2. Literature Review

2.1 Soil Erosion

2.1.1 Erosion Process

Erosion is the detachment and transportation of soil particles from a site. Generally, erosion is categorized as geologic erosion or accelerated erosion. Geologic erosion is affected relatively little by ordinary human land uses, whereas accelated erosion reflects the type and extent of human activity in a given area (Harper, 1986). Both types of erosion generally increase with slope angle.

2.1.2 Effect of Soil Erosion

Soil erosion is a serious problem found on every country, particularly in the humid and semi-humid tropics. It has been the direct cause of the decline and fall of many societies in the world. It is recognized as a major cause of the depletion of soil productivity in agricultural land.

Soil erosion is both a physical and chemical process that eventually results in lower productivity. Maintaining and improving soil productivity is the key reason behind soil erosion control practices. The loss of soil productivity affects the future of urban areas as well as cultivated lands.

Chemical erosion results to the removal of nutrients from the land. This may occur in at least three ways. Some nutrients are lost because they are attached to soil particlesthat are physically removed from the field. Some nutrients are dissolved and carried away in drainage-water. Other nutrients are removed through plant uptake and the product (Williams, 1981). Ultimately, the reduction in soil productivity occurs. Plants are dependent on productive soil, if the soil does not have enough nutrients (minerals), subsoil generally contain fewer plant nutrients than topsoil, plants will not grow properly.

Physical erosion is the actual movement or loss of soil particles and organic matter, resulting to poorer water holding capacity. Lower soil water holding capacity subjects crops to more frequent and severe stress. Plant available soil water may be reduced by changing water holding characteristics of the root zone depth, subsoil are toxic to root or have high soil strength or poor aeration that retards root growth. The water holding characteristics of root zone are almost always changed when topsoil is moved because topsoil usually has higher plant available water capacity than the lower layers.

In addition, erosion reduces productivity by degrading soil structure. Degradation of soil structure increases soil erodibility, surface sealing and crusting and leads to poorer seedbed, which in turn cause poor seedling emergence and low infiltration. Reduced infiltration provides less opportunity for soil water storage.

2.1.3 Erosion Prediction and Estimation

Methods for estimating erosion are important tools in soil conservation. Since erosion cannot be measured easily, estimation methods are used to assess the magnitude of erosion, to identify areas of excessive erosion, and to project long-term changes in crop production from soil erosion.

There are four general categories of soil erosion estimation techniques (Harper, 1986). The first method is observed evidence in the field on the severity of sheet, rill and gully erosion, the exposure of rock or root of the trees and the sedimentation on foothills. The second technique is to model rate of erosion using the Universal Soil Loss Equation, calibrating as closely as possible to real conditions. The third is by setting run-off plots, which is time consuming and costly. The last method is an estimation from rainfall simulator.

The Universal Soil Loss Equation (USLE) has been used in Thailand for decades. When properly used, it is a useful tool for estimating soil erosion on farm-scale plots. Since it was developed from empirical data gathered in the midwestern United Stated where climate, slope, soil and agriculture differ from Northern Thailand. If one wants to use this model, one should adapt and modify the operation of such model to fit local conditions. The equation for estimating soil loss in USLE is as follows:

$$A = R.K.L.S.C.P. \qquad \text{----------- (1)}$$

where : A is total soil loss (t/ha/yr)

R is rainfall erosivity index (t-m/ha/yr)

K is soil erodibility index (t/m-t)

L and S are topographic factor

C is vegetative cover factor

P is erosion control practice factor

Rainfall erosivity index of a given rainstorm is equal to the product of total storm energy(E) times the maximum 30 min intensity (I_{30}). Rainfall energy is directly related to rainfall intensity (Wischmeier and Smith, 1978). The relationship is expressed by the equation.

$$E = 210 + 89 \log(I) \qquad \text{-------------------(2)}$$

Where: E is kinetic energy in tonne-meter per hectare-cm and,

I is intensity in centimeters per hour.

