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SOIL EROSION IN THE TIGRAY HIGHLANDS (ETHIOPIA). II. SOIL LOSS ESTIMATION

L'érosion des sols sur les Hauts Plateaux du Tigré (Ethiopie). II. Estimation de la perte de sol

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RESUME

Après l'analyse de l'érosion des sols par l'eau en Dega Tembien (Tigré, Ethiopie) dans une édition précédente de cette revue, une tentative est faite ici d'appliquer l'Equation Universelle de Perte des Sols dans la même région.

A cause du manque de données, seule une estimation grossière de l'érosivité des précipitations a pu être faite. L'érodabilité des sols est assez faible et ne peut être qu'une cause secondaire de l'érosion des sols. La variabilité de la couverture végétale est cependant très importante: le facteur C de l'Equation Universelle prend des valeurs très différentes - des observations précises de cette couverture végétale sont nécessaires.

Dans les parcelles observées, la perte de sols est estimée en moyenne à 0,9 $mm.an^{-1}$ (11,2 $t.ha^{-1}.an^{-1}$), avec des valeurs extrêmes de 0,02 et 9,75 $mm.an^{-1}$, ce qui se situe dans le tiers inférieur des taux mesurés en Ethiopie.

Ces résultats doivent être considérés avec prudence, car il n'a pas été possible d'éviter des estimations assez grossières pour plusieurs facteurs. Comme l'Equation Universelle de la Perte des Sols est un modèle multiplicatif, les erreurs dans les estimations sont amplifiées dans le résultat final.

ABSTRACT

Having analysed soil erosion by water in Dega Tembien (Tigray, Ethiopia) in a previous edition of this journal, an attempt is made to apply the Universal Soil Loss Equation (USLE) in the same study area.

Due to a lack of data, rainfall erosivity can only be estimated roughly. Soil erodibility appears to be quite low: it can only be a secondary cause of soil erosion. Variations in vegetation cover are, however, very important: the C-factor of USLE takes a wide range of values - very precise observations of this vegetation cover are necessary.

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Average estimated soil loss from the observed plots is 0.9 m. year^{-1} (11.2 t. ha^{-1} year^{-1}), ranging between 0.02 and 9.75 mm.year^{-1}, which is among the lowest values measured in Ethiopia.

Care needs to be taken with these results, since making quite rough estimations for several factors could not be avoided. The USLE being a multiplicative model, errors in the estimations are magnified.

INTRODUCTION

Soil erosion in Dega Tembien (northern Ethiopian Highlands) was analysed in a previous paper, published in this journal (NYSSEN, 1995). During the research, qualitative and quantitative observations were made on 32 spots (Fig. 1), with the aim of estimating the importance of erosion.

Among the quantitative approaches, the *Universal Soil Loss Equation* (USLE) is best known. This equation, based on numerous results of experimental plots, implies the principal physical factors explaining the extent of sheet erosion and requires the knowledge of relatively few variables (WISCHMEIER & SMITH, 1978).

Since the 1980s, new equations have been elaborated which take into account different biophysical environments and different agricultural systems (especially those of the U.S.A.), but which also require the knowledge of a greater quantity of data (WEPP - *Water Erosion Prediction Project* requires daily data!) which are processed by computer. Among these new quantification methods, there are RUSLE (*Revised* USLE) (RENARD *et al.*, 1997), WEPP, due to replace RUSLE (FOSTER, 1990; LAFLEN *et al.*, 1991; LANE *et al.*, 1991) and ANSWERS (DE ROO *et al.*, 1989).

USLE, because of its relative simplicity, tallies better with the scope of this research; moreover, several factors of this equation have been adapted to Ethiopian conditions by HURNI (1985).

For certain factors, it was tried to go further than this adaptation destined to soil erosion technicians: the soil erodibility was analysed by laboratory methods rather than using the easy colour criterion proposed by HURNI. For other factors, RUSLE refines USLE's equations or allows a better response to certain conditions of the analysed watershed; such new contributions were taken into account.

The values obtained in each observation point for the different factors of USLE will be combined in order to obtain estimations of annual soil loss:

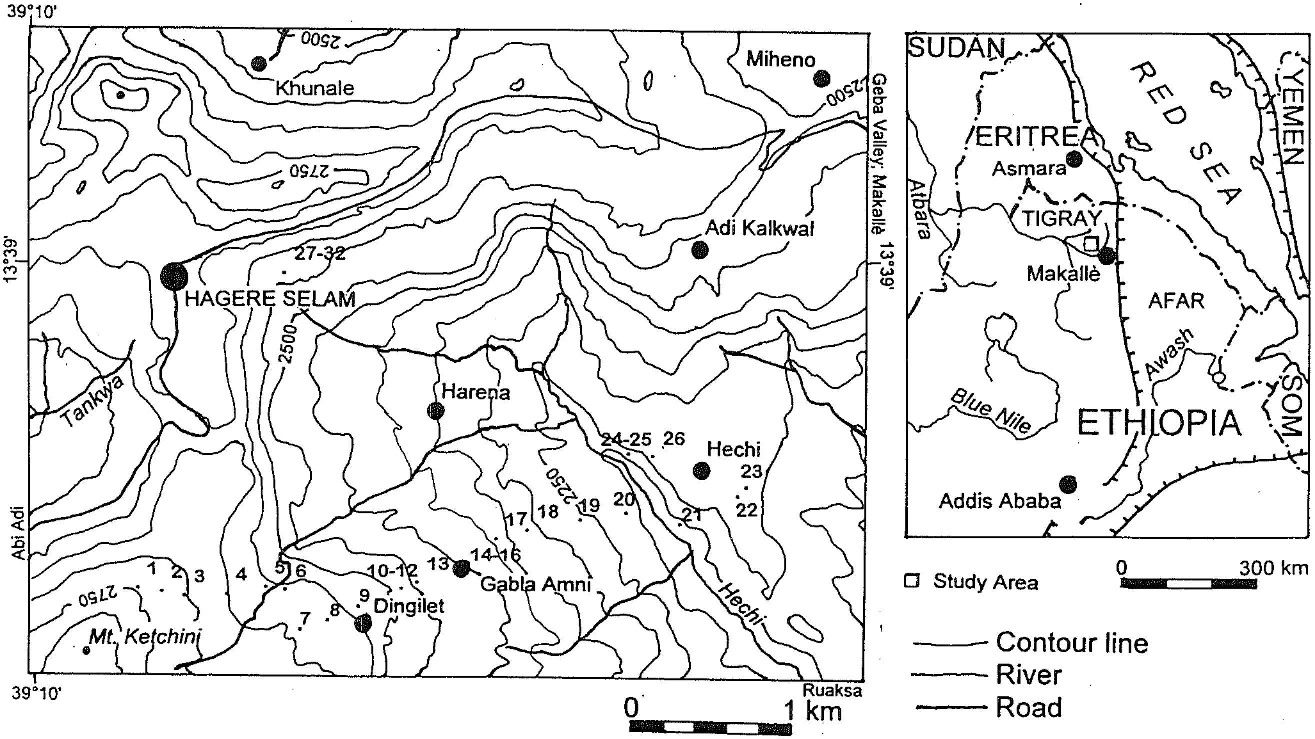

Fig. 1.- Location map with observation sites.

$A = R.K.L.S.C.P$ (1)

where:
A = estimated erosion rate in t/ha.year
R = rainfall erosivity
K = soil erodibility
LS = topographic factor
C = vegetation cover
P = support practice factor

TOPOGRAPHY

Slope angle: USLE's S factor

In Dega Tembien, the average slope angle is 21 % but many slopes exceed 50 % (NYSSEN, 1995). Such steep slopes do favour soil erosion by water: not only is runoff more important (reduction of infiltration), but there is also an increase in kinetic energy as a result of the increase in flow speed.

The S factor of the Universal Soil Loss Equation expresses this influence of the slope angle. The potential erosion is thus thought to increase quicker than the slope, which is expressed by the following empirical equation:

$$S = 65.41 \sin^2 t + 4.56 \sin t + 0.065 \qquad (2)$$

(WISCHMEIER *et al.*, 1958; WISCHMEIER & SMITH, 1978)
where: S = slope factor (dimensionless) in USLE
t = slope angle in degrees

WISCHMEIER *et al.* (1958: 459) indicate that this relationship may be used for slopes between 3 and 22 % and that the poor amount of data used to elaborate the equation (2) does not ease the evaluation of slope effect on soil loss.

More recently, McCOOL *et al.* (1987) obtained the following relations:

$$S = 10.8 \sin t + 0.03 \ (s < 9\ \%) \text{ and } S = 16.8 \sin t - 0.50 \ (s \geq 9\ \%) \qquad (3)$$

In East Africa, slopes often steeper than 22 %, beyond the reliability limit of the equation (2), are under cultivation or used as pastureland. HURNI (1979) studied the relationship between USLE's S factor and slopes up to 56 % in the Simen Mountains (just over a hundred km to the South-West of the study area). This resulted in a linear relation used in the Universal Equation adapted to Ethiopian conditions:

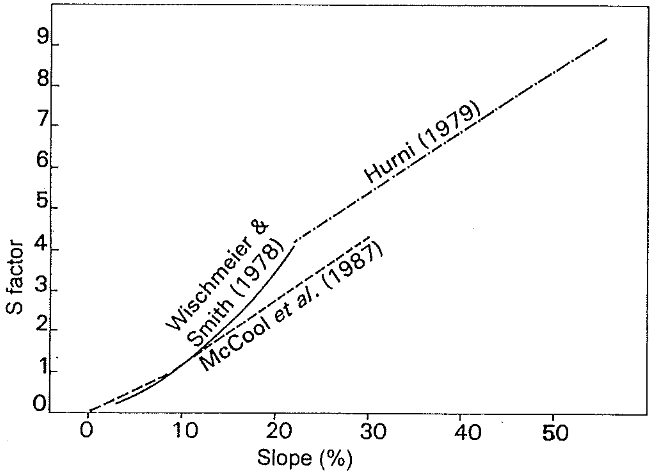

Fig.2 : Some proposed relations between USLE's S-factor and the slope in %.

S = 0.149 s + 0.933   (HURNI, 1979)   (4)
where: s = slope angle in per cent   (s between 22 and 56)

This relationship being based, for its lower value, on the equation (2) elaborated by WISCHMEIER & SMITH (1978), both these equations were used to calculate the S factor (Fig. 2).

Slope length effect

Soil loss increases with slope length: indeed, the accumulation of runoff water on longer slopes increases its detachment and transport capacity (WISCHMEIER & SMITH, 1978: 14). Different authors (WISCHMEIER & SMITH, 1978; BERGSMA, 1985; RENARD *et al.*, 1997) do insist on the necessity of accurately measuring this length, which starts where runoff begins and which ends where there is sedimentation, or at the place where the runoff water is evacuated (gully, path, draining canal, ...). It is only very exceptionnally that the whole slope length between water divide and valley bottom must be considered.

On the other hand, a simple changing of crops does not constitute a slope limit.

