A review of the effect of terracing on erosion

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Abstract

Terracing is one of the oldest means of saving soil and water. The objective of this paper is to provide information on the different types of terraces and their functioning, and to describe advantages and disadvantages of terraces regarding their efficacy to stop or reduce soil erosion. Existing literature and information shows that terraces can considerably reduce soil loss due to water erosion if they are well planned, correctly constructed and properly maintained. If not maintained, they can provoke land degradation. Terracing has to be combined with additional soil conservation practices, of which the most important one is the maintenance of a permanent soil cover. There are several disadvantages to terracing, therefore hedgerows and vegetation ridges could be good alternatives for terraces, but eventually they work in the same way. A future challenge is to develop conservation practices that are also productive. The ancient farming techniques such as terracing may provide a good basis for that.

1. Introduction

It is more and more agreed that soil degradation is a major threat to the Earth's ability to feed itself as nearly 40% of the world's agricultural land is seriously degraded (Kirby, 2000). Water erosion is one of the major causes of soil loss and soil degradation. Terracing could be one way to stop or reduce the degrading effect of soil erosion. It is one of the oldest means of saving soil and water. Moreover, it is the most widely used soil conservation practice throughout the world (see for example Monnier, 1955; Hanway and Laflen, 1974; Mountjoy and Gliessman, 1988; Sutikto and Chikamori, 1993; Christopherson and Guertin, 1995; Skinner and Porter, 1995; Karim et al., 1996; Pipkin and Trent, 1997; Poultney et al., 1997; Ruecker et al., 1998; Franti et al., 1998; Quine et al., 1999; AAFC, 1999; Drechsler and Settele, 2001; Bokhtiar et al., 2001; Kasai et al., 2001). Nowadays terracing is still in many cases promoted as being a best management practice for effective soil and water conservation (Wheaton and Monke, 2001).

Terracing refers to building a mechanical structure of a channel and a bank or a single terrace wall, such as an earthen ridge or a stone wall. Terracing reduces slope steepness and divides the slope into short gently sloping sections (Morgan, 1986), as shown in Figure 1. Terraces are created to intercept surface runoff, encourage it to infiltrate, evaporate or be diverted towards a predetermined and protected safe outlet at a controlled velocity to avoid soil erosion (USDA Soil Conservation Service, 1992; FAO, 2000).

Figure 1: Terraces in China (photo by UN - World Food Programme)

The objective of this paper is to evaluate the effect of terracing on soil erosion. We reviewed existing literature provided by scientific journals, soil conservation services and related organisations. This paper provides information on the functioning of terraces, the existing types of terraces and further it describes advantages and disadvantages of terraces regarding their efficacy to stop or reduce soil erosion.

2. Functioning of terraces

During an intense storm, a large part of the rainfall arriving at the soil surface infiltrates, depending on the soil type. The remainder becomes runoff, which concentrates in natural depressions and runs downhill until it reaches natural zones of deposition. If runoff increases, so does velocity, volume and erosive force. The critical runoff velocity, at which soil particles that have been detached from soil aggregates begin to be transported over the surface, is 5 m/s in sandy soils and 8 m/s in clay soils (Rufino, 1989; FAO, 2000). Terraces belong to the type of soil management practices that aim to protect an area against runoff by systematic land planning. The same accounts for storm water drains and permanent vegetation barriers (Sobral Filho et al., 1980).

The principal objective of terracing is generally to reduce the runoff and the loss of soil, but it also contributes to increasing the soil moisture content through improved infiltration and to reducing peak discharge rates of rivers. Beach and Dunning (1995) state that terracing also could promote rock weathering and eventually increases crop growth. However, like in 1993 (see Schottman and White, 1993), there are hardly any figures showing significantly increased yields in the first five to ten years after terracing.

Local conditions and the dimensions, form and stability of the terraces determine the efficacy of terraces (Rufino, 1989). The efficiency of a terrace system increases by applying additional conservation practices such as appropriate land preparation (contour ploughing and sowing), appropriate cultivation of crops (e.g. strip cropping) and maintaining a permanent soil cover.

