Geo-Eco-Trop, 1995, 19(1-4), 51-82

SOIL EROSION IN THE TIGRAY HIGHLANDS (ETHIOPIA). I. NATURAL AND HUMAN ENVIRONMENT IN ITS RELATIONSHIP TO SOIL EROSION

L'érosion des sols sur les Hauts Plateaux du Tigré (Ethiopie). I. Relations avec l'environnement naturel et humain

J. NYSSEN*

RESUME

Phénomènes naturels et conditions humaines sont analysés quant à leur impact sur l'érosion des sols dans le Dega Tembien (Tigré Central, Ethiopie). Les pentes fortes, les précipitations intenses (dont le début se situe lors des semailles), ainsi que la déforestation en sont les causes principales. D'autre part, les armos *traditionnels, bandes de végétation formant des structures anti-érosives, ont souvent été détruites. La végétation semi-naturelle a été éliminée par les communautés paysannes dans l'espoir d'améliorer la production agricole dans l'immédiat, et ceci en réponse aux famines et à l'appauvrissement de la population par le fait du métayage, à la priorité donnée aux cultures d'exportation, à la stagnation des techniques agricoles, aux guerres souvent d'origine extérieure à la région.*

Les relations entre pauvreté, démographie et érosion des sols sont également prises en considération.

Un article (à paraître) présentera une approche quantitative de l'érosion des sols, ainsi que de la conservation de l'eau et des sols en Dega Tembien.

ABSTRACT

The impact of natural and human phenomena on soil erosion in Dega Tembien (Central Tigray, Ethiopia) is studied. Steep slopes and intensive rainfall occurring during seedtime,as well as deforestation are the main direct causes. Even armos, *the traditional anti-erosive vegetative barriers, have often been destroyed.*

Semi-natural vegetation was removed by the smallholder peasant society in a bid to increase immediate agricultural output in response to famines and impoverishment (which finds its origins in share-cropping, priority to export crops, stagnating techniques, often imposed wars, ...).

* Département de Géographie Physique, Université de Liège, B11, Sart-Tilman, B.4000, Liège, Belgique

The relationships between poverty, soil erosion and demography are also approached.

This paper prepares for a forthcoming one, dealing with a quantitative approach of soil erosion, as well as soil and water conservation in Dega Tembien.

INTRODUCTION

The depletion of the Ethiopian Highlands is very important: the Nile delta is largely composed of sediments whose origin is in Ethiopia (WILLIAMS & WILLIAMS, 1980). Soil erosion removed since the end of the Oligocene (23.5 years B.P.) about 15 mm of soil every thousand years (GROVE, 1980). The present-day rate in Ethiopia is far higher than this average geological rate: HURNI (1988) estimates it at 4 mm yearly and three times as much on cultivated land. This accelerated erosion is explained by a quick tectonic uplift during Pliocene and Pleistocene, the changing climate and the impact of human society.

Approaching these problems, it seems important to try to stride over the gap separating the two main branches of Geography. The study of soil erosion is one of these subjects which allow to make the synthesis: the understanding of physical processes is essential, but one also has to know the socio-economic context (land tenure, social structure, perception of erosion phenomena, ...).

The choice of Tigray, in Northern Ethiopia, for soil erosion studies was motivated by the extent of environmental degradation, and also by the big effort made in soil conservation. Since the abolition of feudality in the seventies, after long years of war (1978-1989) opposing the Tigray People's Liberation Front (TPLF) and the Derg (military government), and several famines (the last two famines happened in 1972-1973 and 1984-1985), a popular will now exists to manage the natural legacy. Particularly striking is the concrete way in which interviewed peasants explain the soil conservation measures. This priority to agriculture, conservation of the environment and participation has existed for many years in TPLF controlled areas.

In a forthcoming paper, besides an assessment of the seriousness of soil erosion in this region, the actual anti-erosive watershed management and the prospects for soil conservation in Tigray will be analysed.

Hagere Selam, mean town of Dega Tembien *woreda* (district), is situated at an altitude of 2650 m, about 50 km to the west of Makalle, Tigray's regional capital, on a pass which separates the studied watershed (Hechi-Ruaksa) and Tankwa watershed. The nearby villages are almost all situated down below the town (Ruaksa e.g. at an altitude of about 1900 m) and are mostly only accessible by foot or on a mule back (Fig.1).

Geological formations outcropping in the Hagere Selam region are of Mesozoic age, or tertiary basaltic flows and make up subhorizontal layers. One

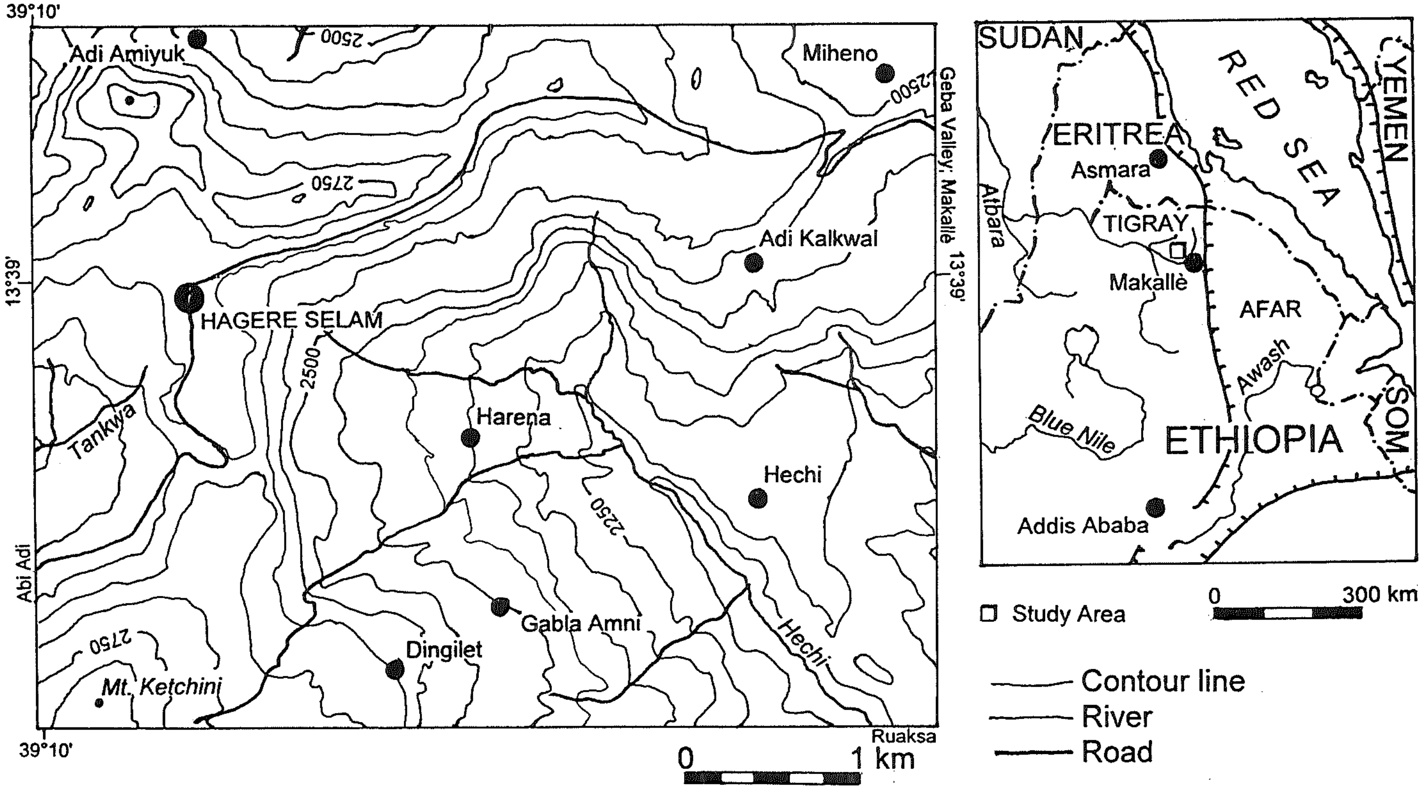

Fig. 1. Location map

also finds some quaternary formations, made up of alluvium, colluvium and travertine (MERLA & MINUCCI, 1938; MOHR, 1963; BEYTH, 1972; MERLA *et al.*, 1979).

Adigrat Sandstone (Jurassic), the basic formation of the mesozoic sedimentary series, crops out in deep valley bottoms.

Antalo Limestone is about 700 m thick and presents alternating hard and soft layers. The last are very marly and correspond to gentle slope morphologies. The very resistant and 50 m thick basic limestone formation forms high cliffs and well-developed lapiez at its summit.

The regressive Amba Aradam Formation (Cretaceous) is essentially composed of red sandstone; it has undergone a subaerial weathering at its summit and then a contact metamorphism when lava has flown over it. The upper 8 m of this formation which is 50 to 100 m thick are very resistant and impervious. The resulting cliff is very clear, except where it is covered by landslides and colluvium, as at the East of Hagere Selam.

The lower unit of the trapp series (tertiary basaltic flows) covers the summits. Issued from a dozen successive flows, this formation has the aspect of huge steps.

On steep slopes exists a very active mass wasting, which has particular interest if the basaltic material has been carried over sandstone and (further downslope) over limestone. This colluvium and other hillside waste, a few metres to more than ten metres thick, forms a pedologic parent-rock very different from the concealed formations. On this colluvium, soils are more fertile and the vegetation is richer and outstanding by the virtual absence of calciphile species. The villagers readily plant eucalyptus trees here, a species which is generally not encountered on limestone, where timber is furnished by the candelabra-type euphorbia. Often villages and hamlets are installed on this more fertile basaltic colluvium.

