CHAPTER I

INTRODUCTION

1.1 Background and Statement of the Problem

Malawi, like most sub-Saharan African (SSA) countries, is faced with declining per capita food production since the 1980s (FAO, 1991). Declining soil fertility is the identified major cause of the declining per capita food production in Africa (El-Swaify et al., 1985). The nutrient resource base for SSA has been shrinking (Stoorvogel and Smaling, 1990). Soil erosion and soil nutrient mining through continuous cultivation of crops coupled with low application of external sources of nutrients is singled out as the major cause of nutrient depletion (declining soil fertility) in the region. The annual net nutrient depletion (due to soil erosion and soil mining) in Malawi and some other countries in the region exceeds 30kg N and 20kg K per ha of arable land [IFDC, 1999; Stoorvogel and Smaling, 1990]. The current average use of nutrients for Africa is about 10 kg NPK/ha/year while the estimated average use required to meet nutrient needs at current levels of production is about 40 kg NPK/ha/year. Therefore, increased agricultural productivity and food production in this region can only be attained through the enhancement of the agricultural resource base.

In Malawi, soil mining due to continuous cultivation of mostly maize (mono-cropping) by smallholder farmers is eroding the fertility and productivity of soils even in the absence of soil erosion. Estimates indicate that smallholder farmers, who occupy almost two thirds of the total harvested agricultural area in Malawi (1.98 million hectares), apply on average 26 kg of fertilizer per hectare of maize, which is far below crop and soil maintenance requirements (Heisey and Mwangi, 1995; FAO, 1994; UN, 1996). Actually, nutrient balances calculated for Malawi indicate a negative balance (IFDC, 1999;1985). Admittedly, continuous cultivation of maize, without adequate application of commercial or organic fertilizers to replenish the soils, as is the case of smallholders in Malawi, has elsewhere been linked to reduction in the organic matter content of soils, and consequently yield decline [Singh and Goma, 1995; Jones, 1972; Andersen, 1970, Grant; 1967]. Unless urgent attention is given to reverse the existing imbalance between the nutrient extraction by cultivated crops and nutrient additions from external sources, productivity of Malawian soils will continue to decline worsening further the food insecurity problem.

Also, urgent attention is required to curtail soil erosion and its degrading impact on soil productivity. Malawi is categorized as one of those countries with the highest level of soil erosion in sub-Saharan Africa (Bojo, 1996). Annual soil loss due to water-induced erosion in Malawi is about 20 ton/ha (Bishop, 1992). It is not surprising therefore, that soil erosion has been singled out as number one threat to sustainable agricultural development in the country (NEAP Secretariat, 1994). Noteworthy, there is low adoption levels of soil conservation technologies among smallholder farmers in Malawi [Mangisoni, 1999; Kumwenda, 1995]. However, small-scale soil conservation techniques are not only affordable to smallholder farmers, but also, quite effective in reducing soil erosion. As such, increased adoption of soil conservation techniques is, obviously, of strategic importance in reducing levels of soil erosion and, subsequently, improving productivity of smallholder farms.

In Malawi, rapid population growth is one of the factors blamed for land degradation as it has exerted much pressure on the agricultural land. However, the view that population pressure usually cause land degradation is sometimes disputed. Recent evidence shows that population and market pressure can be associated with adoption of land conservation techniques and even with reforestation [Templeton and Scherr, 1997; Tiffen et al., 1994]. Nevertheless, the impact of rapid population growth in Malawi is crucial when discussing the problem of land fragmentation and land use (cultivation of marginal lands). Land fragmentation and cultivation of marginal areas in Malawi is connected to the problem of land degradation. To begin with, about 85 per cent of the Malawian population earns their livelihood from agriculture. As such, the rapid population growth has exerted enormous pressure on the agricultural land. In Malawi, population pressure has been absorbed either by splitting further the already small pieces of land (land fragmentation) or by extending cultivation to marginal areas. For example, in 1977 only 37 per cent of the land was classified as suitable for crop production and 86.7 per cent of this land was already under cultivation (Phiri, 1984). Farming families with land size of less than one hectare were estimated to be 55 per cent for the same period (World Bank, 1987). However, this figure had risen to 76 per cent by 1997, with about 41 per cent cultivating less than half a hectare (FAO, 1998). It is inevitable that such rapid decrease in land size per farming family has seriously reduced smallholder farmers' ability to engage in fallow system as a way to recuperate its soil fertility.

Another issue linked to the rapid population growth in Malawi is the alarming increase in levels of poverty. Poverty situation has continued to worsen with now more than 70 per cent of farm families in Malawi classified as poor (FAO, 1998). The growing number of poor households means that fewer and fewer farm families can now afford commercial fertilizers. Chemical fertilizers have been successfully used in other parts of the world to replenish soil fertility. Although maintenance and enhancement of soil productivity hinges upon intensified use of external inputs such as commercial and organic fertilizers, and increased adoption of soil conservation technologies, there are key problems associated with either option for Malawi. Majority of smallholder farmers cannot afford commercial fertilisers due to high prices. Use of fertiliser among smallholder farmers is also hampered by poor delivery and distribution system mainly as a result of poor road and market infrastructure (Nakhumwa et al, 1999; Ng'ongola et al, 1997). Nevertheless, small-scale soil conservation technologies (physical and biological) and use of other cheaper external sources of soil nutrients such as organic manures remain the most affordable options for the majority of smallholder farmers in Malawi. Importantly, reasons for poor adoption of soil conservations technologies by smallholder farmers need to be clearly understood if policy makers are to indeed design proper and strategic interventions aimed at improving adoption among this category of farmers.

Noteworthy, short-term consequences of the declining soil fertility on agriculture and food security are well known at both farm and policy levels. Various studies linked to soil fertility issues have been carried out in Malawi over the years [Mangisoni 1999; Benson 1998; Bishop, 1992]. Some of the analyses carried out in Malawi and linked to soil fertility have included the following:1) crop (maize) response to major soil nutrients such as nitrogen and phosphorous; 2) fertilizer recommendations and levels of fertilizer use in the country; 3) quantifying amount of soil erosion taking place in the country and; 4) adoption levels of soil conservation technologies. However, Malawi's heavy dependence on agriculture entails that the country cannot relax its efforts to preserve land quality bearing in mind it must provide adequately for the well being of both the current and future generations. In order to properly consider the importance of land quality for agricultural productivity in Malawi, it is crucial for policy makers and farmers alike to understand the long-term and dynamic nature of soil erosion and soil-mining problems and their consequent implications. For example, policy makers and farmers need to have knowledge of what is happening to the soil as a productive asset i.e., declining quality due to agricultural production, and its devastating impact on productivity over time. Ignoring the long-term costs of land degradation leads to formulation of unsustainable policy prescriptions based on limited assessment of short-term costs and benefits. Assessment of dynamic costs of soil degradation on agricultural productivity and inevitably, social well being of the people of Malawi, generates some quite useful information that can be used by policy makers in formulating more proactive soil fertility enhancement and soil conservation policies necessary for the achievement of sustainable agricultural development.