3. The different types of terraces

Terraces that protect against soil erosion can be naturally formed upslope contour hedgerows (Poudel et al., 1999), vegetative filter strips (Stark et al., 1999) and grass barriers (Aase and Pikul, 1995; Walle and Sims, 1999). Many terraces however are directly man-made, i.e. the explicit terrace form has been constructed by humans. To classify the various types of terraces, different criteria have to be used. They could be classified according to 1) their main function, 2) the construction process, 3) the size of the terrace base and 4) the shape. A description of the different types according to these criteria will be given below.

1) Main function of the terrace

- Retention terraces, also called absorption or level terraces (Morgan, 1986); these are designed to accumulate and retain runoff in the terrace channel so that it will eventually infiltrate and the sediment accumulates. These terraces are recommended for low rainfall areas, permeable soils, and for land of less than 8 percent slope. They are normally broad-based terraces (FAO, 2000).

- Graded or diversion terraces; these are sloping terraces, designed to intercept or divert runoff into protected waterways. These terraces are recommended for high rainfall regions, for slightly or moderately permeable soils, and for slopes of between 8 and 20 percent (FAO, 2000).

2) Construction process

- Channel or Nichols terrace; these terraces are constructed by excavating soil from the upper side only to form a channel, and depositing it downhill to form a bank (Morgan, 1986). They are recommended for slopes up to 20 percent. They are used in high rainfall regions, and in soils of low or medium permeability (FAO, 2000).

- Ridge or Mangum terrace; a long, low ridge of earth with gently sloping sides and a shallow channel along the upper side. These terraces are constructed by excavating the soil from both sides of the embankment (Morgan, 1986). They are recommended for slopes less than 10 percent, for low rainfall regions, and for permeable soils (FAO, 2000). Ridge terraces control erosion by diverting surface runoff across the slope instead of permitting it to flow uninterrupted down the slope.

3) Size of the terrace base

- Narrow-base terraces; where soil movement is limited to about three metres.
- Medium-base terraces; where soil movement is three to six metres.
- Wide-base or broad-based terraces; where soil is moved more than six metres, but normally less than 12 metres (Fig. 2).

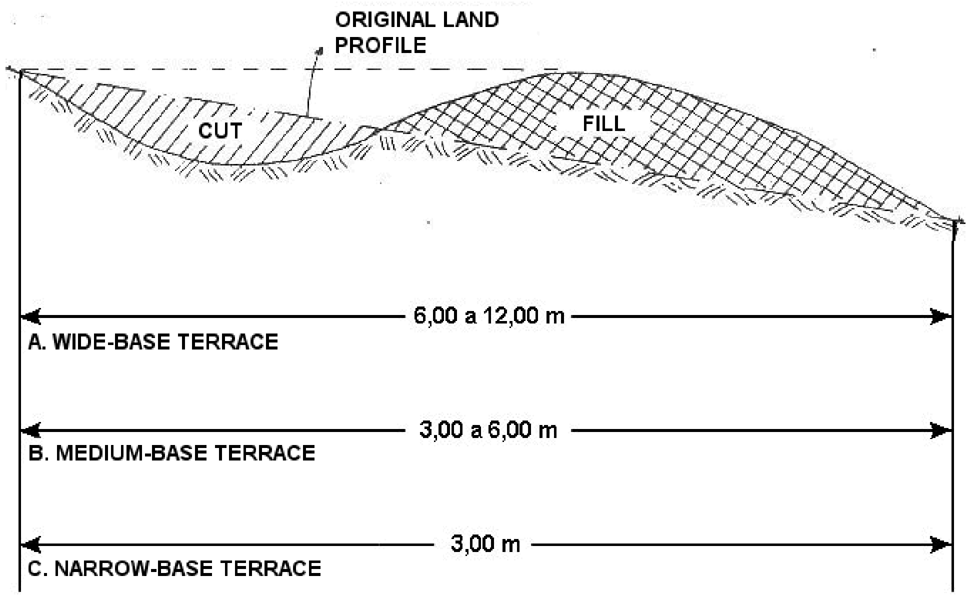

Figure 2. Diagram of a common terrace form explaining the classification according to different base sizes (FAO, 2000).

4) Terrace shape

Bertolini et al. (1989) classify terraces according to their shapes, which are mainly determined by the slope angle:

- A common or a normal terrace (form and slope are shown in Fig. 2) consists of a ridge or bank and a channel, which may be constructed on a gradient or level. This type of terrace is normally used in areas where the slope is less than 20 percent (FAO, 2000). These terraces mostly include broad-based terraces.

