# Land use change in the tropics and its effect on soil fertility

Alfred E. Hartemink[A]

[A]ISRIC - World Soil Information, P.O. Box 353, 6700 AJ Wageningen, The Netherlands, Email Alfred.Hartemink@wur.nl

**Abstract**
Land use changes influence the fertility of the soil. Land use changes mostly focused on deforestation, cropland expansion, dryland degradation, urbanisation, pasture expansion and agricultural intensification. In tropical regions, forest is cleared for the expansion of cropland, wood extraction or infrastructure expansion. Croplands expanded by 50% during the 20th century, from roughly 1200 million ha in 1900 to 1800 million ha in 1990. There are several interacting drivers for land cover change but the exponential growth in human population is important. Currently, 95% of the population growth takes place in tropical regions and soil fertility in tropical regions is affected by rapid land use changes. The effects of deforestation and grassland conversions as well as agricultural intensification have been fairly well-documented but the spatial and temporal effects of soil fertility change and its interaction with land use change remains to be investigated.

**Key Words**
Land use change, tropical regions, soil fertility, deforestation, cropland.

**Introduction**
During the 20$^{th}$ century, the world population more than doubled from about 1.5 billion people in 1900 to 5.2 billion in 1990. Currently, the world population is growing by 1.3% per year compared to 2.0% growth in the late 1960s. More than 90% of the population growth takes place in tropical regions. About 80% of the population lives in developing regions; Asia accounts for 61% of the world total. The rate of population growth is declining and population will reach around 8.9 billion in 2050 (Lutz *et al.* 2001).

Despite enormous advances in remote sensing and GIS technologies in the past decades, systematic examination of trends in terrestrial land cover is yet to be made (Lepers *et al.* 2005). Most analyses of land-cover changes are based on data from remote sensing, censuses (statistical inventory, national, regional), and expert opinion through formal procedures. In order to integrate these heterogeneous data sources there is a need to determine the interrelationships between the data types (Lepers *et al.* 2005). There is a need to understand land cover changes and its effect on the overall ecosystems. Land use change affects the global climate via the carbon cycle, the water cycle through changing evapotranspiration and hydrological regimes but land use change also affects biotic diversity, soil degradation, and the ability of biological systems to support human needs. In other words, such changes influences earth system functioning (Lambin *et al.* 2003).

We roughly know where land use changes occur and we also know that land use changes affect soil chemical and physical properties. Such changes have been fairly well-documented but a systematic global scale link between land cover change and soil fertility change has - to our knowledge - not been made. Here I review the major patterns in land use and land cover change in the tropical regions and how these changes affect soil fertility and nutrient management.

**Land use change**
Lambin *et al*. (2003) used five categories of land cover change: cropland, agricultural intensification, tropical deforestation, pasture expansion, and urbanisation. Throughout this review, I shall more or less follow these categories to discuss trends in land cover change and its implications for soil fertility and its management. The area of cropland has increased from an estimated 300-400 million ha in 1700, to 1500-1800 million ha in 1990. The area under pasture increased from 500 million ha in 1700 to 3100 million ha in 1990. These increases led to the clearing of forests and the transformation of natural grasslands, steppes, and savannas. Forest area decreased from 5000-6200 million ha in 1700 to 4300-5300 million ha in 1990. The area under steppes, savannas and grasslands declined from around 3200 million ha in 1700 to 1800-2700 million ha in 1990 (Lambin *et al.* 2003).

The area under croplands increased by 50% in the 20th century from 1200 million ha in 1900 to 1800 million ha in 1990. This net increase in cropland area includes the abandonment of 222 million ha of cropland since 1900. There has been greater expansion of cropland areas since World War II than in the 18th and early 19th centuries combined. Significant changes in cropland occurred in southeast Brazil. Cropland expansion slowed down in the Midwestern USA, while there was abandonment in the eastern part. Cropland areas in northern Europe, the former Soviet Union, and China stabilized and even decreased in some regions, while it intensified in northeast China. Some croplands were abandoned in Japan. Clearing for cultivation continued in Southeast Asia and Oceania (Ramankutty *et al.* 2002).

Lepers *et al*. (2005) synthesised information on rapid land-cover change for the period 1981-2000 as part of the Millennium Ecosystem Assessment. They produced a series of global maps (10 by 10 km grid) that show how land cover has changed in the past decades. Some parts of the world were covered by several data sets, whereas for others only national statistics were available. As a result, some areas appear to be more affected by rapid land-cover change because they are studied more intensively. A summary of their findings: in Asia there are many areas where land-cover changes occur most rapidly; the Amazon basin is a hotspot of tropical deforestation and it mostly takes place at the edge of large forest areas and along major transportation networks. Deforestation occurs when forest is converted to another land cover or when tree canopy is reduced to less than 10%. Globally about 5.8 million ha is deforested each year, whereas annual forest regrowth is estimated to be 1 million ha. In tropical regions, forest is cleared for the expansion of cropland, wood extraction or infrastructure expansion.