Travertine appears in many places, forming wide surfaces, often dams which trap sediments and raise the base-level of the watertable. This travertine is badly eroded by flash floods due to increased runoff.

As the geological layers are subhorizontal (including the different superposed lava flows), the relief consists of an alternation of flats and escarpments, expressing the unequal resistance of the rocks subjected to weathering. The summits of these scarps follow more or less horizontal lines, underlining the tabular structure.

These scarps and flats are however, in places, interrupted by more uniform or, on the contrary, chaotic slopes, resulting from the deposition of upslope removed materials: rockslides, landslides, alluvial cones and colluvium.

This relief will determine partially the soils, the vegetation and the land use.

RESTRAINTS TO AGRICULTURAL DEVELOPMENT

Land tenure and its environmental consequences

In Northern Ethiopia, before 1978, the fields were, in principle, individually owned by the farmers. This property right was transmitted to the descendants of the ancestor who was considered to be the founder of the village. This direct land tenure is called *rist*. Prefeudal in its origins, this system was nonetheless evolving towards feudality. In practice, there were many disputes for land and "having the capacity to win in court" (as a farmer expressed it) outpassed descendance. Land was also bought by local elites, or belonged to feudal lords. There were many landowners who no longer lived in the village, their fields being cultivated by tenants. Attempts to institutionalise this evolution (attribution of ownership titles after measuring of the land) in 1942, 1950 and 1967 had to be abandoned as a result of resistance by the farmers (SPIEGEL, 1980). Particularly in the Highlands, large parts of arable land were in the hands of the Coptic Church which had received it from the Crown, as a reward for ideological support. The many monastries and churches had land in direct tenure, which was exploited, by way of salary, by the lower clergy. Moreover, the church gave land in share-cropping (*samon*) to tenant farmers (NADEL, 1946; STAHL, 1974).

In the Hagere Selam region, before 1978, about one third of the land belonged to farmers, one third to absentee landlords and one third to the Church. Tenants gave 50 to 60 % of the yield to the plot's owner.

This evolution from rist to share-cropping led to an impoverishment of the small peasants, which was so high that it provoked not only social revolution but also environmental degradation.

The payment of 50 % or more of the yield to the landowner meant an impoverishment of the farmers, compared to the original *rist* system (communal ownership). Such an impoverishment due to share-cropping is not exceptional: MERLE (1958) points out a similar state of desperation for sharecroppers in the French Gâtine (Poitou) region in the 17th century.

Share-cropping also led to soil degradation as farmers were not encouraged to improve their fields, invested time and work only benefiting them a little. "On the contrary, if a tenant increases the value of the holding by planting trees, digging ditches etc., the landowner often responds by increasing the rent" (STAHL, 1974). Interviewed farmers said that the landlords and their agents never controlled how the land was cared for; they only came at harvest time to take the share. The landowner's profit was secured by cheap labour of a great number of farmers rather than by investment and technical improvement.

After the emperor was removed from power, the military *Derg* was installed as the highest State organisation, evicting the popular movements. From 1975 to 1978, the *Derg* organised a land reform. All land was nationalised and distributed to the farmers. This reform was most successful in the South of the country where *gult* tenure was a rule: large domains, acquired by the Amharic aristocracy were farmed by tenants. In the North, ownership relations were more complex: communal ownership under the forms of *rist* and *diessa* (in certain regions, communal property with regular redistributions), Church land and large feudal property were coexisting; the land reform was not exactly fit for these coexisting tenure systems. This land reform will often be perceived as being imposed from above and soil conservation measures (for example) will not be based on the farmers' conviction of need for it.

Land tax

In the Empire, a fixed tax was levied yearly on every province. After the *woyane*, the anti-feudal revolt in Tigray in 1943, the tax imposed on this province was doubled (WRIGHT, 1984). This tax was paid by the landowners (who recovered a large part of it from the tenants - STAHL, 1974), according to the surface of the land or the number of plots (only a small part of the land had been measured) as well as its productivity. Since 1944 the total amount of the land tax has stagnated, which corresponds to a decrease in real terms (STAHL, 1974). After the implementation of the land reform in Dega Tembien, its amount stabilised around 15 to 20 Birr per farmer per year (which is the price of 10 to 15 kg of cereals in 1994).

Three priorities of the state budget: the bureaucracy, the army and, later, export crops

Government revenue, particularly made up of land taxes and a part of land rents paid in cereals, was principally used for the maintainance of the bureaucracy and the army (STAHL, 1990). Threatened by colonial expansion in the second half of the 19th century, "the different princes maintained armies estimated at 200.000 soldiers, in total about 1 million people living as parasites" (GALLAIS, 1985). In the twentieth century, the bureaucracy and the army, even before the militarisation in the eighties, absorbed, taking the good and bad years together, half of the ordinary budget of Ethiopia. The consequences of this constant fact are that, on one hand, this part of the population had to be kept by the peasantry, and on the other hand, the importance of expenditure for these sectors must of course be compared to the low means given to the productive sector and to agriculture particularly.

In his thesis, STAHL (1974) shows how the end of the sixties had to be awaited before some importance was given to agriculture, understanding that this concerned, in priority, the development of the commercial sector. Indeed, in spite of the fact that Ethiopia could conserve a formal independence in the 19th century using the contradictions between the different colonial powers, it privileged export crops (coffee, sugar, cotton), grown in the South of the country and in the Awash valley, in order to allow the importation of manufactured goods for army and elites. This remained a constant fact, "in order to service debt and to purchase the foreign goods on which [Africans] have become so dependent" (SOLOMON INQUAI, 1992). There was, therefore, limited agricultural investment in these regions where subsistence production and production for the local market dominates: the Highlands (FOUCHER, 1985; STAHL, 1990; MULUGETTA BEZZABEH, 1992).

AGRICULTURAL SYSTEM AND AGRICULTURAL TECHNIQUES

WESTPHAL (1975) describes the agricultural system of the central and northern Ethiopian highlands as follows: "near-absence of fruit trees, green vegetables and tuber crops; emphasis is on seed production and broadcast sowing" and he defines it as "grain-plough complex". Most cultivated in Dega Tembien are barley and wheat. Next to these is tef (*Eragrostis tef*), a cereal with very fine grains which is endemic in Ethiopia.

The physical-biological environment is very important for this permanent dryland agriculture. The principal limiting factor is certainly the rainfall regime: on the Ethiopian Highlands prevails a tropical mountain climate with rainfall limited to the period from March to September. Rainfall decreases from South to North. Due to its altitude, the northern Hagere Selam receives however on average 751 mm of rainfall per year, essentially between June and September. This quite short and intense rainy season, with a great variability from year to year, makes annual crops uncertain, as their "planting dates are controlled mainly by the farmers' experience of rainfall in the past" (NIEUWOLT, 1978). The growing period only lasts some hundred days and thus only one yield is possible.

Ploughing

Ploughing is carried out by a plough with a metal point, drawn by two oxen. This implement, called a *mahrasha*, throws the soil onto both sides of the furrow without returning it, and is easy to handle in stony soils; moreover, harvesting residue remains on the surface and may limit soil erosion (WESTPHAL, 1975). Different successive ploughings are necessary in order to reduce soil clumps and to pull up weeds: three for barley and wheat, but up to six for tef which has tiny seeds. Fields prepared for tef are thus very easily eroded by rainfall occurring at seedtime (HUNTING, 1976; THOMAS, 1988).

During the rainy season, plough furrows are nearly all on contour; as water is retained, this method increases infiltration and brings about sedimentation in the furrows; the necessary crossing of successive ploughings is obtained by giving them a slight slope, in alternate directions. On no occasion did I observe downslope ploughing, which seems to have been frequent in the past and which, perhaps, is still implemented elsewhere in Ethiopia.

Seedtime corresponds to the beginning of the period of intensive rainfall

An agricultural calendar (Fig. 2) has been realised by cross-checking information from different sources and information collected by the author. It concerns cereal crops; variations do of course exist, according to species, variety, soil type and altitude. Legume crops harvesting is later (December, January).

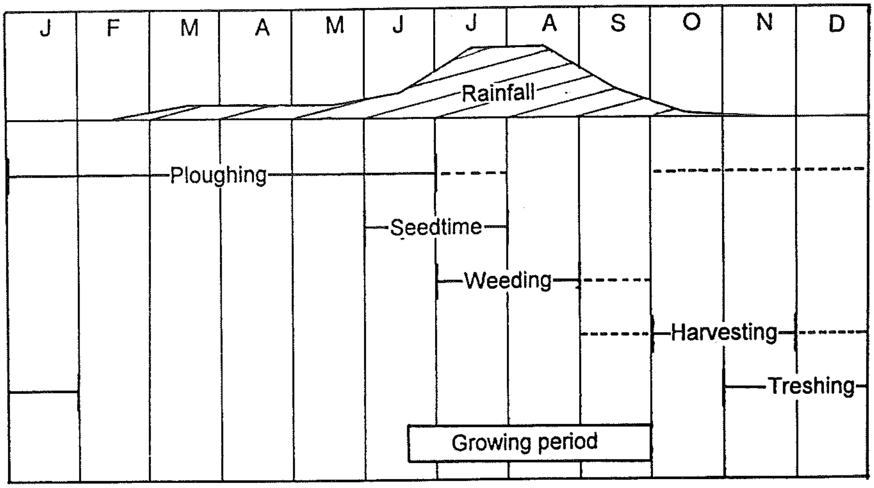

Fig.2. - Simplified agricultural calendar (barbey, weat, tef) of Daga tembien

It can be observed that seedtime corresponds to the beginning of the period of intensive rainfall: the soil which has, by then, undergone at least three ploughings, is very bare, and offers little resistance to splash and runoff. In Dega Tembien, the greater part of the soil erosion is caused by the 40 % of the total rainfall erosivity occurring during seedtime (June and July). As rainfall averages of the 'small rains' season (*belg*) are quite good, advancing seedtime is sometimes considered. In that case, crops would already have acquired a certain size when intensive July rainfall occurs. *Belg* rains are nonetheless very uncertain and premature sowing with a germination possibly followed by a drought period, would result in the loss of the seeds. Soil and water conservation measures, allowing better infiltration, would give more guarantees to advanced sowing (VIRGO & MUNRO, 1978).