- Bench terraces (Fig. 3); these terraces form a series of level or nearly level strips of earth and a steep or vertical downhill face, constructed on or nearly on the contour. The terrace could be supported by a barrier of rocks or similar material (FFTC, 2004). Bench terraces are constructed by cutting and filling, and are used in land with slopes in excess of 20 percent. The bench terrace is perhaps one of the oldest forms of terraces. All other types of terraces have been derived from this terrace type.

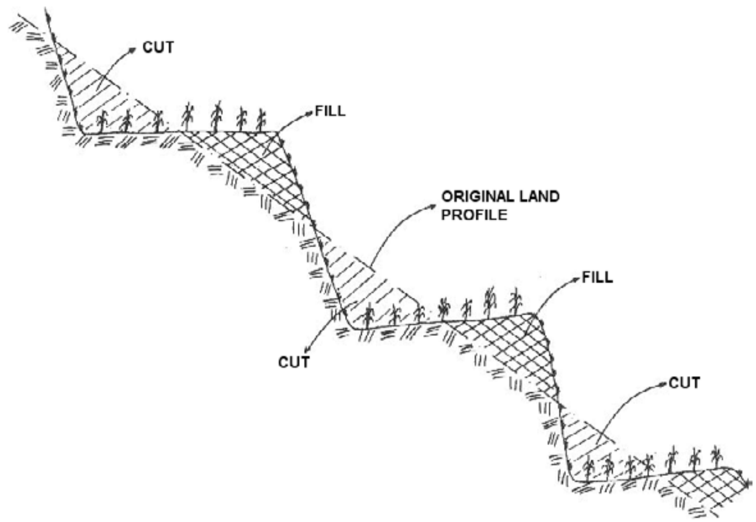

Figure 3. A sketch of a typical bench terrace (FAO, 2000)

The three types that are used most to characterise all existing terraces are: bench terraces, contour terraces, and parallel terraces (Keirle, 2002; NRCS, 2004), although this subdivision mixes different criteria. Contour terraces follow exactly the contour lines of the terrain. Parallel terraces eliminate the production losses associated with contour terraces because they are constructed parallel to each other and, where possible, to the direction of field operations. Today the type most common on agricultural land in the U.S. are parallel terraces. These terraces are very suitable for fields with soils deeper than 15 cm and fairly-uniform slopes that are not too steep (generally less than 8 percent). Some terraces are constructed with steep back slopes that are kept in grass. Most, however, are broad-based having gently sloped ridges that are cultivated as a part of the field (Wheaton and Monke, 2001).

4. Effect of terracing on erosion

Terracing changes the landscape. Therefore, they directly affect local hydrology and consequently runoff characteristics. In addition, terraces indirectly affect soil moisture and soil characteristics (Chow et al. 1999). Terracing has only an effect on water erosion, it does not stop or reduce the impacts of wind erosion. This section describes the advantages and disadvantages of terracing; firstly the direct effects and secondly the indirect effects.

Many scientists, soil conservation services and related institutions (e.g. USDA, 1980; AAFC, 1999; FAO, 2000; FFTC, 2004; GPA, 2004) agree that terracing reduces runoff and soil loss due to water erosion. Results obtained in Paraná (IAPAR, 1984) showed that terracing makes it possible to reduce soil losses by half, independently of the used cultivation system. Chow et al. (1999) observed dramatic decreases in soil loss, from an average of 20 tonnes per hectare, to less than one tonne per hectare by terracing sloping fields in combination with constructing grassed waterways and contour planting of potatoes. Runoff was reduced by as much as 25% of the total growing season rainfall, making it more available to the crop. Similar results have been obtained by Hatch (1981) who showed in Malaysia that a slope of 35 degrees covered with peppers had a soil loss of 63 t/ha/yr. Soil loss on the same slope with terraces and with identical vegetation cover, was 1.4 t/ha/yr. Schuman et al. (1973) found that runoff on a slope with level terraces was 8 times as low as on a comparable slope with contour planted crops. In the granite mountains of western Japan Mizuyama et al. (1999) observed that sediment yield immediately decreased after terracing. In addition, they concluded that terracing is much more effective in reducing sediment yield than planting trees only. The combination of the two resulted in continuous decrease of sediment yield during 35 years as the planted trees matured. The terrace types investigated in the studies mentioned here where often not similar, moreover, they were not always exactly specified in the reports.

