Erosion and its Implication on Economic Plants in Nigeria

BY

EKANEM, Moses Columba
Department of Food Technology,
Akwa Ibom State Polytechnic, Ikot Osurua,
Ikot Ekpene L. G. Area, Akwa Ibom State

AND

ETUK, Iniobong Ita
Science Technology Department
Akwa Ibom State Polytechnic, Ikot Osurua

ABSTRACT

This study sought to investigate erosion and its implication on economic plants in Nigeria. Erosion is widely considered to be a serious threat to the long-term viability of economic plants in many parts of the world. Erosion is particularly serious in certain developing countries. Erosion requires an agent, either wind or water. The level of erosion in a given place is determined by the interaction of a number of factors. The broadest application of the term erosion embraces the general wearing down and molding of all landforms on Earth's surface, including the weathering of rock in its original position. Erosion is a wide spread problem affecting economic plant in the Nigeria system. The watershed optimization taking into consideration the quantum of erosion for sustainable development is necessary. Erosion affects the economic plant and thereby impacting the income of the farmer. The application of economic optimization approaches has been recently started due to low efficiency of its implication on economic plant in Nigeria system. One of the recommendations made was that government should control the erosion by the use of land according to its capability and control runoff before it develops into an erosive force.

KEYWORDS: Erosion, Economic, Plants and Nigeria

Introduction

Erosion remains the world's biggest environmental problem, threatening sustainability of both plant and animal in the world. Erosion, whether induced by water or wind, involves translocation of topsoil from one place to another and represents the most important land degradation problem (Hein, 2007). Over 65 percent of the soil on earth is said to have displayed degradation phenomena as a result of erosion, salinity and desertification (Okin, 2002). In a way, soil is the most vital of earth's natural resources. It hosts both animate and inanimate beings. Over three quarters of the world's man-made developments are on it. And its existence is the basis for the performance of most disciplines of the world. Most earth's natural resources are directly linked to or found in the soil (Abegunde, Adeyinka, Olawuni and Oluodo, 2006). Threat to soil is therefore threat to life. From time immemorial, erosion has been a naturally occurring process (OMAFRA Staff, 2003). At present, it is the single most important environmental degradation problem in the developing world (Ananda and Herath, 2003), especially the tropics (Hanyona, 2001). United Nations (UN) Convention to Combat Land Degradation (CCD) opines that soil erosion automatically results in reduction or loss of the biological and economic productivity and complexity of terrestrial ecosystems, including soil nutrients, vegetation, other biota, and the ecological processes that operate therein (Claassen, 2004). The determining factors of soil erosion are rainfall, vegetation (cover), topography, soil properties, land slope, and exposure as well as socioeconomic factors like population density and severity of poverty (De Graff, 2009). The extent to which erosion actually reduces yields depends on the types of crops and technologies followed, implying that the crop management system can have an influence on crop yields and the effects of land degradation. Erosion has a non-linear impact on crop yields as the erosion of the top-soil depletes nutrients mostly early in the process and rapidly affect yield and further erosion shows limited impact on the soil. The productivity of land has declined by 50% due to soil erosion and desertification (Bai, Dent, Olsson and Chaepman, 2008).

Conceptual Review

Concept of Erosion

According to Allaby (2013), erosion is the action of surface processes (such as water flow or wind) that removes soil, rock, or dissolved material from one location on the Earth's crust, and then transports it to another location. Erosion, as it affects man and its environment, is natural and as old as the earth itself (OMAFRA Staff, 2003). It is seen as the gradual washing away of soil through the agents of denudation which include, wind, water and man (Abegunde, 2003). These denudating agents loose, wear away, dislodge, transport and deposit wear off soil particles and nutrients in another location. Christine and Josef (2007) cited in Wudneh (2012) defined erosion as the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere. The broadest application of the term erosion embraces the general wearing down and molding of all landforms on Earth’s surface, including the weathering of rock in its original position, the transport of weathered material, and erosion caused by wind action and fluvial, marine, and glacial processes (Encyclopædia Britannica, 2015). This broad definition is more correctly called denudation, or degradation, and includes mass-movement processes. A narrow and somewhat limiting definition of erosion excludes the transport of eroded material by natural agencies, but the exclusion of the transport phenomenon makes the distinction between erosion and weathering very vague. Erosion, therefore, includes the transportation of eroded or weathered material from the point of degradation (such as the side of a mountain or other landform) but not the deposition of material at a new site. The complementary actions of erosion and deposition or sedimentation operate through the geomorphic processes of wind, moving water, and ice to alter existing landforms and create new landforms. Thus, the process of erosion could be slow and continues unnoticed, or it may occur at an alarming rate causing serious loss of top soil (Abegunde, et. al., 2006).