Unlike the depreciation of manufactured assets, the effects of soil degradation (declining soil fertility) are not reflected in conventional measures of economic welfare in order for policy makers to understand the long-term dangers of the problem (Magrath and Arens, 1989). This occurs because markets seldom exist for soil resources, due to the pervasive influence of externalities on the true costs of soil erosion, and because systems of national economic accounts treat natural resources as free goods. Literature on the economic costs of soil degradation is limited. So far, only one study was carried out in Malawi that has tried to measure economic costs of soil erosion (Bishop, 1992). However, this study is based on a static formulation and stopped short of providing adequate analysis of the long-term and dynamic consequences of the depletion of soil resources on agricultural productivity and social well being of the people of Malawi.

According to Barbier (1986), land quality is classified as a slowly renewable resource. When the major reason for land degradation is nutrient loss (nutrient mining through crop harvest), soil quality can easily be restored through supply of external inputs such as manure and inorganic fertilizers. In other words, net-extraction of nutrients or soil mining can occur and drastically affect land productivity without posing an irreversible long-run threat to land productivity since measures are available not only to arrest, but also to compensate for nutrient losses ex-post (Brekke et. al., 1999). However, the destruction of soil physical structures and rooting depth as a result of erosion of the topsoil causes an irreversible long-term damage to land productivity. Unfortunately, such distinction is lacking in the study carried out by Bishop (1992) on Malawi. This current study focuses on the problem of soil degradation as a result of soil erosion and soil-mining. An inter-temporal optimisation framework is utilised to determine an optimal extraction path of the soil nutrient stock.

While the main thrust of this study is measuring the dynamic costs of soil degradation (soil-mining), attention is also given to improving our understanding of the problem of adoption of soil conservation practices among smallholder farmers in Malawi. As pointed out earlier, controlling soil erosion is extremely important in reducing the loss of nutrients adsorbed on fine particles (Pieri, 1995). Considering the poverty situation in Malawi, soil conservation is assumed to be the most appropriate and affordable intervention for smallholder farmers in order to limit the damage caused by soil erosion. However, such intervention is currently hampered by the low adoption among smallholder farmers of soil conservation technologies. Although some significant contributions have been made towards understanding this problem (Mangisoni, 1999), no research work has focused on understanding the decision making process of the smallholder farmers when adopting any technology. This study is, therefore, designed to contribute to the improvement of existing knowledge on the key factors influencing adoption of soil conservation technologies. The study separates factors influencing the incidence and the extent of adoption of soil conservation technologies among smallholder farmers in Malawi. Such an approach is assumed vital not only for the formulation of strategic policies that would boost adoption of those technologies, but importantly, the actual designing of appropriate small-scale soil conservation technologies.

1.2 Objectives of the Study

The primary objectives in this study are to measure the dynamic costs of soil degradation (soil erosion and soil-mining) and determine factors influencing the incidence and extent of adoption of soil conservation technologies among smallholder farmers in Malawi.

The following are the specific objectives:

- to calculate dynamic user costs of soil quality (soil nutrient stock)
- to determine the steady state (SS) optimal path for soil nutrient stock and optimal rate of replenishment from external sources (e.g., SS optimal rate of commercial fertilizer application)
- to calculate user cost as percentage of gross domestic product in order to come up with a better measure of national wealth.
- to determine key factors that influence farmers' decision on incidence and extent of adoption of soil conservation practices in Malawi.
- to analyse policy implications and come up with relevant policy recommendations

1.3 Approaches and Methods of the Study

As already pointed out, this study has two main objectives: to measure the dynamic costs of soil degradation and, to determine factors that influence the incidence and extent of adoption of soil conservation technologies among smallholder farmers. As such, two main analytical tools are employed to achieve the objectives stated above.

First, considering that soil degradation (soil erosion) has long-term consequences, this study adopts an inter-temporal framework combining scientific models of crop productivity and soil degradation (see Aune and Lal, 1995). In this framework, smallholder farmers choose optimal levels of labour, capital and external inputs in order to maximize stream of net benefits over time as a dynamic optimisation decision problem.

Second, factors influencing incidence and extent of adoption of soil conservation technologies in Malawi are analysed using a selective tobit model. This model simulates a two-step decision-making process of smallholder farmers when deciding adoption. This approach was adopted in order to deepen our understanding of the way smallholder farmers make decisions concerning adoption with the hope to try explain the main reasons behind the low adoption of soil conservation technologies in Malawi.

1.4 Organization of the Thesis

The following chapter gives a brief background on the importance of agriculture to the economy, describes the physical and chemical characteristics of the soils of Malawi and also, examines some evidence of declining trend of soil fertility in Malawi. Chapter III presents a review of literature on some models that have been used to predict soil erosion and crop productivity. Literature on the theoretical development of erosion economic analyses and the various approaches that have been used to measure the soil economic costs of soil erosion are also presented in this chapter. Chapter IV presents the analytical inter-temporal optimisation framework and discusses analytical results for the optimal control model of the soil-mining problem under study. Chapter V applies the dynamic optimisation model described in chapter IV to the soil-mining problem in Malawi. The specified model is used to solve the soil-mining problem among smallholder maize farmers in Malawi. Empirical estimation of the specified model parameters is performed in this chapter. Data sources and econometric procedures used for estimation of the model parameters are also discussed. Chapter VI presents a selective tobit model used to determine factors influencing incidence and extent of adoption of soil conservation technologies among smallholder farmers in Malawi. Chapter VII presents empirical results and discussion of the selective tobit model. Finally, chapter VIII presents general summary, conclusion and policy implications based on the dynamic optimisation model and also, results of the selective tobit analysis of adoption of soil conservation practices.