In Dega Tembien, stone bunds provoke the sedimentation of most of the eroded particles and are thus to be considered as the end of one slope and the beginning of a new one. Other slope limits are the footpaths if they concentrate runoff, and the gullies.

These slope lengths were measured in the field (Table III, column 8) and the slope length factor L was calculated:

$$L = (l / 22.1)^m \qquad (5)$$

(WISCHMEIER & SMITH, 1978: 14)

where: L = slope length factor (dimensionless) in USLE

l = slope length projected in the horizontal plane (in metres)

m = parameter which is a function of the ratio of rill erosion (due to runoff) and interrill erosion (principally due to splash). This ratio is in its turn a function of the slope :

$$m = \beta / (1 + \beta), \text{ where:} \qquad (6)$$

$$\beta = \sin t / (0.2688 (\sin t)^{0,8} + 0.05) \qquad (7)$$

(McCOOL *et al.*, 1989)

RAINFALL EROSIVITY

Concentrated in three months (June, July and August), rainfall is very erosive in the Northern Ethiopian Highlands. The erosivity index R for Hagere Selam (Dega Tembiens main town) is estimated to be 408.35 (NYSSEN, 1995). Monitoring of both rainfall pattern and erosivity in the studied watershed is necessary.

RELATIVELY LOW SOIL ERODIBILITY

Erodibility is a function of the properties of the soil only. Texture, organic matter content, structure and perviousness are the main variables which explain 85 % of the observed erodibility variance (WISCHMEIER *et al.*, 1971).

Soil texture in Dega Tembien is very variable, mainly due to differences in lithology (NYSSEN, 1995)

The organic matter content

a.- Loss-on-ignition method: discussion.

The analysis of OM content of soil samples (taken at a depth of between 5 and 10 cm) from Dega Tembien, by "loss-on-ignition" (LI) method gives coherent and plausible results, the necessary correction due to clay dehydration being made.

The burning of soil samples at a temperature of 550 °C, which had previously been dried at 105 °C, enabled the determination of the organic matter content (OM).

By this method, conventionally, "all the matter burnt at this temperature is evacuated". One only has thus to weigh the sample before and after burning and to calculate the ratio between this difference and the total mass of the sample to know the content of this matter, which may however not yet be qualified "OM content".

LUNT *et al.* (1950: 11): "[Loss-on-ignition] gives values of much higher magnitude than can be ascribed to the organic matter content, particularly on loamy or clay soils relatively low in humus, due to the volatilization of chemically combined water and certain inorganic elements".

The carbonates of our soils on limestone are almost completely leached out (negative HCl test); there only subsists, here and there, a small fragment of parent rock.

Water linked in clay minerals of soils is only completely evacuated at 450 °C (DE LEENHEER *et al.*, 1957: 329). It is thus compulsory to deduct the fraction of water contained in the 105 °C dried samples from the total weight of the matter evacuated at 550 °C, before calculating the percentage of organic matter.

The optimal solution would be to establish, from decarbonated samples, a relationship between clay content (< 2 m) and loss-on-ignition for each encountered type of soil. The different clay minerals indeed have a different water holding capacity. It was impossible to establish such relationships for the study area. In spite of the great variability in clay mineralogy in Dega Tembien, I could only calculate an overall correction factor from 50 samples of Belgian soils, studied by DE LEENHEER *et al.* (1957: 332).

The following relationship is thus proposed to determine the fraction of water contained in soil samples at 105 °C:

$$y = 0.948 + 0.0825\,x \quad (n = 50;\ r^2 = 0.78) \qquad (8)$$

where:
y = % humidity contained in a soil sample dried at 105 °C
x = clay content (0 - 2 μm).

Consequently, the following equation allows the calculation of OM content:

$$\%\,OM = \%\text{ evacuated by LI} - 0.948 - 0.0825 * \%\text{ clay} \qquad (9)$$

HOUBA *et al.* (1995:40) estimate this correction factor (8) to y = 0.07x "for a large number of representative Dutch soils".

b.- A generally high OM content

OM content is especially high in soils under forest (between 5.03 and 7.36 %) and on basaltic colluvium (between 4.88 and 10.57 %); but lower in pasture lands on steep slopes and in fields exploited for a long time.

These high OM contents are not surprising, since many trees in Dega Tembien were only removed during the 20th century (NYSSEN, 1995).

Several authors, analysing the OM content of topsoil in African tropical mountains, observe high values (Tab. I). Most OM content measurement data of other regions of Tigray are sometimes lower but they are not in discordance with our measures.[1]

Tab.I. - Topsoil organic matter content (African tropical mountains).

Region	Pedol. parent rock	% C	% OM (1)	% OM (2)	Author
NW of Mount Kenia		0.7 - 4	1.2 - 6.9	1.4 - 8	Desaules (1986)
Fouta-Djallon	Dolerite	1.7 - 6.8	2.9 - 11.7	3.4 - 13.6	Diallo (1988)
"	Sandstone	0.6 - 0.8	1.0 - 1.4	1.2 - 1.6	"
Kivu	Volcanic ashes	2.3 - 13.8	4.0 - 13.8	4.6 16	Sebgoya (1970)
Central Ethiopa	Vertisol on basalt	1.3 - 3.7	2.2 - 6.3	2.5 - 7.3	Kamar & Haque (1992)
TIGRAY					
20 km SW of Makalle	Dolerite	0.4 - 2.9	0.7 - 5.0	0.8 - 5.8	Belay Tegene (1996)
W of Adigrat	Basalt (sample 595, 2278 and 594(3)	1.0 - 2.0			Murphy (1968)
W of Wukro and S of Agula	Antalo limestone (3)	1.4 - 3.7			"
S of Adwa	Volcanic rocks	0.4 - 2.0	0.7 - 3.4	0.8 - 4.0	Feoli (1994)
"	Sedimentary rocks	2.3	4.0	4.6	"
Hagere Salam (2 km E.)	Basic colluvium	1.7 - 3.5	3.0 - 6.0	3.5 - 7.0	Hunting (1976a)

(1) Conventionnaly, % C is transformed into % OM by multiplying by 1.72 (Wischmeier *et al.*, 1971 Hunting, 1976a, Desaules, 1986)......