Rotations and fallows

Crop rotation is practised, but does not seem to be fixed. Questioned farmers say that it depends on several factors: previous years' crops of course, but also seed price and availability, climatic conditions, progress of preparatory work, and so on.

In some places, uniform rotations of cereals and legume crops, are practised by all farmers, by consensus, on vast areas. These partial crop rotations no doubt aim to ease stubble grazing. In Miheno village, fallow blocks are included in these partial rotations. Up until a few decades ago, this seems to have been very often the case (HUNTING, 1976).

As a result of impoverishment and famines, farmers want to increase cereal production. The cultivation of legume crops is thus more and more spaced in the rotations, in spite of the fact that the farmers know about their soil improvement properties. This is also the case for fallows. Of course, this brings about a decrease in production; certain fields, particularly those with underlying limestone, have consequently been fallowed.

It must be noted that fallow land only presents a good protection against particle detachment by splash and runoff if it is not overgrazed.

Terraces

For generations, soil bunds/grass strips, or *armos* served as an anti-erosive structure on (pre-land reform) field boundaries. An *armo* consists of a steep incline, about 1 m heigh, and a never ploughed two-metre wide grass strip behind it. Infiltration of runoff water and sedimentation of upslope eroded soil is favoured. This raises the height of the structure year by year and results in cultivation terraces. So far, there do only exist some short descriptions of this traditional technique in WESTPHAL (1975), REIJ (1991) and a publication by the Ethiopian Ministry of Agriculture (1988). The technique cannot be assimilated to stripcropping because grass strips are much narrower than cultivation strips: 'buffer strips' (WISCHMEIER & SMITH, 1978) or 'vegetative barrier' (SHENG, 1989) are probably more exact terms. In Kenya, one has measured that grass strips of 1,6 m wide, planted with trees (every 3 m) and alternating with 5 m wide fields, involve, in a period of six years, the creation of about 40 cm high inclines and a decrease of the field's slope from 13,8 % to 6,8 % (KIEPE & YOUNG, 1992).

Since the 1970's, the farmers ploughed most of the *armos*' grass strip, particularly in order to increase immediate agricultural production. Often, the incline was even levelled.

At present, stone bunds, constructed in catchment-wide terracing programmes, may be built on the edge of the subsisting *armos*' incline, raising it artificially and increasing its efficiency. In other areas the stone bunds are built regardless of the remaining soil bunds. The latter may even be destroyed.

Today the integration of these indigenous and introduced techniques is said to be discussed in village assemblies and more care will be taken to incorporate *armos* in the present terracing programme.

Evolution processes of agricultural techniques

Are traditional knowledges sufficient to stop environmental degradation?

A possible approach is to estimate that, confronted with a decline in production, the most active farmers will adopt new anti-erosive techniques through empirical inventions and taking in the scientific knowledge they possibly come across (BOSERUP, 1981). ASEFFA ABREHA *et al.* (1992), while estimating that this process would cost too much in human and material terms, quote the example of farmers in Tigray who do not bring their cattle to degraded pasture lands anymore. These farmers are aware that energy lost in browsing is higher than what is apported by the food the cattle can find on these slopes. They prefer therefore to keep the cattle close to the homestead and bring crop residues and hay (cut & carry). The sediment trap which Dingilet peasants built nearby a river in order to increase the size of a field is another example of empirical invention.

Adapted modern science, according to BLAIKIE & BROOKFIELD (1987) however, would allow to systematise this local knowledge and result in sustainable innovations. The introduction of more adapted anti-erosive techniques, and intensification by input of labour essentially, would then avoid the necessity of going through extreme degradations before the techniques are modified. STAHL (1990) pleas in favour of this second approach: because of extreme degradation, because of famines and sufferings, "peasant society [in Northern Ethiopia] cannot be expected to propel itself by its own inherent dynamic, into innovative development".

SLOPE GRADIENT

Slope steepness is an important factor favouring soil erosion in Dega Tembien: 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.

A Digital Elevation Model (DEM) of the studied watershed was realised by photogrammetry, resulting in a grid file with a spatial resolution of 30 m (HELAVA, 1994). In the discreetly sampled orographic surface of the DEM, the magnitude of the steepest slope has been calculated for every pixel, in function of the altitude (expressed in dm) of the neighbour pixels, level-headed for their position (Erdas, 1994). A slope frequency histogram (Fig. 3) has been realised.

In contrast to what could be expected (given the relief consisting of alternating flats and steep slopes), the distribution is unimodal. The slopes of the flats are well grouped around the 10 % mode (the part of the histogram between 0 and 20 % is symmetrical), but the steep slopes, dispersed (magnitude of 30 to 90 %), do not present a second mode, but do provoke a dissymmetry to the right.

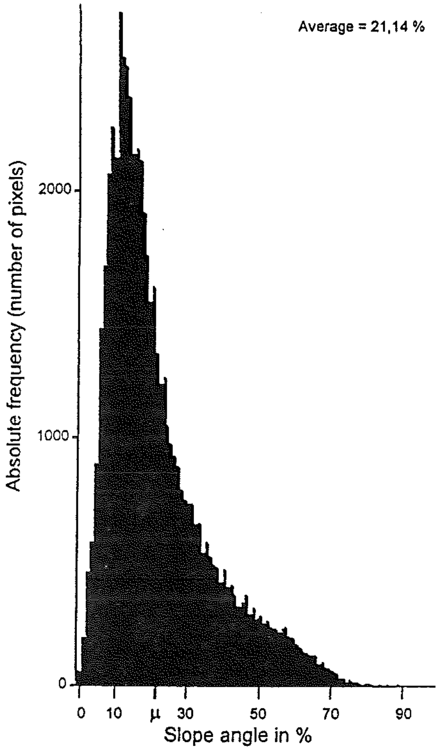

Fig.3. - Slopes frequency histogram of the southern part of the study area

The DEM's pixel size (30 m x 30 m) does not allow, in this case, to give with accuracy the slope of the fields, often only ten metres wide and forming field terraces (Fig. 4). Indeed, colluvium deposited on the first metres behind stone bunds presents generally a horizontal aspect. These numerous little horizontal surfaces do not appear on the histogram. Moreover, smoothing provoked by pixel dimensions means that, in these places where there exist field terraces the slope measured in the field with the help of a clisimetre is inferior to the slope calculated in the discreetly sampled DEM surface

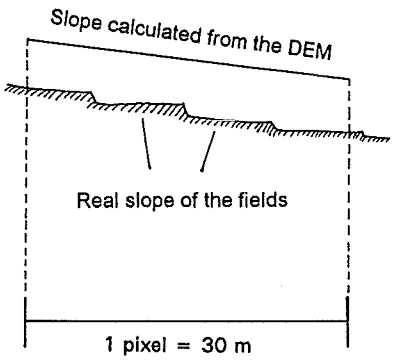

Fig.4. - Slopes of terraced fields are exaggerated if calculated from a descreetly sampled surface with too great a distance between the grid nodes

One must thus be careful while using these derived slope gradients in a quantitative model, when field terraces exist and with pixel sizes larger than the distance between terrace walls. One solution to this problem would be to reduce the pixel size.

The extremely high values of the cliffs do not appear on the histogram either, slope gradients having been smoothed because of pixel size too.

In Dega Tembien there are thus quite few flat or gently sloping < 7 %) areas. The average slope is steep and generally cultivated. Slopes up to 65 % steep may be used as grazing land. So the relief appears to be a major contribution to erosion risk.

Soil loss also increases with slope length: indeed, the accumulation of runoff water on longer slopes increases its detachment and transport capacity (WISCHMEIER & SMITH, 1978). In Dega Tembien, in places where stone bunds have been built, they 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. In addition to the abovementioned decrease of the slope gradient, stone bunds also reduce slope length.

Other slope limits are the footpaths if they concentrate runoff, and the gullies.

VERY EROSIVE RAINFALL

To measure the impact of rainfall and runoff on soil erosion, only erosive rain must be taken into account: this concerns not only exceptional showers, but also many average showers.

The erosivity index R (WISHMEIER & SMITH, 1978), based upon rainfall intensity data, takes into account both the effect of splash and runoff. It is however impossible to apply this index, worked out in the United States, just as it is to rainfall on the Ethiopian highlands. First of all, rainfall characteristics are different: the data of pluviographs installed in Central Tigray during one year indicate that 65 % to 77 % of rainfall is erosive, where a temperate climate produces 5 % of erosive rainfall and a tropical rain climate 40 % (HUNTING, 1976). This high rainfall erosivity is an important soil erosion factor in Central Tigray. HURNI (1979), in an analysis of rainfall erosivity in the Simen Mountains (100 km W of Dega Tembien), insists on two other particularities of Ethiopian mountains: erosivity due to hailstorm (2,5 times more important than erosivity due to rain) and the influence of slope aspect. Erosivity is reduced with a reduction of the angle between slope aspect and average origin of rainfall.