CHAPTER II

AGRICULTURE AND SOIL RESOURCES OF MALAWI

2.1 Agricultural Sector in Malawi

Malawi lacks the mineral resource endowments of its neighbouring countries (Zambia, Mozambique and Tanzania). Agricultural land therefore, constitutes the primary natural resource for the Malawi economy. Agriculture in Malawi is characterized by a degree of dualism that has dichotomised the sector into smallholder and estate sub-sectors (Mkandawire et al, 1990). The dichotomy is essentially reflected in the tenurial systems under which land is cultivated. Smallholder agricultural production is predominantly on customary land. Under this system, land is the property of the community with individual user rights. Under customary land system, chiefs and village headmen are the custodians of land. Smallholder farmers usually have small, scattered and usually fragmented lands emanating mostly from population pressure and other socio-economic factors. The smallholder sub-sector is the backbone of Malawian agriculture occupying about two thirds (1.98 million hectares) of the total harvested agricultural land (FAO, 1998). Maize is the main crop grown under this predominantly subsistence farming system. This crop alone comprises 75 per cent of the total smallholder agricultural land in Malawi (Barbier and Burgess, 1992a). Other major subsistence crops include cassava, sorghum and sweet potatoes. Smallholder farmers also grow a number of cash crops such as burley tobacco, grain legumes (beans and groundnuts), cotton, coffee and spices.

Estate production occurs mainly on leasehold or freehold land. Estates are exclusively involved in cash crop production. Main cash crops are tobacco (dominant export crop), tea, coffee, sugarcane and macadamia nuts.

Agriculture accounts for over 80 per cent of Malawi's export revenue predominantly from tobacco, tea, sugar, and coffee (Figure 1). On average the agricultural sector contributes about 34 per cent of the GDP (Table 1). By 2001, the total labour force in

Malawi was about 4.5 million and almost 84 per cent of this is engaged in agriculture (Table 2). Over 90 per cent of the population engaged in agriculture live in rural areas (Table 2). The slow growth of the manufacturing sector in Malawi means that the agricultural sector will continue to shoulder the burden of providing a livelihood for a large proportion of the country's growing population. It is not surprising therefore, that policy action for Malawi, both agricultural and economy-wide, has largely been based on influencing the dynamism of the agricultural sector.

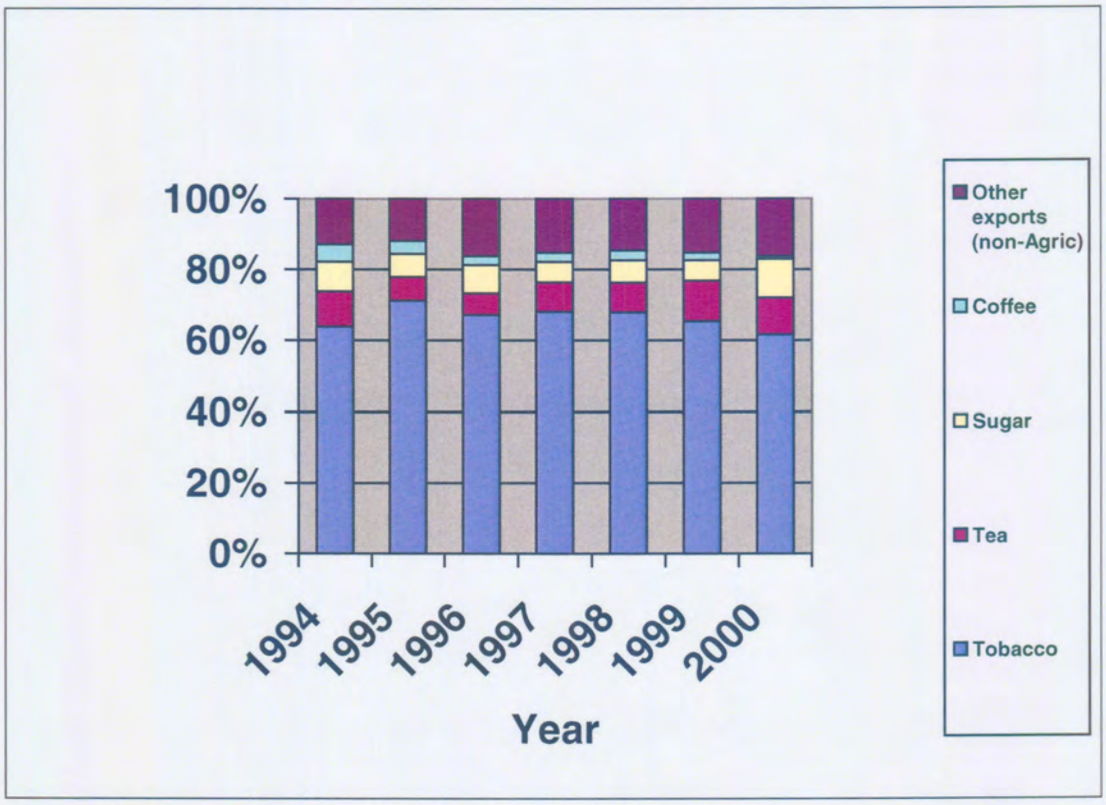

Figure 1: Principle domestic exports for Malawi %: 1994-2000

Source: MNEC (2001)

Table 1: Gross Domestic Product by Sector of Origin at 1994 Factor Price (MK million)

Sector	1994	1995	1996	1997	1998	1999	2000	2001
Agriculture	2,319	3,238	4,064	4,069	4,490	4,944	5,210	5,365
Smallholder	1,624	2,332	3,070	2,964	3,520	3,992	4,059	4,265
Estate	695	906	993	1,105	969	951	1,151	1,100
Mining/quarying	43	47	206	157	164	170	188	210
Manufacturing	1597	1,685	1,675	1,691	1,717	1,749	1,705	1,690
Electricity/ water	149	152	152	161	172	172	189	198
Construction	202	198	231	254	266	293	288	281
Distribution	2537	2576	2575	3,018	2,838	2,765	2,760	2939
Transport &communication	465	550	505	553	559	576	552	580
Financial& professional services	627	691	834	1,128	1034	1,032	1,057	1253
Ownership of dwellings	162	165	169	172	176	180	185	189
Private &social and services	211	215	237	260	262	264	271	279
Producers of govt services	1114	1,198	1,168	1,200	1,232	1,257	1,282	1,297
Unallocatable financial services	-278	-305	-317	-361	-344	-378	-387	-456
GDP factor cost	9,149	10,411	11,498	12,303	12,568	13,023	13,300	13,601
Agric % of GDP	25.34	31.1	35.3	33.07	35.7	39.9	39.17	39.4
Average Agric % of GDP								34.87