The energy of rainstorm was computed from recording raingauge data. The storm was divided into successive increments of essentially uniform intensity and computed the energy for each increment. Rain showers of less than 12.5 mm and separated from other rain periods by more than six hours are omitted from computations, unless as much as 6.25 mm of rain fell in 15 min

(Wischmeier and Smith, 1978). Due to EI-values for such rains are too small for practical significance and have little effect on monthly percentages of annual EI. However, there are few alternatives to estimate R in Northern Thailand with a scantness of continuous recording raingauges. One of the successful efforts in R modeling is the regression equation developed by Andrew Lo (as cited by Harper, 1986). His work was based upon records in the Hawaiian Islands, which rainfall amount, annual distribution and, intensity are similar to Northern Thailand. Lo equation is

$$R = 38.46 + 0.348\ (P) \qquad \text{-----------} \quad (3)$$

where: P is annual rainfall in millimeters and,

R is annual erosivity (EI_{30}) in m-T/ha/yr

Soil erodibility (K), is the annual soil loss from a standard bare plot (21.3 m-long with 9 % slope and kept in fallow conditions) divided by the annual rainfall erosivity. Its unit, in this case, is T/ha/m-T/ha and can be simplified as T/m-T. Direct measurement of the erodibility factor is both costly and time-consuming. However, K sub-factor can also be achieved conveniently by erodibility nomograph which was developed by Wischmeier and Smith (1978).

Topographic factor (LS), is based upon the ratio of steepness and length of slope to those from standard plot with 9 percent slope and 22.13 m in length. Slope length and steepness are measured from the field for each plot. Both the length and the steepness of the land substantially affect the rate of soil erosion by water. LS-subfactor was computed by an equation generated by McCool et al. (1987). The equation is as follows;

$$LS = (l/22.13)^{0.5} \times (0.172s-0.55) \quad \text{----------} \; (4)$$

where : LS is slope length and steepness factor,

l is slope length in meters and,

s is slope steepness in percent.

Cropping factor (C) represents the proportion of erosion under mentioned plant cover condition compared to erosion on bare soil. The value of "C" is affected by the type of crop grown, planting date, plant density and, mulch percentage. For each crop stage period, the erosivity value, mulch subfactor, and canopy subfactor are multiplied to yield of a C-value (Harper, 1986). An equation, describing linear effect of canopy cover, is as follows;

$$Y = 1 - 0.83X \quad \text{----------} \; (5)$$

where : Y is a canopy subfactor and,

X is the proportion of canopy covered (from 0 to 1.0)

An equation describes the effect of mulch cover for mulch subfactor is

$$Y = 0.9826 - 2.196X + 1.963X^{2} - 0.7276X^{3} \quad \text{----(6)}$$

where : Y is mulch subfactor

X is proportion of mulch (0 to 1.0)

Erosion control practices factor (P) is the ratio of soil moving off the field under a given type of supporting practice to that from up and down slope cultivation. The maximum value of "P" obtained from up and down slope cultivation is 1.0.

The value of soil loss can be transformed to soil depth, then relate with the soil productivity index. Since erosion occurs upper soil profile to be removed, productivity will decline if the subsoil is not as favorable as the eroded top soil.

2.1.4 Erosion Control Methods

Control of soil erosion on the fields depends upon selected soil conservation techniques appropriated to the site. Implementation and maintenance of those techniques on a long-term basis are to be considered. Soil conservation is good soil management, and conservation technique is a part of that management (Gil, 1974).

There are two general categories of soil conservation techniques, structural and agronomic methods. The structural methods are operated primarily by reducing the length or steepness of slope. Through these practices, amount of soil moving off a field can be reduced. However, significant erosion still occurs on bare soil between structures and rainsplash can still damage surface soil. The choice of conservation structure depends upon slope, soil type and depth, cropping systems, and availability of labor and capital for construction and maintenance. The major type of conservation structures found in northern Thailand are bench terraces, intermittent terraces, hillside ditches, and contour banks.