Moreover, in the absence of a pluviograph network, maximum hourly rain intensity could only be measured in a small number of research stations in Ethiopia.

Different researchers have thus tried to establish a correlation between total rainfall and erosivity. Here WISCHMEIER & SMITH'S (1978) warning must be taken into account: "Where adequate rainfall intensity data are not available, the erosion index cannot be estimated solely from annual precipitation data. It is a function of the sizes and intensities of the individual rainstorms, and these are not closely related to annual precipitation. (...) However, the United States data indicate that the range of likely values can be somewhat narrowed by knowledge of the general climatic conditions in the particular geographic area". In East Africa (Tanzania, Kenya, Uganda) the relationship between the erosivity index R and total rainfall improves if one groups the rainfall stations by geographic area (MOORE, 1979).

For Ethiopia, HURNI has elaborated, from monthly data of the 6 Soil Conservation Research Project stations, the following correlation:

$R = 5,5\ P - 4,7 \quad (n = 171;\ r = 0,88) \quad (1)$ (HURNI, 1985)

where: P = average yearly rainfall in cm

In the Hagere Selam region (P = 75,1), the erosivity factor calculated with this equation (1) is R = 408,35. This erosivity index, much higher than those measured in Europe, is among average values for Ethiopia (KRAUER, 1988).

A so calculated erosivity varies during the year in the same way as rainfall: close to 30 % of yearly erosivity for each of the months of July and August and a little more than 10 % during the months of June and September. From April to July, when the soil is bare (end of ploughing and seedtime), about 50 % of all erosive rainfall occurs.

This erosivity index only gives an idea of the importance of the phenomenon: rainfall in Tigray might be more erosive than the Ethiopian average. This reservation is based on two erosivity measures obtained from pluviographs during the year 1975 (HUNTING, 1976). It is stated that the used equation gives results which are, for the same two stations in 1975, 50 % lower than R calculated from pluviograph data (NYSSEN, 1995: p.93).

This relationship (1) has been obtained from data of 6 stations of which 5 are situated in the centre and the south of Ethiopia, and it might not be applicable to the northern part of the country. A multiplication of stations and measures would allow for the elaboration of relationships between erosivity and rainfall adapted to different regions of Ethiopia.

Moreover, rainfall distribution in the studied watershed, with close to 1000 m variation of elevation, is not known.

It was not possible either to take into account slope aspect and dominant rainfall incline. Rainfall direction is not known; it is probably variable, given the local topography. A more thorough study would allow the combination of rainfall direction and incline with slope incline and aspect. These two last data can be derived easily from a Digital Elevation Model, taking into account, for every pixel, the altitude of the neighbouring pixels.

NO EVIDENCE OF A TENDENCY OF RAINFALL DECREASE, BUT A TREND TOWARDS INCREASING AGRICULTURAL DROUGHTS

Yearly rainfall

In historic times, different dryer periods have been noted in north-eastern Africa, corresponding to a lesser movement to the north of the I.T.C.Z. (NICHOLSON, 1980). A rainfall decrease in recent times could explain the extension of the cultivated areas to marginal lands in order to maintain agricultural production. Is it not true that the elders say that, presently, rainfall is much less?

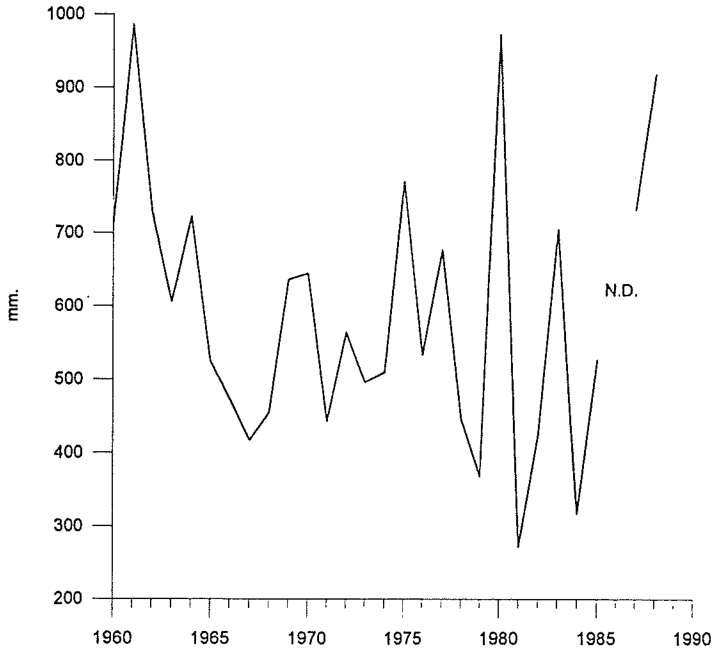

Fig.5. - Yearly rainfall in Makalle/Kwiha (Data: National Meteorological Services Agency, Addis Ababa)

The analysis of the yearly rainfall series for Makallè/Kwiha station from 1960 to 1985 (Fig. 5) shows however no significant tendency. The series is too short to allow such a conclusion; moreover, 1987 and 1988 values (not used in the calculations) are rising. To the contrary of what might happen in West Africa (OZER & ERPICUM, 1995), the climate of Northern Ethiopia seems not to have become dryer since 1960. This conclusion comes close to HUNTING's: "On the evidence available there does not appear to be any justification in assuming that a long term one-way climatic trend has occurred" (1976). BELTRANDO & CAMBERLIN (1995) do not find a clear tendency of rainfall decrease in Ethiopia either, "at least since the beginning of the century".

Seasonal droughts

There do especially exist irregularities from one year to another (971 mm in 1980 against 272 in 1981), several consecutive dry years, as well as a great seasonal variability, which can cause seed loss and yield failures. In 1993, for example, it rained heavily in March, and then there was a great drought during *kremti* (main rainy season, from June to September).

NIEUWOLT (1978) has developed a method which allows the occurrence frequency of agricultural drought months, with rainfall less than 50 percent of the long-term mean, to be rendered. What imports is the ratio of rainfall for a given period to expected rainfall, on which the agricultural calendar is based. The analysis concerns only the growing period months, roughly those where average rainfall exceeds 50 mm. The study of the seasonal droughts series for Makallè/Kwiha, from 1960 to 1985, shows a tendency towards an increasing number of agricultural drought months. BELTRANDO & CAMBERLIN (1995) also conclude that there is "a summer rain deterioration during the last decades".

This probable increase of seasonal droughts will certainly not incite the farmers to advance seedtime which now corresponds to the beginning of heavy rains.

In short, one may say that there is no evidence of a reduction in yearly rainfall since 1960. However a greater frequency of seasonal agricultural droughts might be observed, which, if they take place several years in a row, may provoke bad yields and famines and urge to the cultivation of too steep slopes and of the vegetation strips on field limits (*armos*).

RELATIVELY LOW SOIL ERODIBILITY

The study of soils submitted to erosion features requires the knowledge of their nature, their texture and structure, and their profiles.

Clay minerals present in these soils are varied: smectites, illites, kaolinites, etc... The minerals were analysed by X-ray diffraction (THOREZ, 1976).

Field observations show that soils on basalt and on basaltic colluvium present vertic properties: some vertical shrinkage fissures of 1 to 5 cm large and about 1 m deep, due to the presence of swelling clays (smectites). It must be noted that smectites are much better represented in soils on basaltic colluvium (up to 100 % of clays), which are less weathered by pedogenesis. On the contrary, the smectites of soils issued from in situ weathering of basalt are in an advanced stage of kaolinisation (domination of (K-Sm) interstatified mineral associated to very badly crystallised smectites). Such a domination of the kaolinitic phase engenders an important cation impoverishment and easier disintegration of particles.

Developed soils on Amba Aradam sandstone, if existing (this formation generally forms a cliff), can be qualified as cambisols given the presence of a cambic or B structural horizon.

Soils on sloping limestone are typical rendzinas, whereas soils on limestone in a subhorizontal position are often well developed. Both contain much smectite, which is probably a neoformation smectite (recombination of minerals dissolved in solutions originating from upslope leaching of basaltic rocks).

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).