Inbar and Llerena (2000) mention the important fact that in an Andean basin in Ecuador the vegetation cover is the critical erosion variable rather than the type of terrace. The same accounts for the abandoned terraces in the Mediterranean area in Spain. They further confirm as well that traditional terrace farming reduces erosion in comparison with non-terraced fields, if terracing is combined with contour cropping. They conclude that one of the most important erosion reducing activities is the maintenance of the terrace walls. Abandonment of terraces could create a major risk of massive soil loss, as shown by Vogel (1988), Cerda-Bolinches (1994) and Harden (1996).

There are also many authors that described disadvantages of terracing. Some authors explain that terraces retain too much water leading to saturation and consequently storm runoff (Gallart et al., 1994). Lasanta et al. (2001) describe that the foot of a terrace wall is often affected by erosion, because of the steepness and the sparse vegetation cover. The research carried out by Van Dijk and Bruijnzeel (2003) supports this finding. In addition, they state that the poor management of the terrace toe drain in combination with the steep slope gradient of terraced slopes and the high amount of generated runoff are important causes for the lack of efficacy of terracing in combating erosion. Lasanta et al. (2001) also observed that erosion on the foot of the terrace slope could lead to deterioration of the terrace as a whole as well as gully formation, which eventually leads to increased erosion. Temple (1972) observed in Tanzania that the construction of bench terraces was inappropriate because the topsoil was too thin so that the construction exposed the infertile subsoil. In addition, the bench terraces hold back too much water and induce landslides.

ICIMOD (1998) mentions the following limitations of terracing: the disturbance of the soil strata and considerable decline in soil fertility in the first several years, considerable soil loss during construction and in the first two years, and need of tremendous labour and investment for construction and maintenance. Further, they are not always stable in many cases and not suitable for sandy and coarse soils and on very steep land. Soil loss and nutrient leaching from bench terraces affect about 25% of the marginal land. According to Carson (1992), soil loss from rain fed bench terraces is 5 tonnes/ha/yr. Of the limitations mentioned above, high investment and instability are the main limitations

Regarding the indirect effects of terracing on soil erosion, several authors investigated the change in soil characteristics on the terrace. For example, Hamdan et al. (2000) observed a degrading effect of slope terracing on soil quality. In torrential gullies in Spain, Ternan et al. (1996) observed that altering the characteristics of soil horizons due to bench-terracing, led to increased runoff and soil erosion. Yet, Li and Lindstrom (2001) report that the decrease of soil quality on terraces could be explained by the combined effect of water erosion and consequent homogenisation by tillage. Gebremedhin et al. (1999), Walle and Sims (1999), Stark et al. (1999), Poudel et al. (1999) and Dercon et al. (2003) showed that soil fertility increases from the upper to the lower part of terraces, especially concerning organic matter and nutrients. Roose (1986) found in Western Africa that small contour ridges, made by vegetation and stones, were much more efficient than diversion terraces, because the latter concentrated storm water in single channels, leading to erosion down slope. By using the small ridges, the soil strata would be left untouched, which has a more positive effect on infiltration than creating diversion terraces. These small contour ridges would also entrap sediment and slowly let the slope evolve to a terraced slope after 4 to 10 years.

5. Construction, use and maintenance of terraces

If terraces are necessary to protect an area, a study should be carried out on the nature of the soils. The location of natural drainage lines, low- lying areas, and sites suitable for constructing runoff and storm water diversion drains should be recorded. Where runoff occurs in neighbouring areas, whether along tracks or in gullies, should also be identified. Slope gradients, slope lengths, the presence of rill erosion or gullies, and the location of roads and tracks should be noted. The obtained information has to be used to choose the terrace type to be used. The optimal distance between terraces on slopes with different gradient is not really known, as many researchers come up with different recommendations (e.g. Monnier, 1955; Sobral Filho et al., 1980; Pundek, 1985; Ramos and Porta, 1997). For example, although 50% slope is usually considered a threshold for making terraces (Green, 1978), in Nepal terraces are made on slopes exceeding this limit and cultivation is practiced even on 100% slope by means of contour terracing (Shrestha et al., in press). As a result, however careful the farmers are in maintaining the terraces, land degradation takes place on a yearly basis, e.g. erosion by tunnelling in rice fields and slumping on steep terraced slopes (Shrestha et al., in press). A practical guide for installing terraces that deals with issues such as slope steepness and terrace size is provided by FAO (2000).