Source: MNEC (2001)

Table 2: Economically active persons by industry in Malawi

Industry	Malawi Total	Urban	Rural
Total working	4,458,929	456,084	4,002,845
Agriculture and forestry	3,724,695	90,360	3,634,335
Fishing	41,132	1,754	39,378
Mining and Quarrying	2,499	686	1813
Manufacturing	118,483	42,205	73,278
Electricity, gas and water	7,319	5,261	2,058
Construction	73,402	37,158	36,244
Wholesale and retail trade	257,389	128,502	128,887
Hotels and restaurants	15,303	8,913	6,390
Transport, storage and communication	32,623	24,334	8,289
Finance and insurance	5,099	4,672	427
Real estate and business activities	8,858	6,517	2,341
Public Administration	101,433	75,333	26,100
Community and Social Services	136,357	62,019	74,338
Education	79,572	30,051	49,701
Health and social work	31,931	16,812	15,119
Other community services	24,674	15,156	9,518

Source: National Statistic Office (NSO) (1998) population census results.

Agricultural growth is a catalyst for broad-based economic growth in most developing and low-income countries (Pinstrup-Andersen and Pandya-Lorch, 1995). Agriculture's links to non-farm sectors generate considerable employment, income, and growth in the rest of the economy. Globally, very few countries have experienced rapid economic growth without agricultural growth either preceding or accompanying it. Although diversification out of agriculture may occur in the long-term, in the short-term many developing nations lack alternatives. While the average annual growth rate for agriculture in the low and middle income developing countries slowed down in the first half of the 1990s to 2.0 per cent compared to 3.1 per cent in 1980s, in Sub-Saharan Africa, the growth rate was lower and falling from 1.9 per cent in 1980-90 to 1.5 per cent in 1990-95 (World Bank, 1997). Admittedly, annual percentage growth rate for agricultural GDP in Malawi has been declining and so is the overall annual percentage growth rate for GDP at factor cost (Figure 2). The decline in annual percentage growth rate for agriculture is mainly attributed to the falling tobacco output and exports resulting from limited access to credit by farmers for the procurement of inputs, falling auction prices for tobacco and importantly also, effects of drought [MNEC,1999; 2000]. Falling smallholder maize output in recent years has also contributed to this decline.

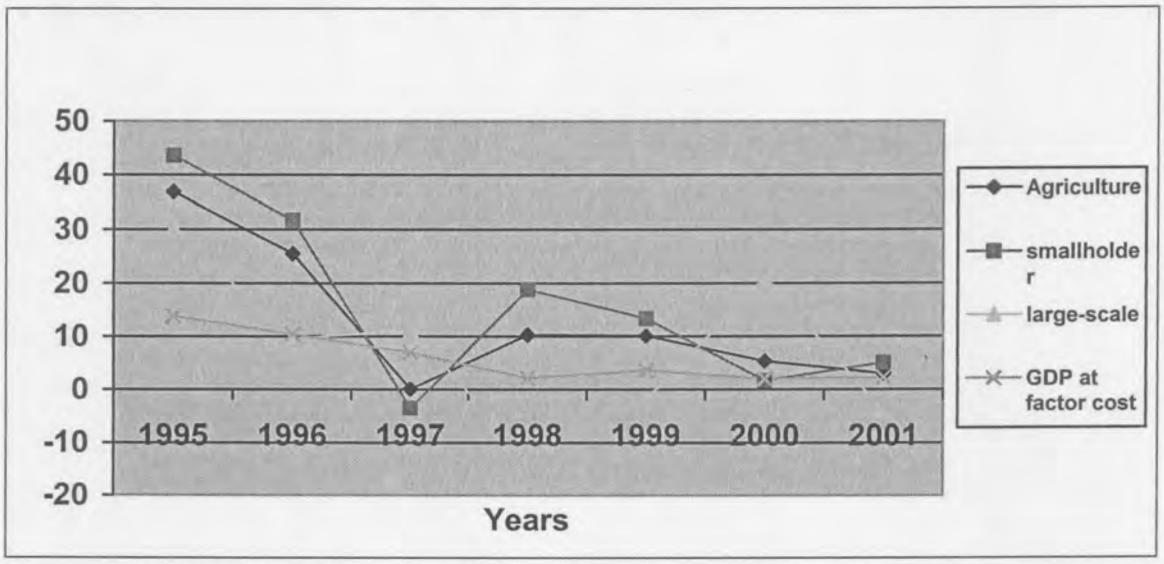

Figure 2: GDP by agricultural sub-sector at 1994 factor cost: Annual percentage growth rate(1995-2001)

Source: Data adapted from MNEC (2002)

Productivity of smallholder agriculture in Malawi has stagnated or decreased over the years. Maize yields between 1985 and 2000 fluctuated a lot in all the eight agricultural development divisions (ADD[1]). A lot of factors contributed to this fluctuation. However, erratic rainfall, drought, and limited credit and capital by farmers for the procurement of inputs were the major causes. Noteworthy, there is an overall declining trend in maize yields observed in all the ADDs (Figure 3). Coupled with a growing population, an obvious implication of the falling maize output over the years has been, to certain extent, a declining trend of per capita kilogram (kg) maize equivalent in the country (Figure 4). The declining per capita kilogram maize equivalent has serious implications on food security, especially among the rural poor households. Most of the rural poor households do not have adequate purchasing power to buy and supplement their maize food reserves in the event of poor harvest.

It is asserted that increase in agricultural production in Malawi has over the years resulted from land expansion rather than increase in productivity. In 1946, over half the land in Malawi (five million hectares) was forested (Orr et al., 1998). However, by 1991, analysis of satellite images revealed that the forested area had decreased by 50 per cent, down to 2.5 million hectares, or only 27 per cent of the country's land area. Of this forested area, 1.3 million hectares are found within protected area boundaries. In other words, 53 per cent of Malawi's current natural woodland lies within reserves and parks. The decline, associated exclusively with agricultural clearing over the past fifty years, has come at a rate of 1.5 per cent per annum (Orr et. al, 1998). Opening more land to agricultural production entails more erosion of the soils. Hence, curtailing soil degradation and improving soil productivity would be a way forward if the country is to achieve sustainable agricultural development.

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[1] Malawi is divided into eight agricultural development divisions (ADD). Blantyre ADD (BLADD), Shire Valley ADD (SVADD) and Machinga ADD (MADD) in the Southern region; Lilongwe ADD (LADD), Salima ADD (SLADD) and Kasungu ADD (KADD) in the Central region and finally, Mzuzu ADD (MZADD) and Karonga ADD (KRADD) in Northern region.