(2).....or by 2 (De Leenheer *et al.*, 1957).

(3) Parent rock recognised by localising the sites where the samples were taken on the geological map (1/250.000).

The equation which allows the calculation of the K factor was obtained by statistical calculations performed from OM contents obtained by the Walkley & Black method (WISCHMEIER *et al.*, 1971). Contents measured by LI should thus conform to those measured by W&B to be usable in the equation; this requirement does not, however, appear in the literature, nor in the Agriculture Handbook N° 537 (WISCHMEIER & SMITH, 1978).

[1] There is however no description of land use in Murphy and Feoli.

If we can accept the hypothesis that the values observed by the "loss-on-ignition" method are coherent and plausible, we can use them without too big a risk in K factor calculations.

c.- Use of the OM content in USLE

The K-factor equation (11) was established from data concerning soils with less than 4 % OM (WISCHMEIER *et al.*, 1971). For higher values:
- one can extrapolate up to 6 % (FOSTER, 1995, personal communication);
- values higher than 6 % must be brought down to 6 % (ARNOLDUS, 1977: 107);
- as far as forest soils are concerned, WISCHMEIER & SMITH (1978: 33), as well as DISSMEYER & FOSTER (1984: 11) recommend a reduction in the C factor (vegetation cover) to 70 % of its value for soils containing more than 4 % organic matter.

Perviousness

In the field, one can observe that clayey soils on basalt are less pervious than silty or sandy soils on sandstone or limestone. Twenty-four hours after rains, water was still standing in the fields and some footpaths were almost impassable (Fig. 3).

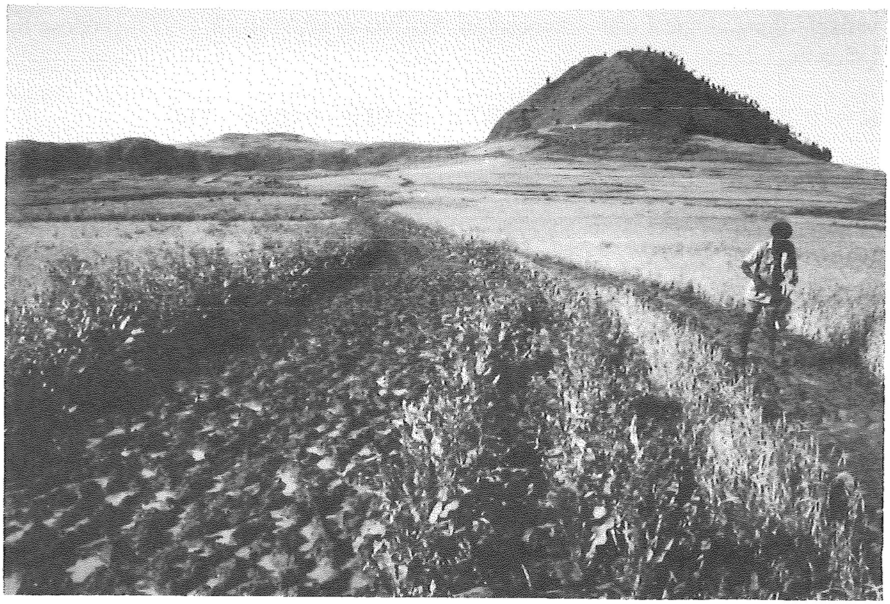

Fig.3. - Path from Hagere Selam to Digingilet, the day after a shower. This basalt-derived soil is almost impervious.

This reduced infiltration of course increases runoff action. If we were to only use the first approximation of K, which takes into account soil texture and OM content, we would probably underestimate the erodibility of soils on basalt. For a better consideration of this, I assigned the following perviousness classes (magnitude from 1 to 6, used by WISCHMEIER & SMITH, 1978):

. soils in place on basalt: low infiltration (class 5);
. soils on basaltic colluvium: low to moderate infiltration (class 4);
. other encountered soil: moderate infiltration (class 3 - default value proposed by WISCHMEIER & SMITH).

Part of the structure in soil erodibility

In USLE's K equation occurs a qualitative code representing the soil structure and considering the structure type (polyhedral, massive, ...) and size. The importance of aggregation phenomena (structure grade) does not occur directely (WISCHMEIER *et al.*, 1971: 191). The 55 soils on which this equation is based are all of vermiculitic type (with a low percentage of other clay minerals) (WISCHMEIER & MANNERING, 1969).

Clay mineralogy, and with it the aggregation mode of micrometric particles, is however very variable in Dega Tembien (NYSSEN, 1995).

Other equations of the K-factor have been established with data of soils with variable mineralogical clay composition: YOUNG & MUTCHLER (1977) propose the following relationship:

$$K = -0.204 + 0.385\,a - 0.013\,b + 0.247\,c + 0.003\,d - 0.005\,e \quad (10)$$

where:
K = erodibility factor in USLE
a = an aggregation index
b = percentage of montmorillonite in the soil
c = apparent density
d = (% silt and very fine sand) * % sand (0.1 - 2 μm)
e = a dispersion index

Soil erodibility lowers with the increase of montmorillonite content. RENARD *et al.* (1997: 75) suggest a possible use of this relationship for soils with swelling clays.