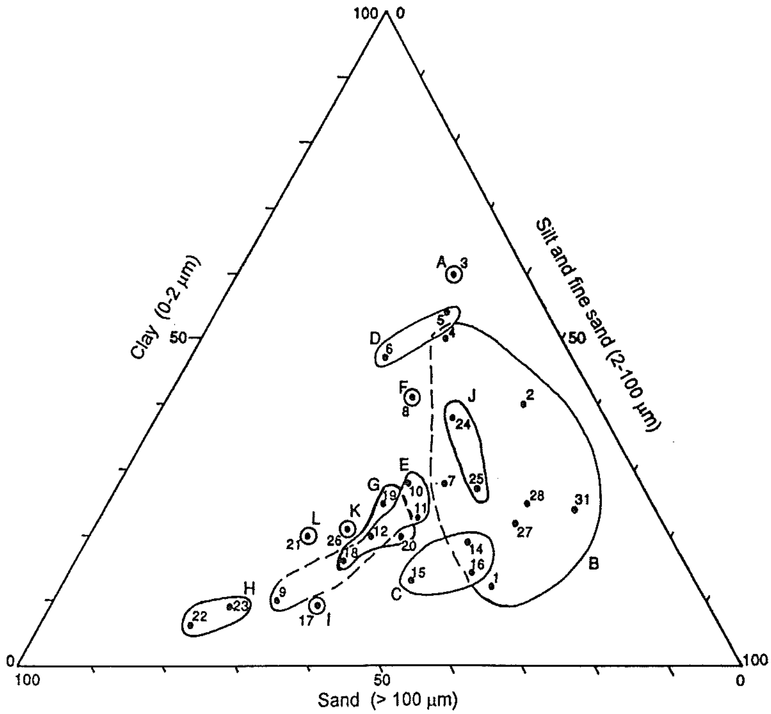

Fig.6. - Texture of topsoils in Dega Tembien

28 topsoil samples, taken on a transect from Mount Ketchini's footslopes down to Hechi, were analysed. This transect crosses the different lithologies and land use types of the studied watershed. A triangular diagram (Fig. 6) represents the texture of the different samples which were grouped according to pedologic parent-rock lithology and land use (Table I). We recognise heavy clay on basalt (A), clay in valley bottoms on basalt (D), silty soils in the fields on the Amba Aradam formation and on Antalo limestone (E and G) and sandy silt in the fields on limestone in Hechi (H). The soils on basaltic colluvium (B) are broad-ranged, from clay to fine silt. No doubt, this is due to the different means of transportation which intervene: sedimentation after upslope erosion, landslides, creep, ... Clay content of these last soils is low as compared to soils developed on basalt rock, which might be due to the fact that the fine particles, after erosion, are transported much farther towards the river.

Tab.I. Soils in the Hagere Selam area, classified according to lithology and land use. Texture and organic matter content (%).

				Sand >100 μm	Silt+Fine Sand 2-100μm	Clay <2 μm.	Oraganic Matter content
	Lithology	Land use	n	avg	avg	avg	avg
A	Basalt	Fields	1	10	30	59	3.76
B	Bas;/coll	Fields	6	19	52	29	5.63
C		Pasture/village	3	32	52	15	10.03
D	Alluvium	Field	2	20	30	50	3.97
E	A.Aradam	Fields	4	41	39	20	4.59
F		Pasture/slope	1	25	34	41	0.31
G	Limestone	Fields/outside	3	40	39	21	4.76
H		Fields/village	2	70	23	8	1.73
I		Pasture/slope	1	54	37	10	3.89
J		Forest/slope	2	22	46	33	6.20
K		Church forest	1	44	35	21	6.32
L		Recent deforestation	1	50	30	20	7.39

Methods: Soil texture: treatment with oxygenated water (H_2O_2); sifting (last sieve: 63 μm); densimetry. Coarse particles (> 2 mm) have not been computed. Texture class limits correspond to the required limits for K factor calculation in the Universal Soil Loss Equation (Wischmeier & Smith, 1978). Organic matter by loss-on-ignition: a) drying (105 °C); b) removing grains > 2 mm and OM which has not been decomposed; c) crushing with pestle; d) weighing; e) burning (550 °C) during 2 h.; f) weighing. Maximum error: 0,2 %. Deduction of the % water retained in clay minerals (DE LEENHEER *et al.*, 1957).

Organic matter (OM) plays an important role in the aggregation of particles, and its resistance to erosion by runoff. Erodibility is higher with lower humus content. After texture, this is the most important factor intervening in it (WISCHMEIER *et al.*, 1971; VORONEY *et al.*, 1981).

The OM content of the analysed samples is also summarised in Table I. Samples of soils on basaltic colluvium (lines B and C) present the highest OM contents. Forested soils also have a high OM content.

Degraded pasture lands on slopes have relatively low OM values. A very low OM content is also found in two fields on limestone (H), in one of the oldest villages of the region.

No correlation between OM content and slope could be found. Many other factors do intervene, of which the duration of cultivation seems the most important. Indeed, the lowest OM content is found in two fields with a slight incline (4 %) on limestone (H), in one of the oldest villages of the region (Hechi). In 3 neighbouring fields east of Gabla Amni (G), 4,1 and 4,3 % of OM is found where there is a low incline (4 to 5 %) and 5,9 % OM in a field on a steep slope (22 %). Due to its high concentration in topsoil and its low density, humus should be preferentially eroded (JUNG, 1956; VORONEY *et al.*, 1981) and we could thus expect a reduction of OM content with slope increase. In the present case however, the field on the steep slope has only been cultivated for a short time (less than twenty years probably), and the forest soil has therefore been exposed to accelerated erosion for a much shorter time than the flat fields, cultivated for decades, or even centuries. The "time" factor is very important for the explanation of OM content.

Moreover, 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 still stands in fields on basalt-derived soils and footpaths may be almost impassable. Low perviousness, by reducing infiltration thus increases runoff action.

Clay mineralogy, and especially the aggregation mode of micrometric particles, plays a role in soil erodibility, which lowers with the increase of montmorillonite (smectite) content (YOUNG & MUTCHLER, 1977). The high smectite content of soils on basaltic colluvium partially offsets high erodibility due to quite low clay and high silt content, as well as to low perviousness.

On average, soil erodibility appears to be quite low, mainly because of a moderately low silt content, a high organic matter content of soils in recently deforested areas and the very high clay content of soils on basalt (NYSSEN, forthcoming). This tends to indicate that soil properties are only a secondary cause of accelerated erosion in Dega Tembien.

INSUFFICIENT VEGETATION COVER

In Dega Tembien, certain slopes are overgrazed and have many erosion gullies and often important alluvial cones forming where the slope becomes less steep. Not far away, the same slope, closed for cattle for only a few years, illustrates the limiting effect of vegetation on soil erosion: the same badlands, recolonised however by grasses and shrubs, present no more visible erosion activity.

Dry evergreen forest probably formed the climax vegetation of the Ethiopian Highlands, between 1500 and 3000 m, *Juniperus procera* dominating the upper stratum in Tigray. This forest subsists partially on the western slopes of the Simen mountains and on the escarpment of the western Rift margin. In the first general geobotanic study of the Horn of Africa, PICHI-SERMOLLI (1957) subdivided the derived semi-natural vegetation into two types:

. The montane evergreen thicket and scrub is composed of shrubs with leathery, thorny or succulent leaves and some scattered trees.

. The montane savanna is fundamentally composed of a grass stratum. All the intermediaries between grass savanna and sparse forest exist. It is a vegetation type "due to the intense and prolungated action of man".

The trees, excepting reforestation trees, encountered in the fields in Dega Tembien (*Acacia etbaica, Acacia* sp., *Euphorbia* sp. (candelabra type), *Ficus sur, Ficus sycomorus, Ficus vasta, Olea europaea* subsp. *africana*), are probably remnants of montane savanna. Interviewed, an older inhabitant describes the region around Hagere Selam before 1945 as "rich grazing lands with many scattered large Acacia trees".

The dominant shrub species have also been listed on two steep slopes, situated on limestone, in the protected Habdi Luqmuts forest, close to Hechi, on a steep slope corresponding to a resistant formation of Antalo limestone, as well as on very degraded pasture lands, along the road from Hagere Selam to Makallè, one km West of the Geba river, at an altitude of about 2100 m. The main species (in decreasing order of importance: *Carissa edulis, Acacia etbaica, Rhus natalensis, Euclea racemosa, Dodonea angustifolia*), which dominate also in quantitative observations realised by WILSON (1977) in a similar place, are very common in the 'Montane evergreen thicket and scrub'.

The semi-natural vegetation of Dega Tembien may be qualified as follows:

- Evergreen thicket on steep slopes, as well as on some very degraded gentle slopes, generally on limestone. In such places, erosion creates an ecological threshold which prevents the installation of climax soil and vegetation: the natural vegetation on rendzinas is a calcicole thicket; lithosols on steep slopes on sandstone and basalt only support species with superficial roots and/or xerophile species, such as the candelabra *Euphorbia*. The thicket may be, according to the location, very degraded by overgrazing and woodcutting;

- Montane savanna on more level places, presently occupied by agriculture. This formation only subsists under a degraded form in some communal pasture lands.

The explanation of the regional distribution of evergreen thicket and savanna is thus before all a pedological one.

Deforestation

Overall tree clearing is a quite recent phenomenon in Dega Tembien. When MERLA & MINUCCI (1938) analysed, for the first time by (non stereoscopic) aerial photo interpretation, the geomorphology and the geology of Tigray, the principal criterion allowing the recognition of steeper slopes, corresponding to resistant strata, still was the alignment of small woods along these strata. Older inhabitants of Hagere Selam also remember that there were much more trees on the flatter areas, up until the fifties. Before 1940, there was sufficient firewood and it was therefore not necessary to burn manure.

Today only isolated trees (*Acacia, Ficus, Olea*) and few shrubs subsist in the fields as well as small protected forests around churches, (often very overgrazed) thickets on the slopes, as well as some recent closured areas showing an impressive spontaneous regeneration.

Besides increasing runoff and sheet erosion, deforestation also modified the rivers' regime: the basic discharge has become very low and in the case of heavy rains, which are frequent in Tigray, severe floods occur. This contributes to gully erosion: in a formerly marshy area near Dingilet, gullying started around 1970, reaching a depth of 8 m in 1994.