Obviously, the fast growing population in Malawi puts more pressure on agricultural land. Population pressure on public land is greatest in the south and central regions of Malawi, with population densities of about 100 people per km^2 in the 1987 census. Current land holding size is estimated to be one hectare per family. Estimated average family size in Malawi is 5 persons, implying a land holding size of 0.2ha per person. Estimates by FAO (1986) indicated that Malawi had the least cropland per capita in 1980s, 0.42 ha, compared to its neighbours; Tanzania, Zambia, and Zimbabwe, with per capita land of 0.48 ha, 0.95ha and 0.56 ha, respectively. Projected cropland demand for 2010 for Malawi, Tanzania, Zambia and Zimbabwe was 0.2 ha, 0.29 ha, 0.49ha and 0.25ha, respectively. The projected reserve of potential cultivable land for 2010 for Malawi, Tanzania, Zambia and Zimbabwe is 0.06ha, 0.36ha, 2.83ha and 0.49 ha, respectively. It is evident that Malawi faces an acute land shortage and the picture is particularly gloomy when we consider the low application of external inputs among smallholder farmers.

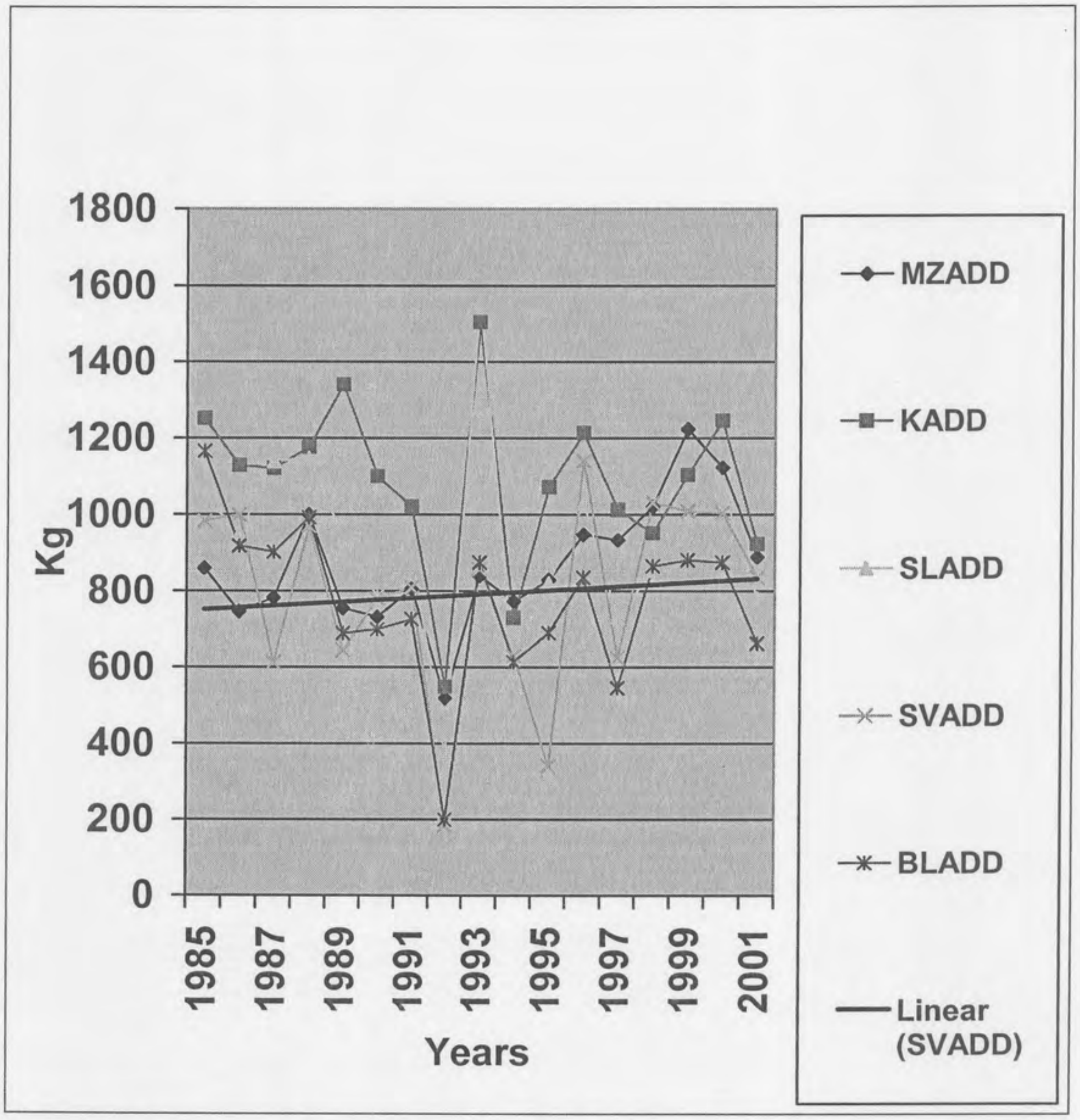

Figure 3: Smallholder Maize Yield Trend in Malawi: 1985-2001

Source: Data adapted from MNEC (2002)

