Review

# Assessment of soil loss tolerance

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## ABSTRACT

Soil degradation in all its forms has a serious effect on crop and biomass productivity and poses potential threat to sustainability of agriculture. Some soil loss is tolerable but not so much that plant productivity diminishes. Thus productivity is of utmost concern in evaluating soil loss tolerance. The effect of soil loss on productivity is difficult to determine. Therefore other alternative approaches are discussed for computing limits of soil loss tolerance. These approaches are soil profile thickness, rate of soil formation, productivity index and weighted additive model. Assessment of soil loss tolerance (T-value) serves as a tool to gauge the potential erosion risk in the given area with regard to long term sustainability. Thus the T-value must be determined scientifically and rationally. Each approach which is used to determine soil loss tolerance has its own assumptions, advantages and limitations Further the soil loss tolerance is used to calculate the erosion tolerance index (ETI) by considering annual soil loss. These can serve as a guide for policy makers to decide upon effective watershed management plan.

**Keywords:** Erosion tolerance index; productivity index; soil degradation; soil loss tolerance; weighted additive model

## INTRODUCTION

Soil degradation in all its forms has a serious effect on environment and crop productivity. Soil degradation has reached alarming proportion in many parts of the world which is the biggest threat to food security. Erosion caused by water is a major factor contributing to land degradation in India and other countries. Globally about 24 BT of the soil is lost annually through water erosion. According to the FAO about 18 per cent of the arable lands in the world could be lost forever if no measures were taken to preserve them. According to the recent estimates more than 120 Mha of land area is under various forms of land degradation in India of which 74 Mha is affected by water erosion (Sharda et al 2013). Water erosion alone contributes to 5334 MT (16.4%) of the soil loss every year that constitutes 29 per cent and is lost permanently into the sea and 10 per cent is deposited in the reservoirs reducing their capacity by 1-2 per cent every year. About 30-50 per cent of the world's arable lands are substantially degraded due to soil erosion which directly affects the rural livelihood, aquatic resources, global C cycling, aquatic and terrestrial biodiversity and ecosystem (Mandal and Sharda 2011). Soil degradation processes can be stopped or reversed by prompted actions of various kinds. Recently FAO has sponsored two expert consultations for assessing soil degradation. The consultation recommended that land be recognised as essential and limited resource. Secondly the adverse effect of soil degradation on the future food suppliers of the world must be considered. Thus it accorded the highest priority to the soil conservation measures to ensure nutrition and adequate diet for increasing population. In this connection suitable soil conservation measures may be undertaken to slow down the process of land degradation on field to watershed scale. The soil loss tolerance (T-value) is defined as the maximum level of annual soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely (Wischmeier and Smith 1978). Quantification of soil loss tolerance value is a major challenge for researchers, planners, soil conservationists and environmentalists. The T-value is assigned to bare soils without considering land use or conservation. However many of the factors used to define a T-value are important in relation to vegetation response (Hacisalihoglu et al 2010). The major objective of assessment of soil loss tolerance is to maintain soil loss at a minimal level and to lower the nutrient losses for better crop production on sustainable basis. The concept of soil loss tolerance rests upon two assumptions that soil scientist can assess reliably and objectively the maximum rate of the soil erosion that can be tolerated and that policymakers can objectively make the policy decisions. Thus the concept of soil loss tolerance is compatible with the current thinking on the sustainability of agricultural system. Therefore soil loss tolerance must be assessed scientifically and rationally.