Unaware of the exact smectite percentages in the analysed samples, the mineralogical composition will be used in a qualitative way in the equation (11) of the K-factor, attributing, on a scale from 1 to 4 representing the influence of soil structure on erodibility, a value of 1 (less erodible) to smectic soils on basaltic colluvium and a value of 2 (default value proposed by WISCHMEIER & SMITH, 1978) to the other soils.

Calculation of K-factor values

The following equation has been used to calculate the values of K:

$$100\ K = [2.1\ M^{1.14}\ (10^{-4})(12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3)] * 1.292 \quad (11)$$

(WISCHMEIER & SMITH, 1978: 10)

where:
K = erodibility factor in USLE
M = particle size parameter = (% silt and very fine sand) * (100 - % clay)
a = OM percentage
b = soil structure code
c = perviousness class
1.292 = proportionality between the metric and the american (p.f.s.) system.

This equation is valid for soils containing less than 70 % silt and very fine sand (100 μm - 2 mm).

Comments on the erodibility of some soils in the Hagere Selam area

The calculated values for K (TAB. III) appear to be quite low, compared with analysed soils in the United States (WISCHMEIER & SMITH, 1978: 9). They are however in the same range as those calculated by HUNTING (1976b) in Central Tigray, those measured in different stations in Ethiopia (WEIGEL, 1986; CHADHOKAR & SOLOMON ABATE, 1988) and those proposed by HURNI (1985) for an empirical determination.

Pasture lands on steep slopes corresponding to resistant Antalo Limestone formations are most erodible, as they combine a very low clay content and a medium OM content on one hand, with a moderately high silt content on the other hand. One can observe that soils on basaltic colluvium are often very erodible, in spite of the high organic matter and smectite content. This is due to their quite low clay and high silt content, as well as their low perviousness. Erodibility is lowest in forests because of the high organic matter content and a moderately low silt content. Finally, in spite of a low perviousness, soils on basalt and on alluvium have a very low erodibility. This is essentially due to their very high clay content.

These relatively low K values indicate that soil erodibility is only a secondary cause of accelerated erosion in Dega Tembien.

Adjustment due to the presence of stones in certain fields.

Stones in the fields are often a consequence of the prolungated action of erosion, and have a negative effect on agricultural production, but they also reduce the effect of splash as well as runoff rates and overland flow velocity (POESEN *et al.*, 1994); they have a similar effect as the permanent presence of litter (RÖMKENS,

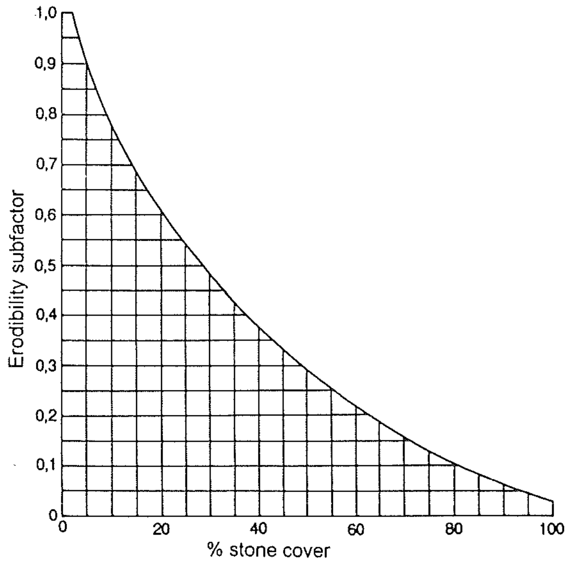

Fig.4.- Effect of stone cover in the calculation of the K-factor (according to WISCHMEIER & SMITH, 1978: 10 and 19, modified).

Fig.5.- Sedimentation in plough furrows on contour (West of Dingilet). Stone cover rate is estimated at 50 %.

1985: 449). This reduction of the erosion risk can be traduced by an adjustment of the K-factor (ARNOLDUS, 1977: 107; WISCHMEIER & SMITH, 1978: 10; WEIGEL, 1986: 47) (Fig. 4).

RENARD *et al.* (1997: 158) present an equation allowing the calculation of this coefficient taking into account cover rate (by litter, by stones, ...), roughness and efficiency of these obstacles in the reduction of soil erosion. This equation, as well as relationships between stone cover and soil erosion, established from measures on experimental plots (see POESEN *et al.*, 1994), have the same aspect as WISHMEIER's curve (Fig. 4).

For this research, the stone (diameter > 20 mm) cover rate was estimated in every observed field (Fig. 5), using measures made on a 400 cm² area in a randomly chosen spot (throwing of an object) near the middle of every field.

The adjustment (Tab. III, column 11) which is to be made to the K-factor of the soil of different fields in the study area can be very important: applying it to very stony soils (80 % stone cover), which are frequent in Dega Tembien, results in the reduction by 90 % of the erodibility of these soils.

This adjustment concerns only fields and bare soils. Indeed, in forests and on pasture land, the principal cover effect is due to vegetation; to introduce also an adjustment of the K-factor, caused by stones which are situated under the vegetation and / or litter would mean that the same phenomena (reduction of splash and runoff effect) would be expressed by a reduction of factors K and C (protection by vegetation cover).

To avoid this possible confusion, it is more common that researchers only let the effect of surface stones intervene in the C-factor (soil cover rate) (RÖMKENS, 1985; RENARD *et al.*, 1997).