An alternative for constructing terraces, which requires a lot of work, time and material, is the use of permanent vegetation barriers, whether or not combined with small contour ridges made by stone or earth. These are strips of vegetation planted along the contour at certain intervals within the main crop, and consist of perennial species that develop a dense cover capable of reducing the velocity of runoff (Sobral Filho et al., 1980). They function essentially in the same way as bench terraces with vegetation barriers.

An example of permanent vegetation barriers are contour hedgerows of nitrogen-fixing trees or shrubs, which are recommended in Nepal by ICIMOD as an alternative for terraces (ICIMOD, 1998). These hedgerows are planted very closely together and food or cash crops grow in the alleys. The hedgerows are spaced usually 3-6 metres apart, depending on the slopes, and are periodically pruned to provide green manure or mulch and to prevent shading of the crops in the alleys. Preliminary results show that contour hedgerows can function effectively as soil erosion barriers from the second year of planting. Collected data indicate that, in the second year, soil loss is reduced with approximately 75% and runoff is reduced approximately 20% compared to areas without hedgerows. In addition, crop yields from areas with hedgerow plantations are higher than in control areas. Contour hedgerows occupy about 15-20% of farming land, which is almost the same as that occupied by terrace risers.

In ancient times, such hedgerows have been planted in many parts of the world to reduce the effects of erosion. In South-Limburg these hedgerows slowly evolved to mature terraces, so called ‘graften’. The efficacy of these structures became very clear after removal due to land consolidation and reallocation and modern farming. This meant that small-scale plots, which still existed in the fifties and sixties, slowly merged into large agricultural fields. As a consequence, small hedges, trees and shrubs growing on the edges of the ‘graften’ disappeared. Land use changed from a diverse mixed agricultural/natural area to mainly maize, wheat and sugar beet. The combination of these agricultural practices and heavy rainfall events resulted in huge erosion problems in the eighties (Kwaad, 1991; Boardman et al., 1994). Tons of fertile soil were removed from the agricultural fields and were deposited in lower parts of the landscape.

Soil erosion control by terracing is often found to be the most expensive soil conservation practice. Therefore, terrace abandonment and terrace deterioration is nowadays observed more often. In many cases there is a shortage of local labour, e.g. as illustrated by Inbar and Llerena (2000). Mountjoy and Gliessman (1988) describe the example of the Cajete terrace system in Mexico. Cajetes are small water reservoirs on the terrace plateaus. This system of collecting water and reducing soil erosion has been in use since pre-Hispanic times (1000 B.C.). The success of the Cajete terrace complex can be judged primarily by its longevity, but the use and maintenance of the Cajetes has been gradually declining. Again, farmers attribute this decline to the rising cost of labour, but there are also socio-economic factors. Many of the farmer's children have left the rural farm for higher paying jobs thus leaving the Cajetes in disrepair. An increase of erosion has been observed in these traditional farming systems, but this could also be attributed to tractors that have entered the fields and filled in the Cajetes. As a result the complicated canal system which maintained the water runoff is disrupted.

Another example that illustrate the labour problem of terraces come from China. Ever since the early 1950s hillside terracing had been greatly promoted by the Upper and Middle Yellow River Administrative Bureau. There, the drawback to terracing is again its labour-intensive nature and the relatively low productivity of the terraced plots. As most of the loess highland is only thinly populated, it is not likely that terracing is still an effective means in implementing comprehensive erosion and sediment control. Even in densely populated areas it is becoming increasingly difficult to mobilize peasants to contribute their labour, with minimal compensation, to terrace the gully slopes (Leung, 1996).