Restoration of the vegetation

Grassy vegetation and tree management are important for soil conservation (reduction of splash and runoff, stabilisation of soil and soil conservation structures, increase of the soil's OM content); the latter also improves the supply of firewood (by far the first energy source). The restoration of the natural equilibrium allows in addition a more efficient struggle against soil erosion which can be illustrated by the following example. Rats and mice, which are large cereal consumers, live in the stone-built anti-erosive constructions. The destruction that they cause, particularly during years of abundance, can be so substantial that farmers wonder if losses due to these little rodents do not exceed productivity gains due to erosion control, hence, their desire to increase the space between newly built stone bunds, in order to decrease these losses. In fact, because of deforestation, the predators of these rodents, like wild cats, snakes, and especially nocturnal birds of prey have greatly regressed. The owls' (*guga* in Tigrinya, probably *Tyto alba*, or *Bubo* sp.; see CHAPIN, 1939) habitat is mainly trees with well developed branches, like *Olea europaea* subsp. *africana* and *Ficus* div. sp. The expansion of the owls' territory could (temporarily) be facilitated by the installation of nest cages, but for a reintroduction to succeed it is evident that the state of the ecosystem must be close to the one existing before regression. The above named trees, and particularly the wild olive tree (Fig. 7) are, however, remnants of climax vegetation. Nowadays, the water table has lowered too much and young shoots die. Hope for the owls (and despair for rodents!) resides in a restoration of the vegetation which will increase water infiltration. The rise of the water table would allow *Olea* and *Ficus* sprouts to be planted.

Reforestation of steep slopes

The most effective measure to allow the regeneration of vegetation on the very sensitive steep slopes is area closure, which can be complete, or with allowance for manual removal of grasses, once or several times a year (cut and carry).

Presently, slopes and other degraded areas are being reforested with indigenous species as well as with *Acacia cyanophylla* and *Cupressus lusitanica. Eucalyptus camaldulensis* was for a long time the preferred reforestation species, because of its rapid growth and its straight trunk, often used as timber. This tree presents however many disadvantages: its roots require a deep soil, it is not convenient on steep slopes; it has a high water consumption and only few grasses and no shrub stratum under it. Observed clearings of Eucalyptus trees, planted in 1970, didn't have any shrubs or small trees growing randomly inbetween the stumps. As this species is not convenient for limestone-derived soils either, it has now been abandoned for reforestation, but remains widely used as a cash tree.

Even in the case of a reforested slope, WILSON (1977), having noted a vigorous regeneration of the indigenous vegetation, estimates that "in the long term, the effects of exclosure will be more significant than the actual planting". Area closure is now practised on many steep slopes. It allows a rapid regeneration of grasses and shrubs (Fig. 8). It must be noted that the absence of bush fires in the traditional agricultural system gives some guarantees for the success of this conservation technique (CHADHOKAR, 1992).

The setting up of "green belts" on these steep slopes, integrating the rare existing forests and the closured pasture lands, would trend towards the restoration of the dry evergreen forest, submitted to forest management (including for example tree pruning in order to supply timber and firewood).

Semi-natural vegetation on agricultural land

The respect of a strip of semi-natural vegetation on the outer edges of cultivation terraces, the protection of trees (as it exists at present), the planting of (leguminous) trees and the introduction of other agroforestry techniques would considerably reduce accelerated erosion on agricultural land. One must bear in mind that the natural secondary vegetation which existed on the flats, the montane savanna, allowed the coexistence between Gramineae and large trees. In

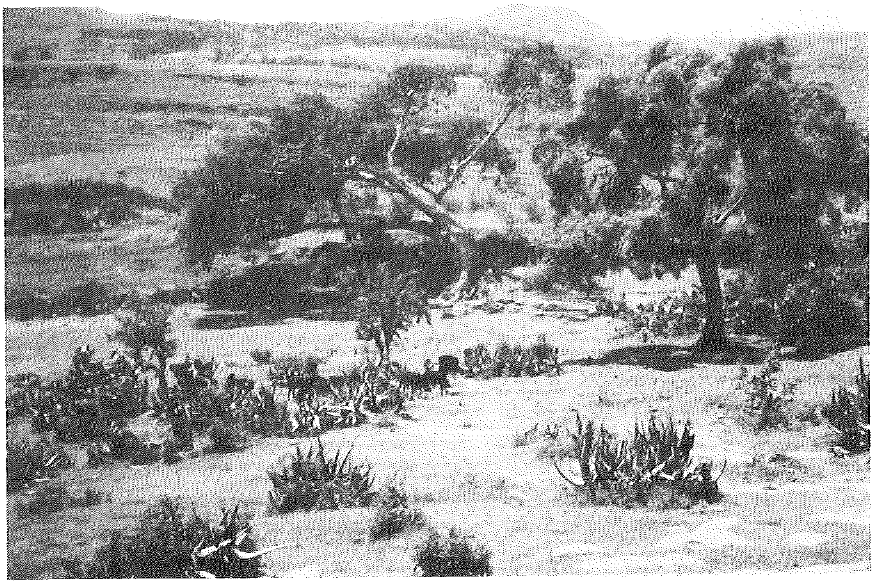

Fig.7. - *Olea europea* subsp. *africana* without regeneration (due to lowering of the water table). Colonisation by *Opuntia Ficus indica* and *Aloe* sp.

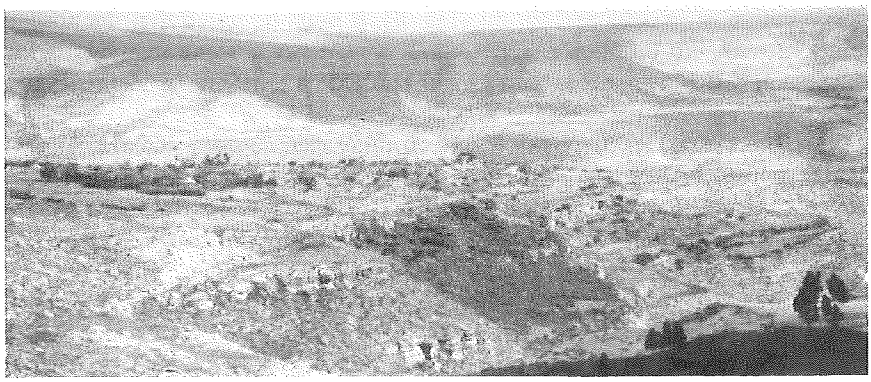

Fig.8. - Habdi Luqmuts forest, protected for 15 years (in the middle). The adjacent slope (left) has been closed to cattle for 2 years. The fields appear in plain light tone

short, "tree-growing concepts that both complement and supplement agriculture rather than compete with it" (SCHREMPP, 1992).

A reorientation of cattle rearing seems to be necessary: at the moment many slopes are overgrazed; moreover, the custom of stubble grazing does not permit tree planting on plot limits (outside of the villages) and on terrace edges. They would not have a resistance to grazing cattle. (Oxen are important as a workforce in agriculture.) One solution would be to reduce livestock (which will increase its quality), together with stalling, carrying of fodder to the cowshed and manure to the fields.

IMPOVERISHMENT, LACK OF REINVESTMENT AND THEIR CONSEQUENCES ON SOIL EROSION

Given the impact of share-cropping, taxes and budget policy on the rural society of Tigray, we must now examine the processes and also the "transformations, commanded from outside the study region" (TRICART, 1984), which have been the consequences with regard to soil erosion: the tendency to overexploit the natural environment and the stagnation of agricultural techniques.

Increasing environmental degradation and decreasing farm size (as a result of population growth) should have commanded an adaptation of agricultural techniques, the equipment of the farmers with knowledge and inputs and the use of efficient anti-erosive techniques. However, as seen, subsistence agriculture was negligible in the Ethiopian budget. Other important obstacles to rural development are analphabetism and the lack of agricultural extension.

Next, impoverishment and famine involve the research of maximum immediate return, even if it means accelerating the soil erosion process. The existence of this situation in Tigray can be illustrated by the following examples:

- In Dega Tembien, average yields are sufficient for 10 months; the rest of the year peasants are dependent on food aid, on other survival strategies and/or suffer from malnutrition and subsequent illnesses. Infant mortality is high. The farmer, having lived through two great famines during the last twenty years and knowing that the slightest decrease in agricultural production might be fatal for one of the members of his family, will increase agricultural surface: cultivating steep slopes and destroying *armos* which in addition allows the recovery of the OM-bearing soil accumulated in it.
- The layout of anti-erosive structures is long work with only little immediate return. Confronted with scarcity, traditionally, the farmers preferred to look for other alternatives to feed their families (working in town, selling cattle, food aid, ...).
- In the study area fallows and legume crops are more and more spaced in rotations, in order to increase cereal production, as an immediate response to famines.

BLAIKIE (1981) summarises it as follows: "Surpluses are extracted from cultivators who then in turn are forced to extract 'surpluses' from the environment (stored-up fertility of the soil, forest resources, long-evolved and productive pastures, and so on) which in time and under certain circumstances lead to degradation and/or soil erosion".

POLITICAL FACTORS FAVOURING SOIL EROSION

Destructions and impoverishment due to war

Since 1850, Tigray has been "a region where many internal wars were fought and where foreign expansionist wars met resistance" (MULUGETTA BEZZABEH, 1992). Each army left behind it many economic and environmental destructions. HENDRIE (1991) analyses how Tigrayan farmers have been hit by the Ethiopian army's counter-insurrection campaign in the eighties: "Targets for attack have included villages and crowded market places, food-aid distributions, relief transports, livestock herds, clinics and schools. Some farmers have reported being attacked by planes while ploughing in their fields. In addition to the killing and maiming of thousands of civilians, the disruption to productive life and the loss of agricultural assets caused by these attacks have caused many families to decline into conditions of absolute poverty".

The consequences of the peasants' impoverishment, particularly the overexploitation of soil, have already been described.