Agronomic conservation methods can protect the soil surface from raindrop energy while the benefits from their practices are better soil structure, texture and nutrient status. These methods vary from use of mulch, strip cropping, cover cropping, multiple cropping, minimum tillage, perennial cropping and agroforestry to maintain good ground cover. Among the agronomic methods, the development of better ground cover leads to the reduction of soil structure breakdown and surface sealing which is the major cause of soil erosion.

2.1.5 Criteria for Determining Tolerable Erosion Rates

Soil loss tolerance or allowable soil loss is defined as the magnitude level of soil erosion that will permit a high level of crop productivity to be maintained economically and indefinitely (Wischmeier and Smith, 1978). The soil loss tolerance will vary with soil type. Browning *et al*. (1947)

suggested that values should range from 4.5 t/ha/yr on soil with a restrictive layer such as a claypan to a high level of 13.6 t/ha/yr on thick loss soil with a deep, favorable rootzone. The USDA-SCS (1973, as cited by Hall et al. 1985) updated soil-loss tolerance of 2.2 to 11.2 t/ha/yr by using favorable crop rooting depth, which are shown on Table 1.

Table 1 Guide for assigning soil loss tolerance values to soil having different rooting depths (USDA-SCS 1973)

	Soil loss tolerance values (t/ha/yr)	
Rooting depth(cm)	Renewable soil*	Nonrenewable soil**
<25	2.2	2.2
25-50	4.5	2.2
51-100	6.7	4.5
101-150	9.0	6.7
>150	11.2	11.2

Note * Soil that have a favorable substratum and can be renewed by tillage, fertilizer, organic matter and other management practices.

** Soil that have an unfavorable substratum, such as rock, and cannot be renewed economically.

2.2 Productivity

2.2.1 Soil Productivity

The current definition of soil productivity is the capacity of a soil in its normal environment for producing a specified plant or sequence of plant under a specified system of management (SCSA, 1976 and SSSA, 1978 as cited by Meyer et al. 1985).

Productivity is usually measured in terms of the yield of one or more marketable plant components. Yields result from the interaction of numerous physical, chemical and biological factors. Although some of these factors cannot be measured satisfactorily, many can. This provides the challenge of selecting the proper parameters and measurement criteria (Meyer et al. 1985). Soils high in organic matter and nutrients, of medium texture, in good tilth, and 150 centimeters or more deep are recognized as highly productive.

Maintenance of soil productivity depends upon management practices as well as soil and site characteristics. The major ones being soil rooting depth, topsoil thickness, available water capacity, plant nutrient storage, surface runoff, soil tilth, and soil organic matter content (Hall et al. 1982).

2.2.2 Relating Soil Erosion and Productivity

The relative productivity of soil and its rate of soil erosion depends upon the presence of favorable rooting characteristics in the profile (Pierce et al. 1983). The soil, which has favorable both in surface and subsoil horizons, will subject to loss in productivity less than favorable surface and unfavorable subsoil horizons or favorable surface and consolidation or coarse fragment subsoil horizons (figure 1).

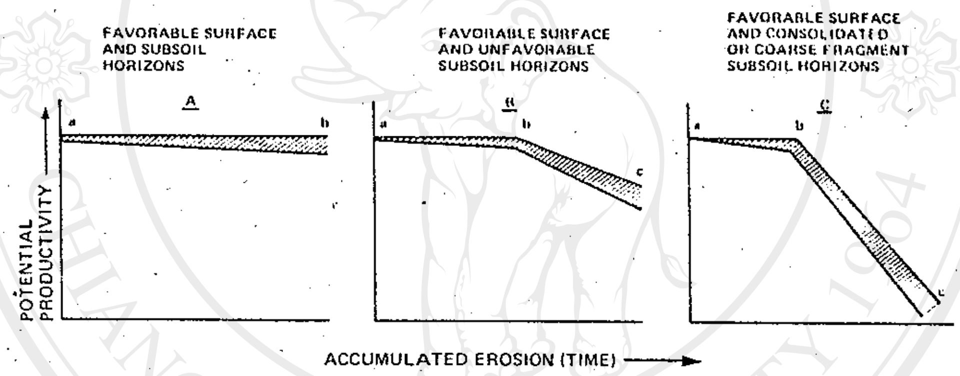

Figure 1 Concept of eroding productivity (Pierce et al. 1983)