*Aerial photographs and satellite images*

Several studies on land use changes used aerial photographs or satellite images from different periods combined with Geographic Information Systems (GIS). Holmgren *et al*. (1994) surveyed woody biomass on farmland in Kenya using aerial photographs and field measurements. A rapid increase of planted woody biomass was observed between 1986 and 1992 and the annual increase was estimated to be almost 5%. Population density was positively correlated with the volume of planted woody biomass: more people, more trees. The results imply that some pessimistic opinions on land-use development in Kenya are incorrect (Holmgren *et al.* 1994) and confirm some of the observations by Tiffen *et al.* (1994).

A study in Tanzania using normalized difference vegetation index (NDVI) imagery showed that the overall greenness increased between 1982 and 1994 (Pelkey *et al.* 2000). A detailed study in the Usambara Mountains in Tanga Region, Tanzania, showed a drastic reduction in forests cover from 53,000 ha in 1965 to 30,000 ha in 1991. Several studies from Kenya arrived at the same conclusions. In Embu region, Imbernon (1999) studied change in land-use in semi-arid and humid areas of Mount Kenya; tree cover decreased from 26% in 1956 to 24% in 1995. In the highlands North of Nairobi, Ovuka (2000) observed that in 1960 there was 15% fallow land but this had decreased to 6% in 1996. Woodlots had increased from 1 to 3% and coffee gardens from 0.2 to 12% over the same period. Areas without soil and water conservation practises increased from about 25% in 1960 to 70% in 1996. Most farmers depended on income from the land and thought that livelihood was better in 1996 than in 1960 (Ovuka 2000).

A study in Lake Malawi National Park, Malawi, using aerial photographs showed conversion of closed *miombo* to sparse woodlands (Abbot and Homewood 1999). Between 1982 and 1990, closed canopy woodland decreased by 7% whereas sparse woodland increased by 342%. In south-western Burkina Faso, Gray (1999) showed that between 1981 and 1993 the area under cultivation roughly doubled at the expense of scrub savannah. Human population doubled between 1971 and 1985. Tekle and Hedlund (2000) compared aerial photographs from 1958 and 1986 in the highlands of Kalu District, Ethiopia. A decrease in coverage by shrublands, riverine vegetation and forests was observed. Areas under cultivation remained more or less unchanged. It was concluded that land cover changes were the result of clearing of vegetation for fuel wood and grazing. In Papua New Guinea Ningal *et al*. (2008) assessed land use change in the Morobe Province (3.4 million ha) using topographic maps and Landsat $^{TM}$ images. Between 1975 and 2000, agricultural land use increased by 58% and population grew by 98%; most new agricultural land was taken from primary forest. The forest area was more than halved from 9.8 ha per person in 1975 to 4.4 ha per person in 2000. Correlation between total population change and total land use change was strongly positive (64%).

**Land cover change and soil fertility**
The majority of land use changes are related to agricultural use of the land, including pastures. Agricultural activities change the soil chemical, physical or biological properties. Such activities include cultivation (mechanised, by hand), tillage, weeding, terracing, subsoiling, deep ploughing, manure, compost and fertiliser applications, liming, draining, irrigation and empoldering (Bridges and de Bakker 1997) but also biocides applications on cultivated crops may affect soil properties. Many soils have been improved since people started cultivation and soil improvements continue in many agricultural areas. Inputs are applied when needed by the crops, losses are minimised and environmental awareness and legislation have created agricultural practises that are ecologically and economically more sustainable. All these improvements are usually not reported in scientific literature. We do not have maps showing the great improvements in conditions in the past 100 years – quite the opposite: there is fair a body of literature on soil degradation in relation to agriculture.

Most of the concerns about soil degradation are fully justifiable, but hard data on the severity, extent, and impact are little which makes soil degradation a debated issue – particular in tropical regions (Hartemink 2006). A major factor in soil degradation is the soil chemical fertility and then in particular its decline as a result of the lack of nutrient inputs. This has been a major concern since sedentary agriculture started and is the main reason why farmers clear more land when farming in forested areas: the soil is depleted from plant nutrients.