Types of Erosion

Erosion is a natural process that wears away the earth’s surface. Soil particles are detached (eroded), transported (as sediment) and deposited (sedimentation) by wind, water, ice or gravity. On the process of erosion, the soil is left bare and unprotected by vegetation. Water and wind erosion will be considered as types of erosion below.

Water Erosion: There are five types of water erosion described below and ranked from least severe to most severe. Splash and sheet erosion can best be prevented by protecting the land surface with vegetation, mulch or erosion control blankets. Sheet, rill and gully erosion can be controlled by keeping runoff velocities slow.

Splash Erosion: Splash erosion results from the direct impact of falling drops of rain on soil particles. This impact breaks the bonds between the particles, dislodges them and splashes them into the air. The dislodged soil particles can then be easily transported by the flow of surface water runoff.

Sheet Erosion: Sheet erosion is the removal of a thin layer of exposed surface soil by the action of raindrop splash and runoff. The water moves in broad sheets over the land, picks up these particles and carries them along as it flows downhill.

Rill Erosion: As the runoff moves down a slope, it cuts small paths or rills. In rill erosion, water flowing through these paths detaches more soil from their sides and bottoms.

Gully Erosion: Further down the slope, water tends to concentrate in channels and pick up speed. In gully erosion, soil is removed rapidly by water gushing over the headcut or uphill end of the gully, by concentrated flow scouring the sides and bottom of the gully and by water removing soils that have slumped from the sidewalls of the gully. A nearly vertical headcut allows water falling over the surface to undermine the bank so the gully moves upslope. Large earthmoving equipment is required to reshape or control gullies.

Wind Erosion: Wind erosion is a serious environmental problem. Suspension, saltation and surface creep are the three types of soil movement that occur during wind erosion.

Suspension: Suspension Occurs when very fine dirt and dust particles are lifted into the wind. The particles can be thrown into the air through impact with other particles or by the wind itself. Once in the atmosphere, these particles can be carried very high and be transported over extremely long distances.

Saltation: Fine particles are lifted into the air by the wind and drift horizontally across the surface increasing in velocity as they go. They travel approximately four times longer in distance than in height and when they strike the surface again they either rebound back into the air or knock other particles into the air. This is the major form of soil movement due to wind.

Creep: The large particles that are too heavy to be lifted into the air are moved through a process called surface creep. The particles are rolled across the surface after coming in contact with the soil particles in saltation.

Ice Erosion: Ice erosion is the process of large chunks of ice, known as glaciers, eroding an area over a long period of time with the help of gravity. The term glacial erosion means the same thing as ice erosion. It occurs in one of three ways.

Abrasion: Abrasion is commonly regarded as being less efficient than plucking (Dühnforth, Anderson, Ward and Stock, 2010). The sediment that ends up getting frozen into glaciers causes further damage to the bedrock as the glacier moves. They function like sandpaper, wearing away the area beneath moving glaciers. This results in glacial striations, which are carved out grooves or scratches.

Plucking: As a glacier moves, it causes the bedrock over which it passes to fracture (Glasser, Crawford, Hambrey, Bennett and Huddart, 2008). Fragments end up getting frozen into the bottom and sides of the glacier itself, and so they move with it. This is also known as quarrying.

Meltwater: Streams of meltwater flow along the base of glaciers, leading to erosion of the ground below, just as a stream or river would do. Of course, due to the extreme weight of the ice, meltwater flows very fast. As a result, it has very high erosion potential.

Factors Affecting Erosion

***Climate*:** The amount and intensity of precipitation is the main climatic factor governing soil erosion by water (Gutiérrez and Gutiérrez, 2013). The relationship is particularly strong if heavy rainfall occurs at times when, or in locations where, the soil's surface is not well protected by vegetation. This might be during periods when agricultural activities leave the soil bare, or in semi-arid regions where vegetation is naturally sparse. Wind erosion requires strong winds, particularly during times of drought when vegetation is sparse and soil is dry (and so is more erodible). Other climatic factors such as average temperature and temperature range may also affect erosion, via their effects on vegetation and soil properties. In general, given similar vegetation and ecosystems, areas with more precipitation (especially high-intensity rainfall), more wind, or more storms are expected to have more erosion. In some areas of the world, rainfall intensity is the primary determinant of erosivity (Zorn and Komac, 2013) with higher intensity rainfall generally resulting in more soil erosion by water. The size and velocity of rain drops is also an important factor. Larger and higher-velocity rain drops have greater kinetic energy, and thus their impact will displace soil particles by larger distances than smaller, slower-moving rain drops (Blanco-Canqui and Rattan, 2008).