Soil and topsoil depth have used frequently as predictors of crop production (Odell, 1950., Engelstad and Shrader 1961., Evans and Nortcliff, 1978., Langdale et al. 1979., Bramble-Brodahl, et al. 1985).

Many factors contribute to decrease in soil productivity due to soil erosion. The most frequently mentioned factor is the reduction in the plant available water-holding capacity of soil.

The crop is subjected to greater moisture stress through the interaction of decrease in soil depth (rooting volume) and the increase in the percentage of the crop root zone in the subsoil. The subsoil usually contains less desirable physical properties, because of more clay and poorer structure.

Degradation of surface structure is also the result of soil erosion. This less desirable structure creates greater bulk density which restricts seedling emergence and root penetration.

The third consequence of soil erosion is the loss of plant nutrients, such as nitrogen, phosphorus and potassium which can be solubilized in surface runoff or attached to soil particles that are removed during erosion.

Fourth, losses in organic matter are also prevalent with erosion, thus further contributing to the loss of nutrients and the decrease of structural stability.

In addition, tillage and seedbed preparation are usually made more difficult by erosion. More energy is needed and soil-seed contact is less complete when less topsoil and greater amounts of denser, more clayey subsoil are mixed in the plow layer.

2.2.3 Approach to Soil Productivity Estimation

Accurate estimations of future soil productivity are essential in agricultural decision making and planning from the field scale to the national level.

Soil erosion depletes soil productivity, however the relationship between erosion and productivity is not well defined. Until the relationship is adequately developed, selected management strategies that maximize long-term crop production will be impossible (Williams and Renard, 1985). One of the most urgent and important needs in research approach was the development of a mathematical model for simulating erosion, crop production, and related processes. This model will be used to determine the relationship between erosion and productivity.

1) Erosion-Productivity Impact Calculator (EPIC). This model is composed of physically based components for simulating erosion, plant growth, related processes and economic components for assessing the cost of erosion, determining optimal management strategies, etc. (William and Renard, 1985).

2) Soil Productivity Index (PI). This is a simple parameter model which evaluates the suitability of the soil as an environment for root growth in successive layers over the rooting depth. The relative productivity potential of soil is based upon soil available water capacity(AWC), resistance to root growth and development, and adequacy of pH to a depth of 100 centimeters (Pierce et al. 1983). The equation for PI calculation is as following:

$$PI = \sum_{i=1}^{r} (Ai \times Ci \times Di \times WF)$$

where :

PI = Productivity Index.

Ai = Sufficiency of AWC

Ci = Sufficiency of bulk density

Di = Sufficiency of pH

WF = Weighting factor

r = The number of horizons in the depth of rooting.

2.2.4 Maintaining and Restoring Soil Productivity

Maintaining and restoring soil productivity could be done by one or all of the following methods.

2.2.4.1 Soil Organic Matter

Raising the organic matter content is one of the most effective and practices always to help restore the productivity of eroded soils. Volk and Loeppert (1982) reported that yield potential increase by an average of 21 % for 1 % increase in soil organic carbon. Organic matter content can be increased by several soil management practices. Mulching, rotation with legume crops, cover crops and green manure are favorable. TAWLD (1985) suggested that cropping systems which returned dry matter more than 10 t/ha could maintain soil fertility on rainfed conditions. Restoring organic matter to the surface horizon of erosion damaged soils over time may eventually return most of physical properties to near original condition, with the exception of soil texture. As organic matter content of the surface soil increases, the degree of aggregation and the stability of the aggregates also increases. This in turn increases porosity, lowers bulk density, increases infiltration, decreases runoff and increases water-recharge. Increasing organic matter generally raises the total water-holding capacity as well as the water-supplying the production potential to erosion damaged soils, especially under rainfed water management (Frye et al. 1985).