In his adaptation of USLE to Ethiopian conditions, intended for field technicians, HURNI (1985) considers the stone cover rate as a sub-factor of P (management and anti-erosive practices), and, especially, he estimates the effect of this cover rate on the reduction of the soil erosion to be much less (0.8 for 40 % stone cover; 0.5 for 80 % stone cover, against 0.37 and 0.1 respectively, according to WISCHMEYER - fig. 4). Unfortunately, the values presented by HURNI are not documented.

INCIDENCE OF THE AGRICULTURAL SYSTEM ON EROSION RISKS

The understanding of the agricultural system, and more particularly of land use and agricultural techniques, is of vital importance for the explanation of soil erosion.

Tef fields are very sensitive to soil erosion

The C-factor (vegetation cover and management) of USLE integrates land use and the crop rotations; it measures their effect on the quantity of eroded soil, all other things being equal, and varies between 0 ("perfect" dense forest) and 1 (bare fallow, regularly ploughed). This C-factor, which is evaluated in a different way for every agricultural region, has been calculated for different crops in Ethiopia by HURNI (1985). The greater sensitivity of the endogenous tef (*Eragrostis tef*) to erosion (C = 0.25) may be noted: the tiny seeds of this crop require a more intense preparation. Of course, in a crop rotation, this C-factor changes from year to year.

Traditional soil and water conservation and contour ploughing

USLE's P-factor expresses support practises, with a value of 1 corresponding to downslope ploughing and total absence of anti-erosive practices, and a value of 0 (never reached) corresponding to support practises preventing any erosion. It is thought that this variable is independent, and thus it is not included in the factor expressing vegetation cover and management (ARNOLDUS, 1977: 111). Table II presents values estimated by HURNI (1985) for different support practises in use in Ethiopia:

Tab. II. Estimations for Ethiopia of USLE's P-factor.

	P
Ploughing downslope:	1.00
Ploughing on contour:	0.90
Stripcropping:	0.80
Intercropping:	0.80
Dense intercropping:	0.70
Mulching:	0.60

Source: HURNI, 1985.

- in Dega Tembien, ploughing is almost always on contour; it is efficient in those areas where erosion rills and small gullies are filled up every year by ploughing (WISCHMEIER & SMITH, 1978: 35). One remarks that erosion decrease due to this agricultural technique is relatively low; this is due to the fact that the furrows formed by the *mahrasha* (traditional plough) are not very deep, about 7 cm on average (HUNTING, 1976c). There exists probably a slight variation around this average (P = 0.9), due to a decrease in the efficiency of this technique on steep slopes (WISCHMEIER & SMITH, 1978).
- intercropping brings about a longer occupation of the field by vegetation, if crops are harvested in succession. Except for *hamfets* (wheat and barley), where both species are harvested together, this technique is generally not found on Dega Tembien heights.
- stripcropping, a technique which consists of alternating grass and cultivation strips of the same width (WISCHMEIER & SMITH, 1978: 36), isn't in use in Dega Tembien.

The *daget*, traditional SWC structures, might however be assimilated to *buffer strips* (*ibidem*) provided that the grass strip on their summit is still wide enough, which is seldom (NYSSEN, forthcoming).

- Finally, the realisation of terraces, one of the most efficient anti-erosive practises, does not appear in the calculation of the P-factor. The effect of terraces being quantified in the topographic factor LS (decrease of slope and runoff length), means that its introduction in the P-factor would make it be counted twice. The P-factor does not account for other the soil conservation practises either: tree planting and crop rotations are counted for in the C-factor, and the use of organic fertiliser in the K-factor (soil erodibility).

CLASSIFICATION OF THE VEGETATION COVER BY GRASSES, SHRUBS AND FOREST

A classification has been proposed (NYSSEN, 1997), as a function of tree and shrub cover as well as the degree of degradation by overgrazing and woodcutting. This classification takes into account the reality observed in the field, photointerpretation possibilities (aerial photographs realised during the dry season), and the necessity to quantify this vegetation cover (C-factor of the Universal Soil Loss Equation, worth 0 in case of perfect vegetation cover and 1 in case of bare fallow). This classification gives the erosion risk corresponding to every vegetation type.

ESTIMATION OF YEARLY SOIL LOSS IN THE HAGERE SELAM REGION

Values measured in the different observation spots (Fig. 1) are entered in table III and an estimation of annual soil loss is made, using USLE (1).

It was not possible to verify estimated soil loss. The construction of experimental plots or the trapping of sediments at the foot of the fields was far too extensive a work for this study.

Estimated quantities of lost soil are situated among the lower third of the observations in the *Soil Conservation Research Project* stations elsewhere in Ethiopia (see HURNI, 1985: 659). A certain number of conditions are favourable to lower soil erosion: the presence of terraces in many fields, a high density of stones on the surface and soils presenting quite a good resistance to erosion.

It is however evident that an at least qualitative check is necessary, for example by observing these fields during the beginning of heavy rains in June and July.

Tab. III. - Quantitative observations, measurements and estimation of eroded soil.