**Assessment of soil loss tolerance: approaches**

The different approaches have been proposed in literature to assess soil loss tolerance of a place. These are soil profile thickness, soil formation rate, productivity index, weighted additive mean methods etc. However no approach can be universally applicable and each approach is based on certain assumptions, advantages and limitations. These approaches are given below:

**Soil profile thickness:** The conceptual model was developed to compute soil loss tolerance by employing the parameters like tolerant minimum soil thickness, current soil thickness and lower limit of soil loss tolerance (Stamey and Smith 1964). It can be applied to any point on the land surface and can be expanded over a region. However it suffers from several limitations such as it is very costly and labour intensive process; involves no guiding criteria for the measurement of soil property and requires exhaustive information on large number of parameters. In this connection the mathematical expression developed for assessment of soil loss tolerance at a point is:

$$\mathrm{I}(x,y) - \int_{to}^{\infty} [\mathrm{E}\,(x,y,t) - \mathrm{R}\,(x,y,t)]\, dt \geq \mathrm{M}\,(x,y) \qquad (1)$$

where I(x,y)= Position function which gives the value of the measure of the soil property at the initial time $t_o$, M (x,y)= Minimum allowable value at (x,y) of the measure of this property, E (x,y,t)= Erosion rate, R (x,y,t)= Renewal rate of the measurable soil property

The equation defines the concept that net change tolerance [E (x,y,t) – R (x,y,t)] integrated over time subtracted from the initial value of the measurable soil property must always exceed the minimum allowable value.

Skidmore (1982) expanded the equation (1) for tolerable degradation and applied the equation to soil depth although it could be used for other measurable properties both extensively and intensively. The new equation proposed is:

$$\mathrm{T}\,(x,y,t) = \frac{\mathrm{T}_1 + \mathrm{T}_2}{2} - \frac{\mathrm{T}_2 - \mathrm{T}_1}{2\cos\left[\frac{\pi\,(z - z_1)}{z_2 - z_1}\right]} \qquad (2)$$

where $T_1$ and $T_2$= Lower and upper limits of allowable rate of change of soil property respectively at point (x,y) (represents soil loss per annum), T (x,y,t) equals $T_1$ when soil depth is at minimum allowable value so that net change function of equation (l) equals zero, z, $z_1$ and $z_2$= Present, minimum and optimum soil depth respectively

In other words [E (x,y,t) – R (x,y,t)] dt equals zero and P (x,y) equals M (x,y) where P (x,y) is the present value of the soil property for a depth. However according to Shtompel et al (1998) this approach is discourteous since the intensity of soil profile restoration is different for soils and depends on the climate, vegetation and the hydrological regime.

The equation proposed requires the input data such as the minimum permissible thickness of humus horizon which is determined in experiment for individual crops. The optimal soil depth which is derived from soil and erosion surveys and rates of erosion-induced soil losses under the main crops determined by modelling. The approach has the advantage as it allows one to take into account changes in the soil quality knowing the humus budget in agro-ecosystem. The model employs the equation as:

$$Q_{set} = \left\{\frac{Q_h}{\Delta t}\left[1 + \sin\left(0.5\pi\,\frac{2h - h_1 - h_2}{h_2 - h_1}\right)\right] - \frac{Q_m}{\Delta t}\right\} - \frac{10}{gpk} \qquad (3)$$

where $Q_{set}$= Soil loss tolerance in mm/year, $Q_h$= Humus store that forms for one rotation in tons/ha, Δt= Duration of the crop rotation in years, h, $h_1$ and $h_2$= Actual, maximal permissible and optimal thickness of humus horizon of soil respectively, $Q_m$= Amount of humus mineralized for one rotation in tons/ha, g= Humus content in the arable layer in per cent, p= Bulk density of the upper (0-10 cm) layer of the soil in tons/$m^3$, k= Coefficient of increase of humus content in sediment than that in soil