Conflicts between populations and government

Situations of conflict induced also an absence of confidence between populations and authorities. "Government policy is designed and implemented in the conventional top-down fashion with little room for adaptation to individual and local conditions" (STAHL, 1990). From 1971 onwards, eucalyptus plantations were established in this way on 1500 ha of steep slope in Tigray, under the auspices of a Food and Work programme by USAID (HUNTING, 1976). This approach was also that of the *Derg*. "Party and administration officials visit Peasant Associations and issue instructions and regulations, their often arrogant ways being bound to create frustration. People are seldom consulted in a genuine way" (STAHL, 1990). The only motivation which could be offered to the peasants was Food for Work. In some regions, soil and water conservation work was considered 'a problem of the government' and after the *Derg*'s fall, in such areas, steep slopes have been ploughed again, the trees cut and terraces destroyed, because the authority for which the farmers had planted trees and built terraces was no longer there, and the motivation presently identifiable in Tigray did not exist (HERWEG, 1993; STAHL, 1993).

POPULATION AND EROSION

Dega Tembien has about 61.000 inhabitants, of whom 7.000 live in a town, Hagere Selam.

Rural density is about 90 inhabitants per km^2, the highest in Central Tigray; it is between 100 and 120 inhab./km^2 in the regions situated at an altitude over 2500 m, but this density decreases quickly with lower altitude: less than 40 inhab./km^2 in the areas situated under 2000 m (HUNTING, 1976). It is a well established fact that the Ethiopian population is concentrated in elevated areas because of higher rainfall and fewer risks of malaria (HOFFMANN, 1987; THOMAS, 1988). The contrast between high density in the most elevated areas and low density in regions which are only a little downslope can probably also be explained by the fertility of the soils situated on summital basalts.

There is no agreement between different reports on the rate of rural population increase in Central Tigray. (The first population census in Ethiopia was only carried out in October 1994.) Population data for Dega Tembien in 1975 and 1994 are very close (HUNTING 1976; REST, 1994), which might be due to the extraordinary conditions the region has known: the victims of two famines and a long war, people displaced or on military duty have to be added to 'ordinary' rural exodus.

Poverty induces population growth

With regard to the relationships between demography and soil erosion, one must not forget that poverty brings about a survival strategy in which the number of children has an important role. "The predominance of a backward agricultural sector in economy still requires an abundant workforce because of the insufficiency of modern production factors" (SAVANE, 1988). MOORE LAPPE & SCHURMANN (1990) do not have an all-purpose model; however, their study of the successes obtained with different approaches (in China, India's Kerala state and Cuba) with regard to a decrease in population growth allow to highlight the importance of literacy, women's conditions, land rights, food, health and access to family planning. In a word, without an improvement of economic and social security, families with many children will remain the only source of security for the Third World poor.

In the same way that environmental destruction on the Ethiopian Highlands is a consequence of the poverty of the population who lives in this environment, it turns out that this same poverty also induces a high demographic growth. Rather than a relation from cause to effect between demography and erosion, both variables are consequences of generalised poverty. This leads us to support a conclusion by Louvain demographers TABUTIN and THILTGES (1992): population growth may be an "immediate and aggravating factor" of environmental degradation. One must however not attribute the crux of the problem of degradation solely to demography. Degradation "comes under rather essential factors (economic model, poverty, North-South inequalities) hard and long to change".

The question might be raised whether, in the case of a rapid demographic growth, the agricultural territory would be productive enough to feed the population. At first, one must remember that famines result more often from a lack of access to food (due to poverty, lack of transportation, exportation) and not from a simple lack of food (BLAIKIE *et al.*, 1994).

In the case of the Ethiopian Highlands, the first stage of the demographic transition took place in a rural society with agricultural techniques which had not evolved for centuries because of a whole series of factors, principally socio-economic ones as already analysed. Both recent (REST, 1992) and older reports insist that "the area is overpopulated in relation to its natural resources *under present systems of utilisation*" (HUNTING, 1976).

"There is, in fact, overpopulation only when the number of inhabitants exceeds the food production possibilities of the concerned region and not its effective food production; in this last case it is a question of under-production, which is very different" (BESSIS, 1981).

"More people, less erosion"...

... is the evocative headline of a recent study which analyses environmental rehabilitation in the semi-arid Machakos district (Kenya) between 1930 and 1990: TIFFEN *et al.* (1994) show how in this region, which has known severe degradation during colonisation, erosion has greatly decreased, whereas population quintuplated. Terrace building in the fields, tree planting on plot limits, diversification (fruit trees, vegetables), the introduction of new technologies (for example compost from urban organic waste; techniques favouring the infiltration of runoff water), the improvement of markets and access to information allowed the degradation process to be reversed and to increase production and the standard of living.

There is no simple answer to the question about the relationship between population pressure and environmental degradation, but it is evident that an attempt to impose a low birth rate policy would lead to an authoritarian approach and loss of confidence by the farmers. This would have negative consequences on the mobilisation for soil conservation, especially if there is, or if the population perceives, a link between low birth-rate and conservation policies. TIFFEN *et al.* (1994) think that "the provision of family planning information and the making accessible of supplies can be justified as adding to peoples' choices and the control which they have over their circumstances", concluding however: "To argue for population limitation on environmental grounds weakens the case for it both theoretically and practically".

A better orientation, to my opinion, consists of a model which integrates environmental protection, improvement of the peasants' production capacity and a social policy (health, women's conditions, alphabetisation).

CONCLUSION

Rainfall impact on Dega Tembien soils, having lost most of their vegetation by century-long action of human society, brings about mass movements, among which especially soil erosion was analysed in this paper. The predominance of steep slopes induces a natural vulnerability of the study area to soil erosion. The heavy intensity of rainfall occurring at the very moment of seedtime, when soils are very nude, aggravates the soil erosion problem. Advancing seedtime is very risky, because rains have become more irregular (however one cannot speak about a trend towards total rainfall decrease).

Soil erodibility is generally low particularly because of organic matter content which I think inversely proportional to deforestation age. On account of the aggregation mode of their micrometric particles, smectites also contribute to reducing soil erodibility. Soils on basaltic colluvium, in spite of a high organic matter and smectites content, are most erodible because of their high silt content and their low perviousness.

Confronted with these difficult conditions, human society was not able to react in an appropriate way. For centuries, the agricultural techniques of the peasants on the Ethiopian highlands have been stagnating. When, in spite of budget priorities in favour of the longstanding bureaucracy and army, investment was made in agriculture, it was especially oriented towards export crops. Moreover, feudality, share-cropping (up to 1978), taxes and the often imposed wars induced impoverishment and incited the farmers to prefer immediate returns, even if it meant aggravating erosion. As a consequence, during this 20th century, most of the trees and shrubs in between the fields and on steep slopes have been cleared, increasing runoff, sheet erosion and gullying.

Demographic growth, itself a consequence of poverty, could possibly be an aggravating factor, in the absence of adoption of agricultural and anti-erosive techniques adapted to environmental changes. The weakness of the educational system and lack of agricultural extension and are also social factors which are important in the explanation of technological stagnation and of soil erosion.

ACKNOWLEDGEMENTS

I thank professors A. OZER, A. PISSART (University of Liège, ULg) and MITIKU HAILE (Makallè University College) for the supervision of this research. Many responsibles and field agents of the Relief Society of Tigray (REST) as well as Dega Tembien Agricultural Office shared field trips and their experience with me; local authorities and many other inhabitants of Dega Tembien facilitated this research. The Fondation Lefranc of the ULg provided financial assistance and professors J. ALEXANDRE (ULg) and J. DECKERS (University of Leuven) commented a draft version of this paper.

REFERENCES

ASEFFA ABREHA, BERHE W/AREGAY, TESFAY BELAI, BERHANE GEBRE EGZIABER, 1992. Report of the symposium on environmental degradation, 15-20 april 1992, Meqhele, 72 p.

BELTRANDO G., & CAMBERLIN P., 1995. Les sécheresses en Ethiopie et dans l'Est de l'Afrique. *Sécheresse*, 6, 87-94.

BESSIS S., 1981. *L'arme alimentaire*, Maspéro, Paris, 341 p.

BEYTH M., 1972. Paleozoic-Mesozoic sedimentary basin of Makalle outlier. *American Association of Petroleum Geologists Bulletin*, 56, 2426-2439.

BLAIKIE P., 1981. Class, land-use and soil erosion. Paper read to the Development Studies Association Annual Conference, Oxford.

BLAIKIE P., 1985. *The political economy of soil erosion in developing countries*, London, NY, Longman, 186 p.

BLAIKIE P.,& BROOKFIELD H., 1987. *Land degradation and society*, Methuen, London, 296 p.

BLAIKIE P., CANNON T., DAVIS I., & WISNER B., 1994. *At risk; natural hazards, people's vulnerability, and disasters*. Routledge, London, 281 p.

BOSERUP E., 1981. *Population and technology*, Blackwell, 255 p.

CHADHOKAR P.A., 1992. Area closure for soil conservation in Ethiopia: potential and dangers. In: HURNI & KEBEDE TATO, (Eds.), pp. 329-333.

CHAPIN J., 1939. The birds of the Belgian Congo. *Bulletin of the American Museum of Natural History*,75, 632 p.

DE LEENHEER L., VAN HOVE J., & VAN RUYMBEKE M., 1957. Détermination quantitative de la matière organique du sol. *Pédologie*, 7, 324-347.

DOORNBOS M., CLIFFE L., AHMED A.G.M., & MARKAKIS J. (Eds.), 1992. *Beyond conflict in the Horn*, The Red Sea Press, Trenton, N.J., 241 p.

ERDAS, 1994. *Erdas Field Guide*. Erdas Inc., Atlanta, 628 p.