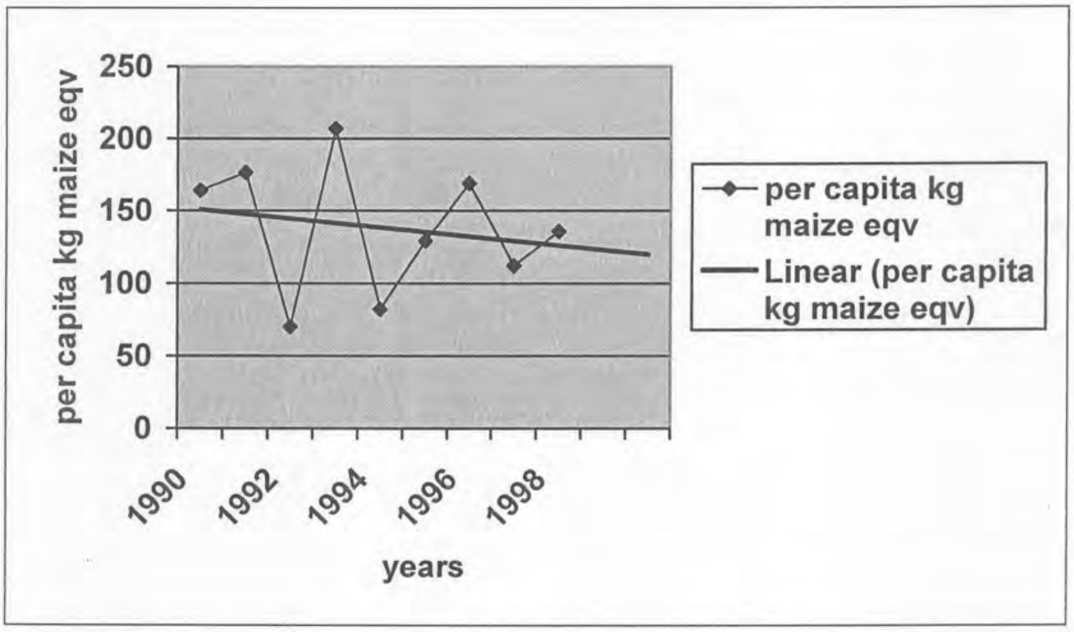

Figure 4: Per capita kg maize equivalent for Malawi: 1990-1998

Source: Data adapted from MoAI (2000)

Worse still, only little proceeds from agriculture have been ploughed back into this sector. The FAO (1996c) has indicated that investments in agriculture declined in Malawi and other Sub-Saharan countries in recent years. The limited budget allocated to the agricultural sector has resulted in some important public institutions of the sector such as research and extension services being under funded (MNEC, 2001). Importantly, the slow agricultural growth and the lack of adequate investment in this sector have been accompanied by rapid degradation of the natural resource base (Oldeman, 1990). Renewable resources, which comprise the environmental base for agriculture and most other economic activities in rural areas, are under threat. However, the threat of soil erosion is extremely high among smallholder farms due to low fertility and fragility of the soils. Nutrients in the tropical soils often concentrate only in the top few inches of the topsoil, making the soils subject to nutrient depletion and other adverse effects from soil erosion [Lal, 1987, 1988]. Unless right policies are put in place to manage and improve the productivity of the soils in a sustainable manner, declining fertility of the soils will seriously undermine benefits of any modern agricultural production techniques.

2.2 Food Security Situation in Malawi

Food security situation in Malawi has worsened over the years. Of late, Malawi has been supplementing its domestic maize production with imports from South Africa and other neighbouring countries. For example, in 1997/98 growing season, the country experienced a maize shortage of 53,942 tons. In 1998/99 growing season, Malawi imported about 181,524 tons of maize and planned to import at least 80,000 tons in 2000 (MNEC, 1999). Declining soil fertility coupled with low application of external inputs such as commercial fertilisers, drought and floods are the main reasons behind the low agricultural production in Malawi.

2.2.1 Agricultural support programs

In order to assist boost smallholder production, the government and the donor community embarked on various support programs. For example, the Starter Pack Program is a Malawi Government and Donor Community (British Government, European Union and World Bank) initiative that envisaged free distribution of suitable cereal and legume seeds among farm families in the country. In addition to the free seed, 15kg of fertilizer was also supplied to each farmer for free. The package supplied was estimated to be enough for 0.25 ha of land. In 1998/99 growing season, a total of 2,524,264 farm families benefited from this program. However, this program is now known today as Targeted Input Program (TIP). Thus the targeted clientele is now the very poor farmers and this has significantly reduced the number of potential beneficiaries.

Another support program aiming to boost smallholder farm productivity is the Agricultural Productivity Investment Program (APIP). This program is supported by the European Union. The program provides hybrid maize seed and fertilizer to resource poor farmers. This is achieved through the provision of credit guarantees to private tenders to buy fertilizer and seed to distribute to farmers. In 1998/99 growing season, about 255,200 farmers received farm inputs from this program [MNEC, 1999; 2000].

2.3 Existing Policy Framework

2.3.1 Agricultural pricing policies and land degradation

Government intervention in agricultural markets can have significant impacts on farm-level incentives for soil management (Barrett, 1989). Government regulations, which artificially suppress producer prices, create a disincentive to invest in land husbandry (Repetto, 1988). Domestic agricultural pricing policies that until 1994/1995 biased against smallholder producers can thus partly be blamed for the persistent soil erosion and soil mining common on smallholder land in Malawi. The government through its marketing board, the Agricultural Development Marketing Corporation (ADMARC) charged implicit tax on all smallholder commodities. This provided no incentive to smallholder farmers to make investment on the land that provided for them. It is not surprising therefore, that most of them only produced for subsistence. Liberalization of input and output markets was done simultaneously in 1994/95 under the auspices of the structural adjustment program. The output market liberalization was aimed at altering incentives towards producers with regard to pricing and marketing of outputs. However, the participation of private traders in the produce market has been seriously constrained by limited access to credit and capital. The Agricultural Development and Marketing Corporation (ADMARC[2]) has, therefore, continued not only to be the major buyer of smallholder produce, but also to, influence producer prices as well (Nakhumwa and Hassan, 1999). Even after market liberalization, producer prices for most of the smallholder crops in Malawi are still low due to lack of competition. Private traders

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[2] Agricultural Development and Marketing Corporation (ADMARC), is the government marketing board.

operating in rural areas, unable to bear the losses which ADMARC absorbed, offer producer prices 20-30 per cent below the official floor price, which narrows the profit margin for maize (Carr, 1997). Noteworthy, input market liberalization in 1994/95, therefore complete removal of input subsidies, coincided with the floatation of the local currency (Malawian Kwacha). The sequential devaluation of the Kwacha and the rising fuel prices inflated input prices beyond the means of most smallholder farmers (Ng'ong'ola et al., 1997). The low producer prices offered to smallholder farmers often times do not offset the high cost of production faced by farmers due to the high cost of mineral inputs. Consequently, a lot of smallholder farmers stick to their traditional way of production since modern agriculture, under the prescribed conditions, is not profitable for most of them.

Prices affect farmers' decisions regarding land husbandry in four ways (Barbier and Burgess, 1992b):

- influences the level of agricultural production;
- incentives to invest in future production;
- changes in crop mixes through relative price changes and;
- effects on price variability (to what extent farmers can reliably predict future prices).