The annual erosion-induced losses of brown forest soils of foothill part of Kuban can reach 0.85 to 2.3 tons/ha under tobacco, 0.64 to 1.7 tons/ha under inter-tilled crops and 0.2 to 0.8 tons/ha under perennial grasses as compared to the equation (3). These rates may be considered as the soil loss tolerance compensated by the natural soil formation and hence allow long term use of brown forest soil in agro-landscape. Rusanov (2006) used the method of score estimation of soil resistance to erosion by considering water permeability, aggregate-size composition and the humus status based on the classical grades of these properties. The method was successfully approved for forest steppe and steppe chernozems of the slope landscapes in the southern Cis-Urals. Kuznetsov and Abdulkhanova (2013) made linear modification of Skidmore's equation to compute soil loss tolerance for chernozems of the central chernozemic region. The soil loss tolerance values were obtained with due account for the soil type, the degree of erodibility and the crop rotation pattern. The maximum possible value (10 tons/ha/year) was obtained for a typical non-eroded chernozem in all the crop rotations. It was significantly at par with non-eroded with leached and typical chernozems (9.6–9.9 tons/ha/year) depending on the crop rotation pattern. The soil loss tolerance for the non-eroded podzolized chernozem was somewhat lower (9.1 tons/ha/year) in the grain-herb inter-tilled crop rotation and 6.3 tons/ha/year in the grain inter-tilled crop rotation. With an increase in the degree of the soil erosion the soil loss tolerance decreased in all the variants of the experiment with an especially abrupt decrease in the grain inter-tilled crop rotation (varying from 9.9-10.0 to 0.3–2.0 tons/ha/year non-eroded and slightly eroded respectively ordinary and typical chernozems). Kereselidze et al (2013) proposed procedure for the determination of the maximum allowable soil disturbance in Georgia in order to develop a strategy of soil conservation and restoration ie within the limits of $0.01 < r < 0.1$ (here r is allowable soil loss). The lower and upper limits of the allowable soil loss were determined for the soils of different thicknesses.

Annual maximum soil loss can be demonstrated as a representative of the total annual soil erosion (Bagarello et al 2014). A threshold soil loss value at the annual temporal scale was calculated by multiplying the frequency factor equal to 2 by the mean annual maximum soil loss values for each given plot length.

**Soil formation rate:** Barth's equation was used by Alexander (1988) for computing rate of soil formation and consider soil formation rate as T-value if the rate of soil loss is in dynamic equilibrium with the rate of soil formation. The equation employed was:

$$W = D + S \qquad (4)$$

where W= Mass of rock or consolidated sediments weathered, S= Mass of residue or soil formed from the weathered lithic or paralithic material, D= Mass of dissolved solid removed in runoff from the soil-parent material system

Alexander (1988) further developed the equation for dissolved load or the concentration of dissolved solid in stream water as follows:

$$dC/dt = k\,(C_m - C)/C_m \qquad (5)$$

where C= Actual concentration, $C_m$= Maximum concentration of dissolved solid, dC/dt= Rate of dissolution of the lithic or paralithic material, k= Constant

Integrating and assuming that C is negligible when t= 0 in that case:

$$\ln\,(1 - C/C_m) = -kt/C_m \qquad (6)$$

The time that a molecule of water remains in the soil or in the proximity of the lithic or paralithic contact is inversely proportional to the amount of precipitation, infiltration and ultimately runoff. The amount of runoff in time t will be equal to the constant k divided by t. So chemical denudation is equal to the product of runoff and concentration, D= QC. The substitution of t as constant/q and C as D/Q in equation (6) developed into new equation:

$$D = C_m Q\,(1 - e^{-k/cmq}) \qquad (7)$$

To obtain an equation for rate of soil formation, he transformed the mass balance equation 1 for the weathering of rock (W) to soil (S) and dissolved solids (D) to obtain D= S (W/S-1) where W/S is the inverse of the soil to weathered bedrock (S/W) ratio.

Substituting this relationship for D into equation (7) leads to new equation as below:

$$S= Cmq\,(1-e^{-k/CmQ})/(W/S-1) \qquad (8)$$

On the basis of these equations Alexander (1988) reported that soil loss tolerance of shallow and moderately deep soils formed from plutonic or non-carbonate metamorphic rocks is much lower than 2.24 mg/ha/yr where the predicted values of soil formation (S) range from 0.3 mg/ha/yr for S/W= 0.75 through 0.9 for S/W= 0.9 to 1.9 mg/ha/yr for S/W= 0.95. Soil loss tolerance for soils formed from calcareous sandstone and shales may be higher. Csaba et al (2001) reported T-value for Hungarian soil that varied from 2 to 12.5 tons/ha/year. However comparing to soil formation estimates it suggests protection on these soils of these areas. Liu et al (2009) compared the rate of soil formation computed by Barth's equation and rate of soil formation measured in the field of entisols in southwest China and through this the results obtained were contradicted in nature. Estimated rate of soil formation from the Barth equation were much smaller than the measured values in all corresponding treatments. Therefore the Barth equation is unreliable for predicting short term and on plot-scale soil formation rates. Even for soils with high rate of soil formation it underestimates the rate of soil formation values (Velbel 1985). The estimated rate of soil formation was based on the quantity of chemical denudation (*Di*) which is mainly controlled by the runoff volume and concentrations of element in the runoff. As soil formation involves both physical and chemical processes the former process plays an especially important role in soil formation which may contribute to the low estimated SR values.

**Productivity index model:** Soil parameters viz available water capacity, bulk density, aeration, pH and electrical conductivity are the parameter(s) most influencing the root growth and the productivity index (PI) is calculated using the following equation:

$$PI \sum_{i=1}^{r}(A_i \times B_i \times C_i \times D_i \times E_i \times WF_i) \qquad (9)$$

where Ai= Sufficiency of available water capacity, $B_i$= Sufficiency of aeration, $C_i$= Sufficiency of bulk density, $D_i$= Sufficiency of pH, $E_i$= Sufficiency of electrical conductivity, $WF_i$= Weighted factor.

The description of the model parameter has been given in the Table 1.

For an erosion-prone soil in Tanzania the Neill's PI model explained only 47 per cent of the variability in sorghum yield. Mulengera and Payton's PI model incorporating evaporation explained 87 per cent of the variability (Mulengera and Payton 1999). Pierce et al (1983) modified Neill's model to include some additional concepts and used data available in the SOIL-5 data base and developed a numerical approach. The model for evaluating productivity index (PI) is:

$$PI = \sum_{i=1}^{r}(A_i \times C_i \times D_i \times WF) \qquad (10)$$

where $A_i$= Sufficiency of available water capacity, $C_i$= Sufficiency of bulk density, $D_i$= Sufficiency of pH, WF= Weighted factor

Here PI varies from 0 to 1. The value 1 corresponds to a soil without any kind of limitation for root development. The method has certain advantages such as easy to identify critical land resource areas which are facing productive capacity loss due to erosion and provide a framework for continual use and protection of soil and water resources. However it requires a complicated depth-wise data set for available water capacity, bulk density and pH which at present is not available for most of ecological regions of India. It is very labour intensive and time consuming approach for gathering the information on different parameters.

**Soil loss tolerance:** The soil productivity permissible loss rate planning horizon for sustainable land use (δ - H) approach is used to evaluate soil loss tolerance (Delgado and Lopez 1998) by using following socioeconomic variables viz soil productivity permissible loss rate δ (%) and the planning horizon for sustainable land use H (years). Soil erosion vulnerability curve relating PI values and soil losses are employed to estimate T-value by following the equation:

$$PI_f = PI_i(1 - \delta) \qquad (11)$$

where $PI_f$= Final soil productivity index after soil removal, $PI_i$= Initial soil productivity index, δ= Soil productivity permissible loss rate in per cent

With the value of $PI_f$ on the respective vulnerability curve the correspondence amount of soil loss in cm is obtained which when divided by a previously selected planning horizon (H, years) allows the calculation of soil loss tolerance in cm/year. Knowing

Table 1. Description of model parameters

| Parameter | Computation | Abbreviation |
|---|---|---|
| Sufficiency of available water capacity ($A_i$) | $A_i = C_w \times D_b$ | $C_w$= Mass water content<br>$M_{sm}$= Mass of wet soil<br>$M_s$= Mass of dry soil<br>$D_b$= Bulk density (g/cc) |
| Sufficiency of bulk density ($C_i$) | $C_i = 0.826 \times D_{bc}$ | $D_{bc}$= Critical bulk density (g/cc)<br>f= Porosity (%)<br>$D_p$= Particle density (g/cc) |
| Sufficiency of pH ($D_i$) | $D_i = 1.0$<br>$D_i = 0.12 + 0.16$ pH<br>$D_i = -1.31 + 0.446$ pH<br>$D_i = 0.0$ | if pH >5.5<br>If pH= 5.0-5.5<br>if pH= 2.9-5.0<br>If pH <2.9 |
| Weighing factor (WF) | | D depth of each horizon (cm) |

Source: Delgado et al (1998)

the values for bulk density in Mg/m$^3$, soil loss tolerance can be expressed in Mg/ha.