***Topography*:** The topography of the land determines the velocity at which surface runoff will flow, which in turn determines the erosivity of the runoff. Longer, steeper slopes (especially those without adequate vegetative cover) are more susceptible to very high rates of erosion during heavy rains than shorter, less steep slopes. Steeper terrain is also more prone to mudslides, landslides, and other forms of gravitational erosion processes (Wainwright and Brazier, 2011; Blanco-Canqui and Rattan, 2008).

***Vegetative Cover*:** Vegetation acts as an interface between the atmosphere and the soil. It increases the permeability of the soil to rainwater, thus decreasing runoff. It shelters the soil from winds, which results in decreased wind erosion, as well as advantageous changes in microclimate. The roots of the plants bind the soil together, and interweave with other roots, forming a more solid mass that is less susceptible to both water (Gyssels, Poesen, Bochet and Li, 2005) and wind erosion. The removal of vegetation increases the rate of surface erosion (Styczen and Morgan, 2005).

***Tectonics*:** Tectonic processes control rates and distributions of erosion at the Earth's surface. If the tectonic action causes part of the Earth's surface (e.g., a mountain range) to be raised or lowered relative to surrounding areas, this must necessarily change the gradient of the land surface. Because erosion rates are almost always sensitive to the local slope, this will change the rates of erosion in the uplifted area. Active tectonics also brings fresh, unweathered rock towards the surface, where it is exposed to the action of erosion (Burbank and Anderson, 2011). However, erosion can also affect tectonic processes. The removal by erosion of large amounts of rock from a particular region, and its deposition elsewhere, can result in a lightening of the load on the lower crust and mantle. Because tectonic processes are driven by gradients in the stress field developed in the crust, this unloading can in turn cause tectonic or isostatic uplift in the region (Nichols, 2009).

Concept of Agricultural Sector

Agriculture is the most comprehensive word used to denote the many ways in which crop plants and domestic animals sustain the global human population by providing food and other products. The English word agriculture was derived from the Latin word ager (field) and colo (cultivate) signifying, when combined, the Latin agricultura: field or land tillage (Allaby, 2010). But the word has come to subsume a very wide spectrum of activities that are integral to agriculture and have their own descriptive terms, such as cultivation, domestication, horticulture, arboriculture, and vegeculture, as well as forms of livestock management such as mixed crop-livestock farming, pastoralism, and transhumance (Harris and Fuller, 2014). Also agriculture is frequently qualified by words such as incipient, proto, shifting, extensive, and intensive, the precise meaning of which is not self-evident. Many different attributes are used too to define particular forms of agriculture, such as soil type, frequency of cultivation, and principal crops or animals (Aguwamba, Chukwu, Chukwu, Paul and Chika, 2020). The term agriculture is occasionally restricted to crop cultivation excluding the raising of domestic animals, although it usually implies both activities. The Oxford English Dictionary (2007) defined agriculture very broadly as the science and art of cultivating the soil, including the allied pursuits of gathering in the crops and rearing live stock (sic); tillage, husbandry, farming (in the widest sense). Thus, agriculture is the art and science of cultivating the soil, growing crops and raising livestock. Agriculture is defined with varying scopes, in its broadest sense using natural resources to "produce commodities which maintain life, including food, fiber, forest products, horticultural crops, and their related services (Aguwamba, et. al., 2020).