However, impact of price change cannot be generalized because of its contradictory effects (Barbier, 1988a). While an increase in the output price creates an incentive for increased soil erosion in the current period (to increase production and profits—Lipton, 1987), the price increase if it is permanent, also increases returns to future production and thus creates an incentive to conserve more soil for future use (Repetto, 1988). By increasing the profitability of agriculture, a price increase will lead farmers to use more inputs and increase agricultural output through intensification or cultivating more land. Using more non-conservation inputs will tend to increase rate of soil erosion, assuming that production increases can only be achieved in the short-term at the expense of increased soil erosion. But the increase in profitability will also create an incentive to conserve soil as an agricultural "input", implying greater soil depth and less soil erosion

(Eaton, 1996). However, smallholder farmers in Malawi are currently faced with exorbitant input prices and low producer price making agriculture unprofitable. In other words, smallholder farmers have no incentives to conserve the soil, the very resource that spells their survival.

Also, changes in agricultural prices will effect land degradation indirectly by altering the crop mix grown by farmers (Barbier and Burgess, 1992b). Certain crops can be characterized as leading to more soil erosion under conventional methods of cultivation than others [Barbier, 1991; Barrett, 1989]. Barbier (1991) examined cropping patterns in Malawi over the period 1969-1988 to see if there is any correlation with observed shifts in relative gross margins. However, the evidence was sparse. Another way in which agriculture pricing can affect land management is through price variability (Barbier and Burgess, 1992b). If relative prices and returns from different cropping systems fluctuate significantly then one might expect farmers, particularly smallholders, to be less likely to switch between systems given the high degree of risk involved. Barbier (1991) examined the variability of non-erosive to erosive crop price ratio in Malawi over the same period and found that farmers face a high degree of price risk "which could have important influence on the incentives for improved land management". Due to the high volatility of agricultural prices, many smallholder farmers in Malawi consider production of maize first (staple food), although it is an erosive crop.

2.3.2 Soil fertility policy

Before independence in 1964, the colonial government in the then Nyasaland (Malawi) put soil conservation and soil fertility high on the agricultural agenda. In many instances coercive methods were used to enforce soil conservation measures among the indigenous people [Wellard, 1996; Mangisoni, 1999]. Immediately after independence, soil conservation was put at the peripheral, as it was associated with colonialism. However, increased attention to soils was evidenced again during the 1980s and early 1990s through the government and donor partnership. Such initiatives, however, did not emphasize on soil fertility *per se*. In 1995, the Ministry of Agriculture and Livestock Development, for the first time, highlighted the need to tackle the land degradation problem (NRI, 1998). The policy objective was stated as "prevention of degradation and restoration of soil fertility". The strategy to attain the policy included the following:

- Developing and promoting economically viable and sustainable farming systems;
- Encourage watershed management as an integral part of targeted intervention for the resource poor;
- Publicizing security and vulnerability of the natural resources.

The government's current agricultural development, environment and poverty alleviation policies address soil fertility degradation as a major issue. The Agricultural and Livestock Development Strategy and Action Plan (ALDSAP) priorities for resource-poor rural households are:

- Restoration and maintenance of soil fertility
- Conservation of natural resources
- Improve food security
- Promotion of income-earning opportunities
- Gender issues to be explicitly incorporated in the development process

The National Environment Action Plan (NEAP) identifies soil erosion as the biggest threat to sustainable agricultural production and as a major source of water resources contamination. Urgent attention is required to arrest soil degradation. In 1996, a Land Use Policy and Management Action Plan was prepared with support from FAO and UNDP but was never implemented. The Government of Malawi commissioned three studies on land use and tenure. The output, is hoped, may lead to policy recommendation for consideration by the Presidential Land Commission of Enquiry.

2.4 Malawi Soil Resource

Soil is a primary natural resource base for agriculture. It has been argued that enhancement of soil productivity is essential to the sustainability of agriculture and to meeting basic food needs of the rising population in Malawi. Bearing in mind the enormous pressure on land due to the rapidly growing population in Malawi and the imbalanced extraction and application of nutrients in the smallholder sub-sector, it is believed that the quality of agricultural land in Malawi is steadily declining.

This section presents the distribution of major soils of Malawi according to ADDs (Map 1). Physical and chemical characteristics of the major soils are also presented to indicate the fertility status of the soils. Map 2 shows the distribution and levels (%) of nitrogen (N), the most important nutrient for crop production in Malawi. Importantly, a trend of Soil Organic Matter (SOM) is established from research data for the 1970s and 1990s. Such trend is worthwhile as it shows what is happening to the nutrient stock of Malawi soils. Declining SOM typically results in soils with lower nutrient holding capacities and lower levels of available plant nutrients. Findings of the SOM trend are augmented by research data on maize response to nitrogen over a period of time. Soil nutrient balances for the major nutrients have also been incorporated to indicate the way the current farming systems are utilizing and managing the soil resource.

2.5 The Major Soils of Malawi

Soils in Malawi are broadly divided in two groups, namely (a) the residual (upland) soils and (b) alluvial soils. Each of these broad groups can be further divided into subgroups. The 13 major subgroups are grouped using the FAO classfication and are spread throughout the country (Figure 5). Some of these soils have been described below.

Ferralsols, also known as Oxisols (soil taxonomy) or Ferrallitic soils (Malawi classification system), are widely prevalent in Malawi and include, Xanthic Ferralsols (orthox in soil taxonomy). These soils are normally deep but others are shallow. Xanthic Ferralsols soils are moderately acidic to acid (pH 5.5-5.7). Both nitrogen (0.05-0.12%) and organic matter (0.4-1.6%) are very low to low. Available phosphorous (P) ranges from trace to medium (0-22ppm) and potassium ranges from low to medium (0.11-0.36 cmols/kg soil). Levels of organic carbon and nitrogen indicate rather poor soil fertility status. The other key elements (P and K) are lacking as well.

However, the most productive upland soils in Malawi are the Ferric Luvisols, commonly known as ferruginous soils or Ferric Rhodustalf (soil taxonomy). These soils have moderate to strong structures and are normally deep except on dissected sites. Ferric luvisols are acidic to almost neutral (pH5.3-6.7), and base saturation is moderate to high (60-90%). The cation exchange capacity (CEC) is low to moderate (5.44-8.5 cmols/kg soil). Organic matter is low to high (0.5-4.5%) while nitrogen is low to medium (0.04-0.2%). Available phosphorous is trace to medium (0-24ppm). Levels of both organic matter and nitrogen content clearly indicate that these are not rich soils.