Delgado et al (1998) (Table 1 and 2) used the δ - H approach to compute soil loss tolerance of three sectors of Las Playitas watershed at the Venezuelan Andes. Lal (1984) used this model for several soils in Nigeria and observed that in spite of modifications made in sufficiency functions there were significant differences in observed yield trends versus computed PI values. The PI values of Ekili soil series were 0.413, 0.412, 0.403 and 0.398 for erosion levels of 0, 50, 100 and 200 mm respectively. Lobo et al (2005) reported that soil productivity index can be used as a criterion of tolerance of soil loss due to soil erosion. Soil productivity and erosion risk indices (ERI) allowed classification of general land use areas in view of soil conservation systems. Xingwu et al (2012) provided a methodology to calculate a quantitative T-value for different black soil species based on a modified soil productivity index model which varied from 68 to 358 tons/km$^2$ yielding an average T-value of 141 tons/km$^2$ for the 21 soil series. This is 29.5 per cent lower than the current national standard T-value. Two significant factors that influenced the T-value were soil thickness and vulnerability to erosion. An acceptable reduction rate of soil productivity over a planned time period of 1 per cent is recommended as necessary for maintaining long term sustainable soil productivity. So this method has more practical implications for effective and sustainable management of soil and water conservation. Singh (2011b) computed productivity index of the Bhadiar micro-watershed located in block Garhshankar, district Hoshiarpur, Punjab which constitutes the southern part of Shiwalik ecosystem. The productivity index of the profiles ranged from 0.08 to 0.30 (Table 3).

**Weighted additive mean:** Weighted additive mean or fuzzy modeling technique is the methodology for quantitative assessment of permissible limits of soil loss based upon soil quality attributes. This approach follows a quantitative model to sum up overall soil performance with respect to resistance to water erosion (Anon 1999). It is simple and less time consuming and less labour intensive that requires five factor score only such as infiltration rate, bulk density, erodibility, organic carbon and pH.

The main steps involved in this approach are selection of five indicators representing soil functions related to erosion however each indicator is selected on the basis of sensitivity analysis and used for developing an integrated index for assessing the soil loss tolerance limit (SLTL). The indicators are further transformed into dimensionless score between 0 and 1. Different scoring curves were used for converting the measured attribute values to a common membership grade (0–1) (Wymore 1993) according to the class limits specified by McBratney and Odeh (1997). The basic model used was:

$$MF(x_i) = [1/(1 + \{(x_i - b)/d\}^2)] \quad (12)$$

where MF ($x_i$)= Individual membership function values for the *i*th soil property x, b= Central concept, d= Width of the transition zone

As there are *n* soil characteristics to be rated and combined, using a convex combination function to produce a joint membership function (JMF) of all attributes, JMF(Y) is computed as follows:

$$JMF\ (Y) = \sum_{i-1} \lambda_i\ MF\ (x_i) \qquad (13)$$

where Y= Convex membership function (JMF) of all attributes, $\lambda_i$= Weighting factor for the *i*th soil property *x*, MF ($x_i$)= Membership grade for the $i^{th}$ soil property *x*

Model functions used for fuzzy membership classification of soil attributes are based on semantic import approach which utilizes a bell-shaped curve (Burrough et al 1992). The following forms of the models can be applied:

Optimum range equation (14) can be employed:

$$MF\ (x_i)= 1 \text{ if } (b_1 + d_1) < x_i < (b_2 - d_2) \qquad (14)$$

Asymmetric left 'more is better' equation (15) can be employed

$$MF(x_i)=[1/(1+\{(x_i-b_1-d_1)/d_1\}^2)] \text{ if } x_i<(b_1+d_1) \quad (15)$$

Asymmetric right (Model 4) 'less is better', equation (16) can be employed

$$MF(x_i)=[1/(1+\{(x_i-b_2+d_2)/d_2\}^2)] \text{ if } x_i>(b_2-d_2) \quad (16) \text{ If } x_i>(b_2-d_2)$$

where $b_1$= Lower crossover point (LCP), $d_1$= Upper crossover point (UCP)

Weights are assigned to the indicators depending on their importance. By summing up of the score and weight of each indicator a quantitative value (Q) is obtained. This indicates the state of the soil condition which can be described through equation listed below:

$$Q = q_{rir}W_{wir} + q_{rk}W_{wk} + q_{rbd}W_{wbd} + q_{roc}W_{woc} + q_{rpH}W_{wpH} \qquad (17)$$

where Q= State or condition of the soil in terms of structural and functional integrity, $q_{rir,}$ $q_{rk,}$ $q_{rbd,}$ $q_{roc}$ and $q_{rpH}$= Rating of infiltration rate, erodibility, bulk density, organic carbon and pH, $W_{wir}$, $W_{wk}$, $W_{wbd}$, $W_{woc}$, and $W_{wpH}$= Weight factor assessed for infiltration rate, erodibility, bulk density, organic carbon and pH

After this soil grouping can be done on the basis of aggregate score (Q) obtained from the above model.

A general guideline developed at the Iowa State University Statistical Laboratory was followed to assign soil loss tolerance limit (Mandal et al 2010).

Table 2. Soil loss tolerance T (Mg/ha/year) for two productivity permissible loss rate δ and two planning horizon H on Las Playitas, Merida, Venezuela

| Sector 1, $PI_i$= 0.227 | | | | Sector 2, $PI_i$= 0.304 | | | | Sector 3, $PI_i$= 0.365 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| δ= 5% | | δ= 10% | | δ= 5% | | δ= 10% | | δ= 5% | | δ= 10% | |
| $T_{100}$ | $T_{200}$ | $T_{100}$ | $T_{200}$ | $T_{100}$ | $T_{200}$ | $T_{100}$ | $T_{200}$ | $T_{100}$ | $T_{200}$ | $T_{100}$ | $T_{200}$ |
| 3.8 | 1.9 | 7.5 | 3.7 | 2.7 | 1.3 | 5.3 | 2.6 | 3.7 | 1.9 | 7.4 | 3.7 |

$PI_i$= Initial productivity index, δ= Soil productivity permissible loss rate, $T_{100}$ & $T_{200}$= Planning horizons for 100 and 200 years respectively
Source: Delgado et al 1998

Table 3. Productivity index of pedons at Bhadiar micro-watershed

| Pedon | Productivity index |
|---|---|
| 1 | 0.30 |
| 2 | 0.28 |
| 3 | 0.10 |
| 4 | 0.08 |
| 5 | 0.13 |
| 6 | 0.14 |

Source: Singh (2011a)