Slope unit N°	SOILS								TOPOGRAPHY			
	Pedol. parent rock	Texture (1)	(2)	(3)	(4)	(5)	(6)	K	(7)	S	(8)	L
1	bas/coll.	28	60	12	6.6	4	1	0.28	10	1.2	15.4	0.8
2	bas/coll.	10	50	40	5.2	4	1	0.16	15	2.2	14.3	0.8
3	basalt	10	30	59	3.8	5	2	0.14	10	1.2	21.4	1.0
4	bas/coll.	16	34	50	5.8	4	1	0.07	35	6.1	15.1	0.8
5	all/coll.	14	32	53	3.1	4	1	0.09	10	1.2	13.9	0.8
6	all/coll.	26	27	47	4.8	4	2	0.11	23	4.4	10.2	0.7
7	bas/coll.	27	45	27	4.9	4	1	0.19	2	0.2	60.0	1.3
8	bas+sandst.	25	34	41	0.3	3	2	0.19	65	10.6	15.9	0.8
9	AA sandst.	59	31	10	5.1	3	2	0.16	12	1.6	39.7	1.4
10	AA sandst.	32	40	27	3.4	3	2	0.21	20	3.6	29.4	
11	AA sandst.	33	44	23	4.7	3	2	0.21	35	6.1	7.6	1.6*
12	AA sandst.	41	39	20	5.6	3	2	0.17	18	3.0	8.9	
13	coll. B+AA	44	48	7	4.1	4	1	0.30	9	1.0	49.8	1.5
14	bas/coll.	28	53	19	9.8	4	1	0.22	8	0.8	100.0	2.1
15	bas/coll.	39	48	13	10.6	4	1	0.21	12	1.6	100.0	2.3
16	bas/coll.	30	56	14	9.7	4	1	0.25	17	2.7	150.0	3.1
17	limestone	54	37	10	3.9	3	2	0.23	18	3.0	80.0	2.2
18	limestone	47	37	16	4.1	3	2	0.20	4	0.4	35.0	1.2
19	limestone	37	38	25	5.9	3	2	0.24	22	4.2	21.5	1.0
20	limestone	37	43	20	4.3	3	2	0.22	5	0.5	9.3	0.6
21	limestone	50	30	20	7.4	3	2	0.12	45	7.6	160.0	3.9
22	limestone	73	21	7	1.9	3	2	0.15	4	0.4	34.0	1.2
23	limestone	66	25	9	1.6	3	2	0.19	4	1.4	17.0	0.9
24	limestone	21	41	39	5.0	3	2	0.14	45	7.6	160.0	3.9
25	limestone	23	50	27	7.4	3	2	0.19	45	7.6	160.0	3.9
26	limestone	44	35	21	6.3	3	2	0.14	1	0.1	240.0	1.4
27	bas/coll.	20	58	23	5.6	4	1	0.24	24	4.5		
28	bas/coll.	17	58	25	5.9	4	1	0.22	24	4.5		
30	bas/coll.	21	55	23	5.4	4	1	0.24				
31	bas/coll.	11	65	25	5.7	4	1	0.26	9	1		
32	bas/coll.	11	56	33	4.1	4	1	0.25	9	1		
AVERAGE								0.19		3.01		1.064
MINIMUM								0.07		0.12		0.65
MAXIMUM								0.3		10.6		3.94
NUMBER								31		30		24
MAX/MIN								4.1		90.5		6.1

(1) % sand,
(2) % silt and fine sand
(3) % clay
(4) % organic matter
(5) perviousness
(6) soil structure class
(7) slope in %
(8) horizontal length of plot
(9) adjustment of the C-factor soils with more than 4% O.M.
(10) % stone cover
(11) adjustment of C for stone cover

VEGETATION COVER						MANAGEMENT		EROSION		
Land use	crude' C	Adjustments (9)	(10)	(11)	C	Cultural practices (12)	P	A (13) t./ ha.year	mm/year	Slope unit N°
lentils	0.150	1.0	30	0.47	0.071	pl/c	0.9	7.0	0.6	1
legumes	0.150	1.0	35	0.42	0.063	pl/c	0.9	6.6	0.5	2
tef	0.250	1.0	50	0.29	0.073	pl/c	0.9	4.3	0.3	3
lentils	0.150	1.0	30	0.47	0.071	pl/c	0.9	9.5	0.8	4
tef	0.250	1.0	25	0.54	0.135	pl/c	0.9	4.2	0.3	5
grazing l.	0.050	1.0	25	0.54	0.027		1.0	3.6	0.3	6
hamfets	0.150	1.0	20	0.60	0.090	pl/c	0.9	1.4	0.1	7
degr.graz.	0.100	1.0	20	0.60	0.060		1.0	41.6	3.3	8
tef	0.250	1.0	80	0.10	0.025	pl/c	0.9	3.2	0.3	9
tef	0.250	1.0	80	0.10	0.025	pl/c+daget	0.8			10
hamfets	0.150	1.0	80	0.10	0.015	pl/c	0.9	8.4*	0.7*	11
hamfets	0.150	1.0	80	0.10	0.015	pl/c+daget	0.8			12
wheat/lent.	0.150	1.0	80	0.10	0.016	pl/c	0.9	2.5	0.2	13
grazing l.	0.050	1.0	50	0.29	0.017		1.0	2.2	0.2	14
grazing l.	0.050	1.0	50	0.29	0.018		1.0	4.4	0.4	15
grazing l.	0.050	1.0	50	0.29	0.019		1.0	12.5	1.0	16
degr. Graz.	0.200	1.0	0	1.00	0.200		1.0	121.9	9.7	17
hamfets	0.150	1.0	10	0.77	0.116	pl/c	0.9	3.6	0.3	18
wheat/lent.	0.150	1.0	80	0.10	0.015	pl/c	0.9	2.9	0.2	19
tef	0.250	1.0	60	0.22	0.055	pl/c	0.9	1.3	0.1	20
closed area	0.010	1.0	NA	1.00	0.010		1.0	14.1	1.1	21
tef	0.250	1.0	3	0.98	0.245	pl/c	0.9	5.7	0.5	22
tef	0.250	1.0	5	0.90	0.225	pl/c+daget	0.8	4.3	0.3	23
forest	0.001	0.7	NA	1.00	0.001		1.0	1.2	0.1	24
forest	0.001	0.7	NA	1.00	0.001		1.0	1.6	0.1	25
grazen for.	0.025	1.0	5	0.90	0.023		1.0	0.2	0.0	26
legumes	0.150	1.0	37	0.40	0.060	pl/c+daget	0.8			27
legumes	0.150	1.0	22	0.58	0.087	pl/c+daget	0.8			28
lynchette	0.013	1.0	40	0.37	0.005		1.0			30
tef	0.250	1.0	6	0.88	0.220	pl/c	0.9			31
tef	0.250	1.0	8	0.82	0.205	pl/c	0.9			32
					0.071		0.92	11.18	0.90	AVERAGE
					0.001		0.80	0.21	0.02	MINIMUM
					0.245		1.00	121.85	9.75	MAXIMUM
					31		31	24	24	NUMBER
					350.0		1.3	582.1	582.1	MAX/MIN

