 percent slope.
a bare, fallow 22.6 m

C :- It is expected ratio of soil loss from land cropped under specific conditions to soil loss from clean till fallow on identical soil & slope & under same rainfall.
C value ↓es with ↑ in soil cover.

P :- ~~Crops on land subjected~~
Factor P in USLE is the ratio of soil loss with a specified erosion control practice to the corresponding loss with up land - down cultivation.

Thus expected soil loss in any location can be controlled using USLE. Given values as

$R = 150$

$K = 0.03$

$LS = 0.5$

$C = 1.0$

$P = 0.5$

Expected soil loss would be

$A = R \times K \times LS \times C \times P$

$= 150 \times 0.3 \times 0.5 \times 1.0 \times 0.5$

$= 11.25$ t/ha/yr.

Working together, these factors determines how

→ how much water enters the soil.

→ how much runoff

→ how much soil is transported &

→ when & where it is redeposited.

Assumptions of USLE :-

① Tolerable soil loss :- At the heart of USLE is the assumption that a certain soil loss can be tolerated b/c soil forming processes will replace some of the lost soil.

The equation can then be used to determine if soil loss exceeds this amount.

Soil scientists have decided that soil losses b/w one & five tons/acre/year can be tolerated depending on quality & depth of soil. Symbolized by letter T in each soil series

② USLE predicts sheet & rill erosion only if a slope shows sign of gully erosion the results from equation will under state the amount of soil loss.