The effects of land cover changes as well as subtle conversions on soil fertility are fairly well-documented. Land use change always affects soil quality and productivity. On-site effects are mostly related to changes in soil organic matter content. The most dramatic changes occur directly after a major land use conversion, such as deforestation. Mineralisation increases while the change in cover usually induces erosion and other landscape processes. Conversion has a large short term (1-5 years) on-site impact on soil properties such as soil organic C and bulk density, whereas land use intensification has longer term (10 to 80 years) effects on soil properties. We reviewed some studies in which the trends and rates of soil fertility changes were varying. Obviously, soil fertility is a complex issue consisting of several attributes that interact over time. Measurements require long-term research commitment as well as detailed knowledge about spatial and temporal variability. Most studies about the interaction between land use and soil fertility are on the profile and field scales which makes a direct link with spatial data on land cover change complicated. Systematic, consistent measurements of soil properties should be undertaken at a global scale, at a relatively fine resolution, since soil attributes are an important component of land cover (Lepers *et al.* 2005).

The ability of a region of the world to produce or access food is determined access to an adequate amount of productive cropland; the ability to maintain high crop yields on that land (often with the aid of external inputs, such as fertilizers, pesticides, and irrigation); or the ability to purchase and import food from other regions (Ramankutty *et al.* 2002). The majority of the world's fertile soils are already under cultivation. Much of the remaining cultivable land lies in marginal areas or in the richly forested regions of tropical Latin America and Africa. Clearing for cultivation implies a loss of forest. Prime farmland is lost to urbanization and the impact of soil degradation will further increase the pressure on the remaining croplands.

**Conclusions**
Globally, land use has changed considerably in the past decades – mostly reflecting the enormous growth in human population and their need for food. The world's population has doubled since 1960. The developing world accounts for about 95% of the population growth with Africa as the world's fastest growing region. The growing population has many implications but most of all it requires an increase in agricultural production to meet food demand. This demand can be met by expansion of agricultural land or by intensification of existing systems. Conservation and improvement of the natural resources on which agricultural production depends is essential. Soil degradation and in particular the decline of soil chemical fertility, is major concern in relation to food production and the sustainable management of land resources. It also affects land use but the spatial and temporal effects of soil fertility change and its interaction with land cover change remains to be investigated. Many studies on soil land use and land cover change are local and mainly aimed at specific systems such as shifting cultivation. More emphasis should be put on more intensive land use systems at more aggregated scales in a spatially explicit way.

**References**


Abbot JIO, Homewood K (1999) A history of change: causes of miombo woodland decline in a protected area in Malawi. *Journal of Applied Ecology* **36**, 422-433.

Bridges EM, de Bakker H (1997) Soils as an artefact: human impacts on the soil resource. *The Land* **1**, 197-215.

Gray LC (1999) Is land being degraded? A multi-scale investigation of landscape change in southwestern Burkina Faso. *Land Degradation & Development* **10**, 329-343.

Hartemink AE (2006) Assessing soil fertility decline in the tropics using soil chemical data. *Advances in Agronomy* **89**, 179-225.

Holmgren P, Musakha EJ, Sjöholm H (1994) Not all African and is being degraded: A recent survey of trees on farms in Kenya reveals rapidly increasing forest resources. *Ambio* **23**, 390-395.

Imbernon J (1999) Pattern and development of land-use changes in the Kenyan highlands since the 1950s. *Agriculture Ecosystems & Environment* **76**, 67-73.

Lambin EF, Geist HJ, Lepers E (2003) Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment & Resources* **28**, 205-241.

Lepers E, Lambin EF, Janetos AC, DeFries R, Achard F, Ramankutty N, Scholes RJ (2005) A synthesis of information on rapid land-cover change for the period 1981-200. *Bioscience* **55**, 115-124.

Lutz W, Sanderson W, Scherbov S (2001) The end of world population growth. *Nature* **412**, 543-545.

Ningal T, Hartemink AE, Bregt A (2008) Land use change in the Morobe province of Papua New Guinea between 1975 and 2000. *Journal of Environmental Management* **87**, 117-124.

Ovuka M (2000) More people, more erosion? Land use, soil erosion and soil productivity in Murang'a District, Kenya. *Land Degradation & Development* **11**, 111-124.

Pelkey N, Stoner C, Caro T (2000) Vegetation in Tanzania: assessing long term trends and effects of protection using satellite imagery. *Biological Conservation* **94**, 297-309.

Ramankutty N, Foley JA, Olejniczak NJ (2002) People on the land: Changes in global population and croplands during the 20th century. *Ambio* **31**, 251-257.

Tekle K, Hedlund L (2000) Land cover changes between 1958 and 1986 in Kalu District, Southern Wello, Ethiopia. *Mountain Research and Development* **20**, 42-51.

Tiffen M, Mortimore M, Gichuki F (1994) 'More people, less erosion. Environmental recovery in Kenya.' (John Wiley & Sons Ltd: Chichester).