Erosion and Agricultural Productivity

Erosion and agricultural productivity is complex and involves many different factors. By altering soil properties, erosion has direct effects on crop production. Erosion can decrease rooting depth, soil fertility, organic matter in the soil and plant-available water reserves (Lal, 2007). Thus, the exposed soil remaining will be less productive in a physical sense. These effects may be cumulative and not observed for a long period of time. Erosion may also affect yields by influencing not only the soil’s properties but also the micro-climate, as well as the interaction between these two (Lal 2007). While the negative effects of erosion on productivity are well documented, it is their magnitude which is of interest from an economic point of view (Crosson 2003). Unfortunately, quantifying the effects of erosion on crop production presents many difficulties. First of all, the extent to which erosion affects crop production will vary depending on the type of crop, the type of soil, the micro-climate, local topography and the management system (Lal, 2007). Thus, the extent to which quantification of the relationship can be transferred between sites may be very limited. Secondly, even supposing that collecting vast quantities of location-specific data presented no problems, it is still extremely difficult to determine the influence of any single factor on crop yields. Any attempt to measure the effect of erosion on yields will be almost impossible to control for other effects, such as variations in precipitation. These difficulties are particularly acute when one considers that the time frame involved (typically at least a few growing seasons) can result in many such uncontrollable variations. Long-term data is essential however, since the effects of erosion on productivity will change throughout the soil profile (Stocking, 2004). In addition, the interaction among the various factors affecting crop production are only poorly understood. Despite these difficulties, various attempts have been made to measure the erosion productivity relationship. These have been reviewed by Stocking (2004) and Lal (2007). Much of this work has been done in temperate countries. Given that there tend to be significant differences (even in general terms) between not only temperate and tropical soils but also the crops grown on them, it is dangerous to generalise the research results of temperate areas (Lal, 2007). Stocking concludes that absolute yield declines due to erosion appear to be much greater in the tropics than in temperate regions. Moreover, initial yields in the tropics tend to be lower to begin with, meaning that declines will be even more serious (Stocking, 2004).

Effect of Erosion on Economic Plants

The effects of erosion on crop productivity have become emotional issues and have attracted the attention of agriculturists, environmentalists, and the public in general (Lal and Moldenhauer, 2008). In spite of heavy investments in research and development, the global rates of accelerated erosion are now presumably higher than ever before. According to Bakker, Govers, Jones and Rounsevell (2004), erosion continues to have detrimental effects on global crop productivity. Some claim that during the last 40 years nearly one-third of the world's arable land has been lost through erosion and continues to be lost at a rate of more than ten million hectares per year (Pimentel, Harvey, Resosudarmo, Sinclair, Kurz, Mcnair, Crist, Shpritz, Fitton, Saffouri and Blair, 2005). A study by Wilkinson and McElroy (2007) estimates that soil loss from global farmlands is currently running at a rate of more than 6 t ha−1 y−1, which is more than 15 times the estimated average rate of erosion (0.42 t ha−1 y−1) during the whole Phanerozoic Era, a period of 542 million years spanning. Current land abandonment in some parts of world has probably been driven by erosion (Bakker, Govers, Kosmas, Vanacker, Van Oost and Rounsevell, 2005a), whereby abandoned areas have reverted to unproductive scrubland. It seems likely that modern societies and landscapes are threatened by the loss of crop yields and subsequent land abandonment if erosion continues to degrade soil resources.

Erosion has a detrimental effect on soil quality for agricultural production because erosion degrades soil functions for crop growth such as the supply of water, nutrients and rooting space. These effects have been demonstrated through numerous experiments conducted on plots where erosion was either simulated by artificial desurfacing (Gollany, Schumacher, Lindstrom, Evenson and Lemme, 2002; Malhi, Izaurralde, Nyborg and Solberg, 2004; Tanaka, 2005), or by comparing yield on strongly eroded areas with yield on less eroded areas (Mielke and Schepers 2006; Olson and Carmer 2009). The reported results, however, showed a wide variability and a systematic overestimation of the effects due to the use of flawed methodologies may explain a large part of the research results (Bakker, et. al., 2004). Nevertheless, systematic analysis of the available data allowed some general conclusions to be drawn: under intense, mechanized agriculture, yield reductions at the field scale are of the order of 4% for each 0.1 m of soil loss and crop productivities. This finding applies to European, North American and African studies, where yield reductions could generally be attributed to a reduction in rooting depth and/or plant available water (Olson, Mokma, Lal, Schumacher and Lindstrom, 2009; Bakker, et. al., 2004). The effects of erosion on crop productivity may vary per agro-ecological zone and the effects may also depend on the scale level studied. Within larger spatial units, compensatory effects may occur: regional productivity may be maintained by the simple reallocation of arable land to less erosion-prone areas with arable areas becoming permanent grassland or forest (Bakker, et. al., 2005a). Furthermore, inclusion of depositional areas within the spatial unit studied may offset the negative effect of erosion upslope, as deposition may improve soil properties and productivity may increase.