$$A = R . K . L . S . C . P$$ where

A = estimated erosion in t. $ha^{-1}.year^{-1}$

R = rainfall erosivity, estimated at 408.35 (NYSSEN, 1995)

K = soil erodibilty

L, S = topographic factor

C = vegetation cover

P = support practise factor

The highest erosion rate (122 $t.ha^{-1}.year^{-1}$) is observed on a degraded pasture land (< 50 % vegetation cover, 18 % slope) without any conservation measure.

Erosion is, of course, the lowest in forest (N° 24, 25 and 26), even if it is situated on long and steep slopes. Pasture land (N° 21) on the same slope, even after two years of area closure, presents ten times more erosion risk.

Interesting to note also is how slight differences for every factor may, when multiplied, end up in a very different erosion risk. Such is for example the case in the communal pasture land inside Gabla Amni village. Observations were made on three spots, at first sight similar (N° 14, 15 and 16): estimated erosion varies between 2.2 and 12.5 $t.ha^{-1}.year^{-1}$; the difference is principally explained by variations in slope, but the other factors are also important.

POSSIBILITIES OF DIGITAL MAPPING, SUPER-IMPOSING LAYERS IN A GIS AND EROSION RISK MAPPING

It was not possible to realise a soil erosion risks map of the studied watershed, superimposing information layers representing every USLE factor in a Geographical Information System (GIS).

The observations and measurements are too few and need to be verified in the field. Moreover, the slope map does not express well the decrease in slope incline due to the construction of cultivation terraces (NYSSEN, 1995). The estimation of the slope length by calculating the distance from the water divide to the valley bottom on a DEM, as proposed by different authors (HELLDEN, 1987; BONN *et al.*, 1994), also appears to lead to a big overestimation: in fact, the slope ends where the water is being evacuated or on spots where there is sedimentation (behind stone bunds for example). EWEG & VAN LAMMEREN (1996: 48), in a study concerning the application of a GIS at the rehabilitation of degraded areas, carried out in the Adwa - May K'inet'al area, some 50 km NW of Dega Tembien, question the accuracy of modelling soil erosion using GIS and the USLE model. Errors are mainly due to the important locational inaccuracy for each USLE factor and the lack of reliability of the measurements and factors, as also discussed in this paper. These authors also question the USLE model itself as it neglects gully erosion, rill erosion, landslides and deposition in the area itself.

CONCLUSIONS

The R-factor expresses rainfall erosivity. It has been calculated from the rainfall-erosivity relationship established by HURNI (1985). It has not been possible to estimate the spatial variation of this factor in the study area. Furthermore, rainfall erosivity might have been underestimated.

Soil properties are expressed by the erodibility factor K. It accounts for particle size and organic matter content. Qualitative estimations of perviousness and structure (taking into account particularly the characteristics of clay minerals) have allowed the obtained values to be refined. Soil erodibility is, in general, quite low.

The topographic factor LS has been calculated from field measures. The slope angle appears to be exaggerated by the Digital Elevation Model for those area where the farmers have built cultivation terraces. These structures also reduce slope length and thus the quantity of eroded soil.

Vegetation cover is expressed by the C-factor, which is the one which explains most of the observed differences between quantities of eroded soil in the different sampling places. It varies from 0,0007 (dense forest) to 0,245 (tef field almost without stones); it presents a ratio of the highest observed value to the lowest observed value (last row of table III) which is much higher than the same ratio calculated for other USLE factors. There is therefore a need to insist on the necessity for very precise observations for the elaboration of this factor.

Stone cover, assimilated to mulch cover, would reduce greatly the erosion risk in certain fields. Indeed, earlier erosion of fine particles has brought about an "armourage" of the soil by remaining stones, in the same way as a desert pavement is fashioned by aeolian action. It must be noted that some fields (N° 11, 12, 13 and 19 in table III) would be as well, or even better, protected by stones than are pasture lands in good shape (N° 6, 14, 15, 16) by vegetation.

The P-factor expresses support practises which decrease the amount of runoff water or modify its path (RENARD *et al.*, 1997: 186). In Dega Tembiens fields, this concerns principally contour ploughing and *daget*. The topographic factor accounts for the effect (decrease of slope length and incline) of stone bunds and cultivation terraces which are formed subsequently.

For several factors, the obtained values are only approximate; in USLE, these *guesstimations* are multiplied. To extrapolate such soil erosion estimations for scattered observations spatially into an erosion risk map would give results which are too far from reality. The problem of scale (generally, much less soil is exported from a catchment than what is foreseen by calculations using the plot-based USLE) and of the neglect of slope processes other than sheet erosion should also incite to be very cautious with such maps.

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