Restoring organic matter also has beneficial effects on the chemical properties of soils. It is an important mobilizer of plant nutrients. Acids produced during the decomposition of organic matter facilitate the release of plant nutrients from minerals soil. And, as the organic matter decomposes, plant nutrients are mineralized to be available for plant use. Biologically, organic matter supplies the food for microorganisms in the soil. These microorganisms are important in the decomposition of organic matter, formation of humus, and transformation of plant nutrients into the forms available to higher plants (Frye et al. 1985).

2.2.4.2 Soil Amendments

The productivity of eroded soil can be increased by using soil amendment, such as fertilizer, lime, manure and other organic wastes. On eroded soils, the value of manures and organic matter goes beyond their value as sources of plant nutrients. They serve as mulch, reducing runoff and further erosion. They also increase soil aggregation, promote infiltration, and are good sources of organic matter, microbes for the rhizosphere, and organic ligands for chelation and movement of major plant nutrients into the soil profile (Hall et al. 1985).

2.2.4.3 Earth-Moving Restoration

Filling and leveling the land may be necessary before severely eroded and gullied soil can be used for crop production. Land leveling often creates a soil condition similar to growing plants on exposed subsoil or on reclaimed surface-mine soil. Heavy applications of lime, fertilizer, and organic waste usually are necessary for satisfactory soil restoration. Transporting topsoil sediments from depositional areas within a field to eroded areas of the field has been suggested as a means of restoring the productivity of eroded soils (Frye et al. 1985). The economic feasibility would depend on the increase in productivity offsetted to the cost of the operations.

2.2.4.4 Cropping and Tillage System

For restoration efforts to be beneficial, present and future soil erosion must be controlled on the site. One of the outstanding feature of the modern view of soil conservation is emphasized on the superior value of biological erosion control in contrast to mechanical methods (Frye et al. 1985). The vegetative cover needed to control soil erosion can be provided by crop residue, by cover crop grown during the intercrop period. Crop rotations that include forage, pasture, and small grain crops can provide sufficient and timely cover to control erosion.

Plant cover reduces runoff and soil erosion by retarding the flow of water over the soil surface and protecting the soil from the erosive forces of water or wind. The effectiveness of live vegetative cover is controlled mainly by the cropping system and the effectiveness of crop residue is controlled mostly by the tillage system. The conventional tillage system destroies the effect of plant cover in protecting the soil from erosion. While tillage is once used mainly to prepare a seedbed and control weeds, the tillage system has become a very important measure in soil conservation in recent year. Conservation tillage system which leaves the soil protected by vegetative cover increases infiltration of water, reduce runoff, improve soil water efficiency, and increases the soil organic matter content. Crop residues conserve soil and water either mixed into the soil or left on the surface. They are far more effective when left on the surface (Mannering and Meyer, 1963., Wischmeier and Mannering, 1965).

2.2.5 Development and Practices for Sustainable Productivity

Traditionally, highland farmers prepared their lands by "slash and burn" method. The lands to be cultivated were cleared by traditional tools, such as hoe, axe and spade. The debris or residue of the preceding crops were collected and burned. This resulted in a serious erosion problem, because the ground surface was free vegetative cover during high erosive power of the rain at the beginning of rainy season. This led to the degradation of both soil structure and fertility resulting in unacceptable decline in soil productivity. One possible solution to these problems should be an introduction of appropriate agronomic practices which can provide better ground cover. Social and economical facets of farmers should also be taken into considerations when agronomic practices are designed. Thus an approach of a research to meet the above conditions is to study soil subsystems, crop-ecosystem, and farmers' managements that may affect soil erosion.