Conclusion

Based on the review of this paper, it was concluded that erosion has been identified as the most threatened environmental hazards in the country. Whether erosion is induced by water or wind, its involve translocation of topsoil from one place to another and represents the most important land degradation problem. Some of the factors affecting erosion has been reviewed in this paper including climate, topography, vegetative cover and tectonics. Erosion automatically results in reduction or loss of the biological and economic productivity and complexity of terrestrial ecosystems, including soil nutrients, vegetation, other biota, and the ecological processes that operate therein. Erosion has a direct effect on agricultural productivity. During the process of erosion, it decreases rooting depth, soil fertility, organic matter in the soil and plant-available water reserves. Thus, the exposed soil remaining will be less productive in a physical sense.

Recommendations

1. Government should control the erosion by the use of land according to its capability and control runoff before it develops into an erosive force.

2. Government should reinforce its budgetary allocations and monetary policy instrument to the agricultural sector, ensure adequate release of funds, ensure strict implementation towards achieving improvement in agricultural productivity.

3. Large scale production and highly mechanized cultivation should be encouraged. This would in invariably improve the agricultural sector thereby promoting industrialization.

REFERENCES

Abegunde, A. A. (2003). *The impact of Erosion on Rural Economy*: The Case of Nanka in Anambra State of Nigeria". In Urban Finance and Infrastructure Development in Nigeria. Yomi Fawehinmi (ed.) Atlantis Books. PP227-243.

Abegunde, A. A., Adeyinka, S. A., Olawuni, P. O. and Oluodo, O. A. (2006). *An Assessment of the Socio Economic Impacts of Soil Erosion in South-Eastern Nigeria*. Shaping the Change XXIII FIG Congress, Munich, Germany. Pp. 8-13.

Aguwamba, C. A., Chukwu, I. C., Chukwu, B. C., Paul, N. L. and Chika, E. J. (2020). Effect of Agriculture on Industrialization of Nigerian Economy (1981-2018). *Journal of School of Arts and Social Sciences*, 8(1), 1010-111

Allaby, M. (2013). *Erosion*. A dictionary of geology and earth sciences (Fourth ed.). Oxford University Press.

Allaby, R. (2010). Integrating the processes in the evolutionary system of domestication. *Journal of Experimental Botany*, 61: 935-44.

Bai, Z. G., Dent, D. L., Olsson, L. and Chaepman, M.E.S (2008). Proxy global assessment of land degradation. Soil use and management, 24, 223-234.

Bakker, M. M., Govers, G. and Rounsevell, M. D. A. (2004). The crop productivity–erosion relationship: an analysis based on experimental work. Catena 57:55–76

Bakker, M. M., Govers, G., Jones, R. A. and Rounsevell, M. D. A. (2007). The Effect of Soil Erosion on Europe's Crop Yields. *Ecosystems*, 10(1), 1209–1219

Bakker, M. M., Govers, G., Kosmas, C., Vanacker, V., Van Oost, K. and Rounsevell, M. D. A. (2005a). Soil erosion as a driver of land-use change. Agric Ecosyst Environ 105:467–481

Blanco-Canqui, H. and Rattan, L. (2008). *Water erosion*. Principles of soil conservation and management. Dordrecht: Springer. pp. 21–53.

Blanco-Canqui, H. and Rattan, L. (2008). *Water erosion*. Principles of soil conservation and management. Dordrecht: Springer. pp. 21–53

Burbank, D. W. and Anderson, R. S. (2011). *Tectonic and surface uplift rates*. Tectonic Geomorphology. John Wiley & Sons. pp. 270–271.

Claassen, R. (2004). *Have conservation Compliance Incentives Reduced Soil Erosion*? Amber Waves. The Economic of Food, Farming, Natural Resources and Rural America. Available at: http://evs.usda.gov/Amwber wave/

Crosson P. (2003). *Soil Erosion in Developing Countries*: Amounts, Consequences and 36 Policies. Paper presented at the University of Wisconsin, Department of Agricultural Economics.

De Graaff, J. (2009). *Soil conservation and sustainable land use*: an economic approach. Royal Tropical Institute, Amsterdam, Netherlands. 191 pp.

Dühnforth, M., Anderson, R.S., Ward, D. and Stock, G. (2010). Bedrock fracture control of glacial erosion processes and rates. *Geology* 38, 423-426.

Encyclopaedia Britannica (2015). *Erosion*. Encyclopedia Britannica. Retrieved from: https://www.britannica.com/science/erosion-geology

Glasser, N.F., Crawford, K.R., Hambrey, M.J., Bennett, M.R. and Huddart, D. (2008). Lithological and structural controls on the surface wear characteristics of glaciated metamorphic bedrock surfaces: Ossian Sarsfjellet, Svalbard. *Journal of Geology*, 106, 319-330.