FOUCHER M., 1985. L'Ethiopie: à qui sert la famine? *Hérodote*, 39, 88-112.

GALLAIS J., 1985. Sécheresse - Famine - Etat: le cas de l'Ethiopie. *Hérodote*, 39, 60-87.

GROVE A.T., 1980. Geomorphic evolution of the Sahara and the Nile. In: WILLIAMS M. FAURE H. (Eds.), pp 7-16.

HELAVA, 1994. *Digital photogrammetric workstation user's manual.* GDE Systems Inc., 127 p.

HENDRIE B., 1991. The impact of war in Tigray. *Life & Peace Review*, Uppsala, 5, 1, 6-8.

HERWEG K., 1993. Potentiale und Limitierungen für eine nachhaltige Landnutzung im Hochland von Aethiopien. *Geomethodica*, 18, 21-58.

HOFFMAN R., 1987. Zu einigen Beziehungen zwischen vertikaler Gliederung und Flächennutzung in Aethiopien. *Wissenschaftliche Zeitschrift der Pädagogische Hochschule K. Liebknecht*, Potsdam, 31, 493-501.

HUNTING, 1976. Tigrai rural development study. Phase Two. Main report. Hunting Technical Services Ltd., + annexes.

HURNI H., 1979. Semiten-Äthiopien: Methoden zur Erfassung der Bodenerosion. *Geomethodica,* 4, 151-182.

HURNI H., 1985. Erosion - Productivity - Conservation Systems in Ethiopia. Proceedings IV International Conference on Soil Conservation, Maracay, Venezuela: pp. 654-674.

HURNI H., 1988. Land degradation, famine, and land resource scenarios in Ethiopia. In: PIMENTEL D. (Ed.), *World soil erosion and conservation.* Cambridge University Press, pp. 27-61.

HURNI H., & KEBEDE TATO (Eds.), 1992. *Erosion, conservation and small-scale farming.* A reviewed selection of papers presented at the 6th international soil conservation conference held in Ethiopia and Kenya, 6-18 november 1989, Vol. 2, Geographica Bernensia, 582 p.

JUNG L., 1956. Neue Untersuchungen über Bodenabtrag und Nährstoffverlagerung. *Mitteilungen aus dem Institut für Raumforschung*, Bonn, 20, 2, 179-193

KIEPE P., & YOUNG A., 1992. Soil conservation through agroforestry: experience from four years of demonstrations at Machakos, Kenya. In: HURNI & KEBEDE TATO. (Eds.), pp.303-311.

KRAUER J., 1988. Rainfall, erosivity & isoerodent map of Ethiopia. Soil Conservation Research Project, Research Report 15, University of Berne, Switzerland, 115 p.

MERLA G., & MINUCCI E., 1938. *Missione geologica nel Tigrai.* Reale Accademia d'Italia, 3, Roma, 363 p.

MERLA G., ABBATE E., AZZAROLI A., BRUNI P., CANUTI P., FAZZUOLI M., SAGRI M., & TACCONI P., 1979. *A geological map of Ethiopia and Somalia* (1973) *1:2.000.000 and comment*. University of Florence, Italy.

MERLE L., 1958. *La métairie et l'évolution agraire de la Gâtine poitevine de la fin du Moyen Age à la Révolution.* S.E.V.P.E.N., Paris, 252 p.

MINISTRY OF AGRICULTURE, 1988. Study of traditional conservation practices, Addis Ababa, 135 p.

MOHR P., 1963. *The geology of Ethiopia*. University College of Addis Ababa Press, 270 p.

MOORE T.R., 1979. Rainfall erosivity in East Africa. *Geografiska Annaler*, 61A, 147-156.

MOORE LAPPE F., & SCHURMANN R., 1990. *Taking population seriously*. Institute for food and development policy, San Francisco, 87 p.

MULUGETTA BEZZABEH, 1992. Attempts in the transformation of Ethiopia's agriculture: problems and prospects. In: DOORNBOS *et al.* (Eds.), pp. 143-153.

NADEL S.F., 1946. Land tenure on the Eritrean plateau. *Africa*, 16, 1, 1-22.

NICHOLSON S.E., 1980. Saharan climates in historic times. In: WILLIAMS M., & FAURE H. (Eds.), pp. 173-200.

NIEUWOLT S., 1978. Seasonal droughts in East Africa. *East African Agric. For. J.*, 43, 208-222.

NYSSEN J., 1995. Approche de l'érosion des sols sur les Hauts Plateaux du Tigré (Ethiopie). Exemple en Dega Tembien. Licentiate Dissertation, University of Liège, 322 p.

NYSSEN J., 1998. Soil Erosion in the Tigray Highlands (Ethiopia) (2). Assessment of its seriousness and prospects for soil conservation. *Geo-Eco-Trop* (in preparation)

OZER P., ERPICUM M., 1995. Méthodologie pour une meilleure représentation spatio-temporelle des fluctuations pluviométriques observées au Niger depuis 1905. *Sécheresse*, 6, 03-108.

PICHI-SERMOLLI, R.E.G., 1957. Una carta geobotanica dell'Africa orientale. *Webbia, Raccolti di Scritti botanici*, 13, 15-132.

REIJ C., 1991. *Indigenous soil and water conservation in Africa*. International Institute for Environment and Development, London, 33 p.

R.E.S.T., 1992. Central Tigray Integrated Agricultural Development Programme 1993-1997. Programme proposal. Relief Society of Tigray, Makallè, 38 p.

R.E.S.T., 1994. Report on the socio-economic baseline study in Central Tigray, Part I (Draft), Relief Society of Tigray, Makallè.

SAVANE L., 1988. *Population. Un point de vue africain*, EPO, Anvers, 212 p.

SCHREMPP B., 1992. Non-conflicting multipurpose tree integration: a case study in the Harerge Highlands, Eastern Ethiopia. In: HURNI & KEBEDE TATO (Eds.), vol. 1, pp. 109-117.

SHENG T.C., 1989. Soil conservation for small farmers in the humid tropics. *FAO Soils Bulletin*, 60, 104 p.

SOLOMON INQUAI, 1992. Comment. In: DOORNBOS *et al.*(Eds.), pp. 63-64.

SPIEGEL E., 1980. Zum Charakter der sozialen Verhältnisse auf dem Lande im vorrevolutionären Aethiopien. *Asien, Afrika, Lateinamerika*, 8, 1005-1020.

STAHL M., 1974. *Ethiopia: political contradictions in agricultural development*, Rabén & Sjögren, Stockholm, 186 p.

STAHL M., 1990. Environmental degradation and political constraints in Ethiopia. *Disasters, the journal of disaster studies and management*, 14, 140-150.

STAHL M., 1993. Combatting land degradation in Eastern Africa -Technical, institutional and social aspects. In: BAUM E., WOLFF P., & ZÖBISCH M.,(Eds.). *Acceptance of soil and water conservation. Topics in applied resource management in the tropics*, vol. 3, Deutsches Institut für tropische und subtropische Landwirtschaft, Witzenhausen pp. 363-389.

TABUTIN D., & THILTGES E., 1992. Relations entre croissance démographique et environnement. *Revue Tiers-Monde*, 33, 130, 273-294.

THOMAS D.B., 1988. Conservation of cropland on steep slopes in eastern Africa. In: MOLDENHAUER W.C., HUDSON N.W. (Eds), *Conservation farming on steep lands*. Ankeny, Iowa, Soil and Water Conservation Society, pp. 140-149.

THOREZ J., 1976. *Practical identification of clay minerals*, Lelotte, Dison, 90 p.

TIFFEN M., MORTIMORE M., & GICHUKI F., 1994. *More people, less erosion. Environmental recovery in Kenya.* John Wiley, Chichester, 311 p.

TRICART J., 1984. Quelques réflexions écogéographiques sur le développement rural. Le Développement rural en Questions. *Mémoires ORSTOM*, 106, 1-14.

VIRGO K.J., & MUNRO R.N., 1978. Soil and erosion features of the central plateau region of Tigrai, Ethiopia. *Geoderma*, 20, 131-157.

VORONEY R.P., VAN VEEN J.A., & PAUL E.A., 1981. Organic C dynamics in grassland soils. 2. Model validation and simulation of long-term effects of cultivation and rainfall erosion. *Canadian Journal of Soil Science*, 61, 211-224.

WESTPHAL E., 1975. *Agricultural systems in Ethiopia.* Centre for Agricultural Publishing and Documentation, Wageningen, 278 p.

WILLIAMS M., & FAURE H. (Eds.), 1980. *The Sahara and the Nile. Quaternary environments and prehistoric occupation in northern Africa*, Balkema, Rotterdam, 607 p.

WILLIAMS M., & WILLIAMS F., 1980. Evolution of the Nile basin. In: WILLIAMS M., & FAURE H. (Eds.), pp. 207-224.

WILSON R.T., 1977. The vegetation of Central Tigray, Ethiopia, in relation to its land use. *Webbia*, 32, pp. 235-270.

WISCHMEIER W.H., & SMITH D.D., 1978. *Predicting rainfall erosion losses.* Agricultural Handbook 537. United States Department of Agriculture, Washington, 58 p.

WISCHMEIER W.H., JOHNSON C.B., & CROSS B.V., 1971. - A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation*, 26, 189-193.

WRIGHT K., 1984. Combatting famine; a revolutionary strategy. *Horn of Africa*, 6,4, 39-44.

YOUNG R.A., & MUTCHLER C.K., 1977. Erodibility of some Minnesota soils. *Journal for soil and water conservation*, 32, 180-182.