**Soil loss tolerance in different physiographical regions of India**

Adjusted T-value for central India ranged from 2.5 to 12.5 Mg/ha/year compared with the default value of 11.2 Mg/ha/year (Lakaria et al 2008). Mandal and Sharda (2011) computed the soil loss tolerance in the different physiographic regions of India by using weighted additive model. The T-value ranged from 2.5 to 12.5 Mg/ha/year indicating the wide variations in soil function to resist the impact of water erosion on crop productivity. Among the all physiographic regions, great plains are better placed with higher T-values (12.5 Mg/ha/year) followed by coastal plains. The T-value in the northwest Himalayas ranged between 5.0 and 12.5 Mg/ha/year (Mandal et al 2006). Bhattacharyya et al (2011) tested weighted additive model on 14.86 Mha of land in northern India comprising states of Punjab, Haryana and Himachal Pradesh. In those states SLTLs varied from 2.5 to 12.5 Mg/ha/year compared to the single value applied earlier. The SLTL values varied between 7.5 and 12.5 Mg/ha/year. However in sub-montane Punjab SLTL varied with depth of soil ie 5.0 to 10.0 Mg/ha/year for 0-15 and 15-30 cm and 7.5 to 12.5 Mg/ha/year for 30-60 cm in the area (Singh 2011a). This is due to favourable soil depth though a high degree of soil heterogeneity existed with respect to soil depth, infiltration, bulk density, organic matter content, erodibility and pH. The magnitude of SLTLs is very low for Himalayas ie between 2.5 and 10.0 Mg/ha/year due to very shallow soil depth (25 to 50 cm). The value of soil loss tolerance varied between 7.5 and 12.5 Mg/ha/year in Haryana. Around 97 per cent of areas in Haryana falling under alluvial plains had an SLTL of 12.5 Mg/ha/year. The permissible limit of soil loss tolerance in the different physiographical regions of West Bengal also differs from 2.5 to 12.5 Mg/ha/year (Lenka et al 2014). The T-value was computed using aggregate score verses soil depth matrix. Soils of the northern part of the Uttarakhand are very prone to erosion hazard as indicated very low soil tolerance limit that varied from 2.5- 5.0 Mg/ha/year (Jha and Mandal 2010).

The sensitivity index was used to make relative comparison of the weighted additive model with that of the productivity index (PI)-based method in the Doon valley soils of India (Mandal et al 2010). The parametric paired T-test showed that the overall mean of the sensitivity index was statistically insignificant at $P < 0.05$. Hence the estimation of soil loss tolerance by weighted additive approach was generally in good agreement with the results of PI-based approach. This validation test suggests that the weighted additive approach could well be used by soil managers and policy planners for assigning T-values. The PI-based approach requires a comprehensive depth-wise dataset including available water capacity, bulk density and pH which at present is not available for most of the agro-ecological regions. Generating such a dataset involves time, labour and monetary investment. On the other hand the weighted additive model requires a minimum dataset of soil attributes which are readily available at most of the locations.

**Erosion tolerance index**

The erosion tolerance index (ETI) is computed by using annual soil loss rate (A) and soil loss tolerance level (T) in the form of T/A ratio. The T/A ratio less than 1.0 indicates that annual soil loss could exceed the tolerance level and vulnerability of land. The numerical value 1 for T/A is an ideal point. The erosion tolerance index is expressed in continuous value from 0 (highly vulnerability) to 1 (almost no risk) (Baja et al 2002). The quantitative ETI value can be used as a guide for the policy makers for examining and deciding what land use management practices and which sub-watershed should be adopted on priority on a given individual land unit to reduce the degree of soil erosion up to the soil loss tolerance limit. Sudhishri et al (2014) computed the ETI in the different sub-watersheds in Chamoli district of Uttarakhand. It was found that use of soil loss tolerance limit will improve conservation planning and help to meet erosion control regulations for development of sustainable watershed management strategies.

## CONCLUSION

Each watershed is unique in characteristics. It becomes labour intensive and time consuming to monitor both runoff and soil loss on a watershed employing the conventional techniques. Therefore it is imperative to employ suitable approach for assessment of soil loss tolerance (T-value) that involves less time and requires less database. The T-value can be used as a guide to decide the maximum soil loss that can be permitted without causing soil degradation. The different approaches proposed in the paper to compute soil loss tolerance are soil profile thickness, rate of soil formation, productivity index method and weighted additive mean etc. Each approach is based on some assumptions and advantages and suffers from some limitations. However the selection of a particular approach depends upon the objectives of the study, availability of funds, availability of facilities, time etc. Weighted additive mean approach has found a wider application in Indian condition over other approaches. For further refinement of the assessment of soil loss tolerance approach, the assessment of soil loss tolerance must be compatible with the current thinking of sustainable agriculture.

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