Gollany, H. T., Schumacher, T. E., Lindstrom, M. J., Evenson, P. D. and Lemme, G. D. (2002). Topsoil depth and desurfacing effects on properties and productivity of a typic Argiustoll. *Soil Sci. Soc. Am. J.*, 56:220–225

Gutiérrez, M and Gutiérrez, F. (2013). Climatic Geomorphology. *Treatise on Geomorphology*, 13(2), 115–131.

Gyssels, G., Poesen, J., Bochet, E. and Li, Y. (2005). Impact of plant roots on the resistance of soils to erosion by water: a review. *Progress in Physical Geography*, 29(2): 189–217.

Hanyona Singy (2001). *Soil Erosion Threatens Farm Land of Saharan Africa*. In The Earth Times, January, 2001 http://forests.org/archieve/african/so erthre htm

Harris, D. R. and Fuller, D. Q. (2014). *Agriculture*: Definition and Overview. In Encyclopedia of Global Archaeology (Claire Smith, Ed.). Springer, New York. pp 104-113

Hein, L. (2007). Assessing the costs of land degradation: A case study for the Puentes catchment, southeast Spain. *Land Degradradation and Development*, 18:631-642.

Lal R. (2007). Effects of Erosion on Crop Productivity. *Critical Reviews in Plant Sciences*, 5(4):303-67.

Lal, R. and Moldenhauer, W. C. (2008). Effects of soil erosion on crop productivity. *Critical Reviews in Plant Sciences*, 5(4), 303-367

Malhi, S. S., Izaurralde, R. C., Nyborg, M. and Solberg, E. D. (2004). Influence of topsoil removal on soil fertility and barley growth. *J. Soil Water Conser.*, 49:96–101

Mielke, L. N. and Schepers, J. S. (2006). Plant response to topsoil thickness on an eroded loess soil. *J. Soil Water Conserv*., 41:59–63

Nichols, G. (2009). *Sedimentology and Stratigraphy*. John Wiley & Sons.

Okin, G. S. (2002). *Toward a Unified View of Biophysical Land Degradation Processess in Arid and Semi-Arid Lands*. In Global Desertification: Do Humans Cause Deserts? Edited by J. F. Reynolds and D.M. Stafford Smith. Dahlem University Press. Pp 95-97.

Olson, K. R. and Carmer, S. G. (2009). Corn yield and plant population differences between eroded phases of Illinois soils. *J Soil Water Conserv*., 45:562–566

Olson, K. R., Mokma, D. L., Lal, R., Schumacher, T. E. and Lindstrom, M. J. (2009). Erosion impacts on crop yield for selected soils of the north central United States. In: Lal R (ed). Soil quality and soil erosion. Soil and water conservation society, Ankeny, Iowa, pp 259–283

OMAFRA Staff (2003). *Soil Erosion, Causes and Effects*. Ridge Town and College of Agricultural Technology, Ontario Institute of Pedelogy.

Oxford English Dictionary (2007). The Oxford English dictionary. Oxford: Oxford University Press.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., Mcnair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R. (2005). Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117–23

Stocking M. (2004). *Erosion and Soil Productivity*: A Review. Rome: Soil Conservation Programme; Soil Resources, Management and Conservation Service; Land and Water Development Division; Food and Agriculture Organisation (FAO).

Styczen, M. E. and Morgan, R. P. C. (2005). *Engineering properties of vegetation*. In Morgan, R.P.C.; Rickson, R. Jane (eds.). Slope Stabilization and Erosion Control: A Bioengineering Approach. Taylor & Francis.

Tanaka, D. L. (2005). Spring wheat straw production and composition as influenced by topsoil removal. *Soil Sci. Soc. Am. J.*, 59: 649–654

Wainwright, J. and Brazier, R. E. (2011). *Slope systems*. In Thomas, David S.G. (ed.). Arid Zone Geomorphology: Process, Form and Change in Drylands. John Wiley & Sons.

Wudneh, A. (2012). *Characteristics and Onsite Costs of the Sediment Lost by Runoff from Dapo and Chekorsa Watersheds, Digga District*. Master Thesis submitted to the School of Graduate Studies of Ambo University, Ethiopia

Zorn, M and Komac, B. (2013). Bobrowsky, Peter T. (ed.). *Encyclopedia of Natural Hazards*. Encyclopedia of Earth Sciences Series. Springer Netherlands. pp. 289–290.