As shown by the first example and by many other authors, abandonment of terraced land could cause land degradation (excessive soil erosion, gully formation and landsliding, such as slumping) due to deterioration of the terrace walls (Inbar and Llerena, 2000), which sometimes collapse due to massive soil movement as shown by Lasanta et al. (2001). They also found a positive correlation between the volume of small landslides occurring on deteriorated terraced lands and the height of former terrace walls. However, without disturbances, abandoned terraces can also be successfully colonized by vegetation, resulting in an increase of organic matter in the upper soil horizon (Tatoni et al., 1994), which sometimes leads to efficient erosion control (Lasanta et al., 2001). In contrast, Van Beek (2002) found that revegetation of former bench terraces in Spain led to increased landslide activity on terraced slopes. He showed that the increase of the storage capacity of the soil due to the vegetation cover overruled the moisture depleting effect of evapotranspiration and rain interception. Therefore landslides on terraces were triggered during extreme rainfall events. These examples show that terrace maintenance is important to prevent additional soil degradation. As a result, farmers are not always enthusiastic about terraces.

A factor that adds up to the labour involved with terraces is that fertility and soil characteristics may vary considerably on the upper part and the lower part of a terrace. Some authors propose therefore to improve soil fertility by spreading nutrients on the upper part of terraces (Stark et al., 1999; Dercon et al., 2003). David and Raussen (2003) propose to leave terrace uncultivated for some years to improve soil characteristics, but then it is important to maintain a permanent soil cover to prevent erosion.

Most present-day farmers in Guatemala view ancient terraces only as relics. They are mainly concerned with surviving until the next year. Thereby, they view soil erosion as a problem over which they have no control, so it does not concern them. This accounts for many farmers in the world, most are logically more concerned with production than with conservation. Therefore, the challenge is to develop conservation practices that are also productive.

6. Terracing in the future world

A short, but interesting contribution on the role of terracing in agriculture today and in the future is written by Keirle (2002). He states that, in agricultural based societies in the third world, terracing was not an optimal soil and water conservation practice from a socio-economic point of view. It does not increase crop yield and it requires much labour. These issues were also raised by Vogel (1988) and in the above mentioned examples of Mexico, Guatemala and China. This theme has been extensively discussed at the workshop of the Soil and Water Conservation Society in March 1987 in Puerto Rico. One of the outcomes was that if soil and water conservation measures are to be applied by farmers all over the world they have to offer short-term benefits. In the past, runoff was considered the main cause of the erosion problem. Then terraces would be installed only if the consequences of erosion were endangering production due to significant loss of the fertile top soil. In such cases runoff was often stopped, but against a high price for the farmer, partly because the land had little remaining productive potential left and partly because such works were ineffective without changes in land use and management that addressed the true causes of the problem (Keirle, 2002). If unavoidable runoff is expected to occur, terraces are very appropriate, but they should be used in accordance with other good farming practices, which in turn have to rewarded by an increased yield, better food quality, and thus more reasonable prices, or subsidies.

7. Conclusion

It may be concluded that terraces could considerably reduce soil loss due to water erosion if they are well planned, correctly constructed and properly maintained. There are many examples showing that terraces have to be maintained to prevent processes leading to land degradation such as excessive soil erosion, gully formation and landsliding. There is a large variety of terrace types, each adapted to certain landscapes with various slopes gradients, but all terraces can be divided in three groups: bench terraces, contour terraces and parallel terraces. All of these three terrace types could be effective regarding soil and water conservation, there is no such thing as the best terrace type, because it all depends on local conditions. The most important aspect of terracing is that it has to be combined with additional soil conservation practices, of which the most important one is the maintenance of a permanent soil cover. This latter is especially needed on the foot slope of the terrace, because terraces themselves could be easily eroded and they generally require a lot of maintenance and repair. Other disadvantages are the disturbance of the soil strata during construction and considerable decline in soil fertility in the first several years, considerable soil loss during construction. Hedgerows could be good alternatives for terraces, which eventually work in the same way.

A very important point regarding terraces or any soil and water conservation practice is that most farmers are more concerned with production than with conservation. Therefore the challenge is to develop conservation practices that are also productive. The ancient farming techniques such as terracing may provide a good basis for that, because far too often attempts have been made to modernize or improve farming practices without looking at existing well established practices first (Mountjoy and Gliessman, 1988). Unfortunately it has never been shown that terraces increase yield, but it has been shown by many researchers that terraces could provide a basis for good farming that aims to keep fertile soil resources in place and in a good productive state.

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