Prevalent in high rainfall areas of the country are Dystric Nitosols, also known as Paleustult (soil taxonomy) or Ferrisols (Malawi classification). These soils have high CEC and are highly weathered. They are usually very deep soils (>150cm), well drained with dark or red colour and clay texture throughout the profile. For most of the soils in this group, aluminium toxicity is the major limiting factor to sustainable crop production. In such soils, phosphorous is also limiting because either the high aluminium and iron oxides fix P, or P may just be inherently deficient. Most of these soils have low potassium (K), typical examples being Bembeke series, Thyolo, Mulanje, Chikangawa and some parts of Nkhatabay district. Dystric Nitosols are strongly acid (pH 4.3-5.0) and base saturation ranges from very low to low (17-19%). CEC is very low (1.97-2.73 cmols/kg soil). The organic matter is medium to high (1.7-4.6%), and nitrogen ranges from low to high (0.08-0.23%). Available P is low to moderately high (10-33ppm). Potassium, magnesium and calcium are very low. Tables [3a-c and 4] present detailed physical and chemical analyses for major soils in Malawi.

2.5.1 Physical and chemical properties of Malawi soils

Sanchez and Palm (1996) define nutrient capital as the stocks of nitrogen (N), phosphorous (P) and any other essential elements in the soil that become available to plants during a time scale of 5 to 10 years. It is reported that nitrogen and phosphorous, in that order, are the two most limiting nutrients to food production in Africa [Ssali et al., 1986; Woomer and Muchena, 1996; Bekunda et al., 1997]. Physical and chemical properties of the soil, portrays a picture concerning the fertility status of the soils. Nutrient capital may be expressed as kilograms per ha of N or P within the rooting depth of plants.

Using survey data and secondary data, physical and chemical properties of soils for the ADDs (Tables 3a-3c), are reported. All physical and chemical properties of soils at ADD level were based on reports from the department of Land Resources (under Ministry of Agriculture and Livestock Development). Noteworthy, these reports were compiled in 1991 and therefore, caution should be taken when interpreting the results for the ADDs. Since some time has elapsed, it is more likely that the levels of nitrogen and phosphorous could even be lower bearing in mind the following characteristics of smallholder farmers in Malawi: (1) poor use of external inputs such as inorganic or organic fertilizers, coupled with; (2) continuous cultivation of maize on same pieces of land; and (3) low adoption of soil conservation technologies. Figure 6, presents the distribution and levels (%) of nitrogen, a key soil nutrient for crop production in Malawi. Most soils in Malawi have low levels of nitrogen [Figure 6; Table 3a-c] meaning that the soils cannot adequately support crop production without supplementation of key nutrients such as N and P from external sources. More recent data depicting soil physical and chemical characteristics of the soils were calculated using survey data for Nkhatabay and Mangochi districts (Table 4).

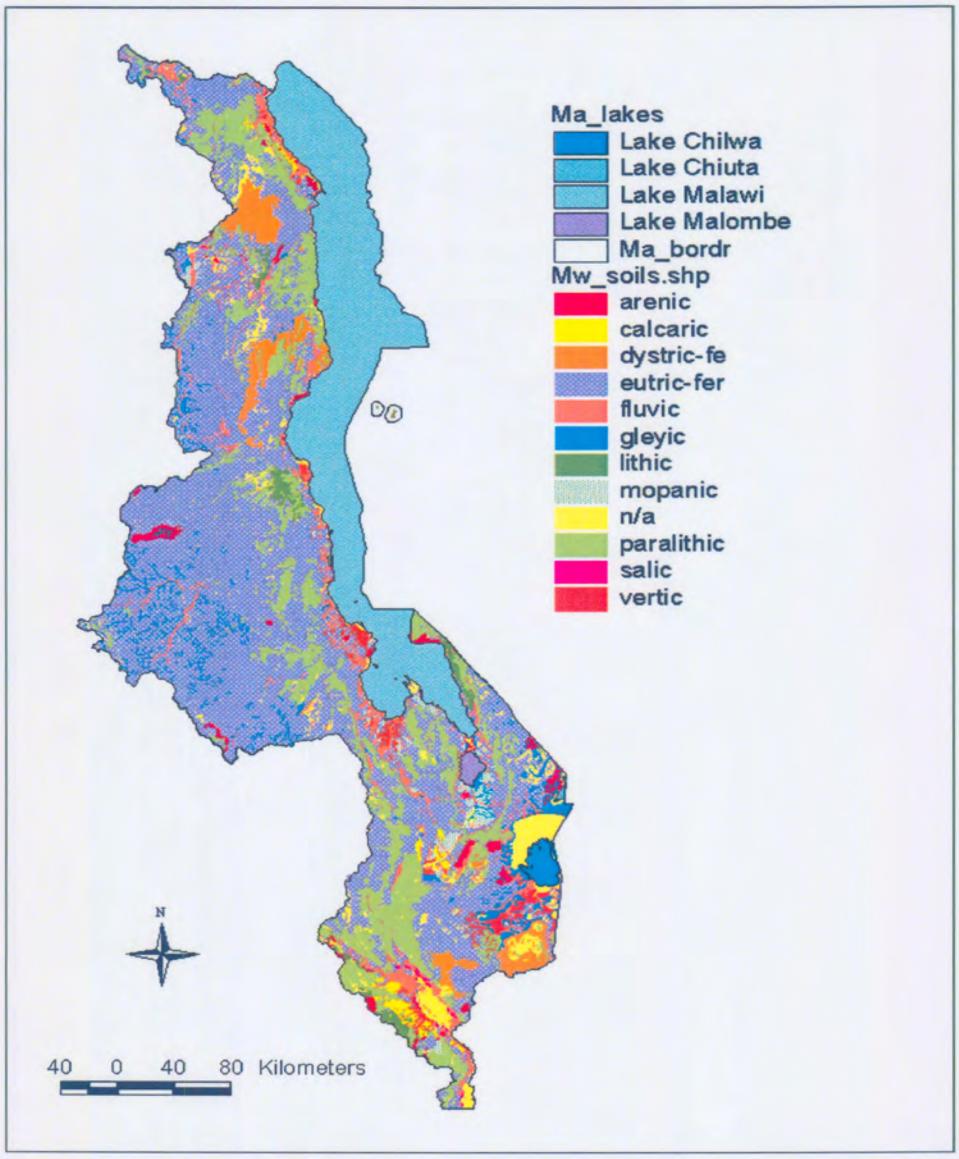

Figure 5: Distribution of Major Soil Groups in Malawi

Source: Mkandawire 2001 (data adapted from dept. of Land Resource, 1991)

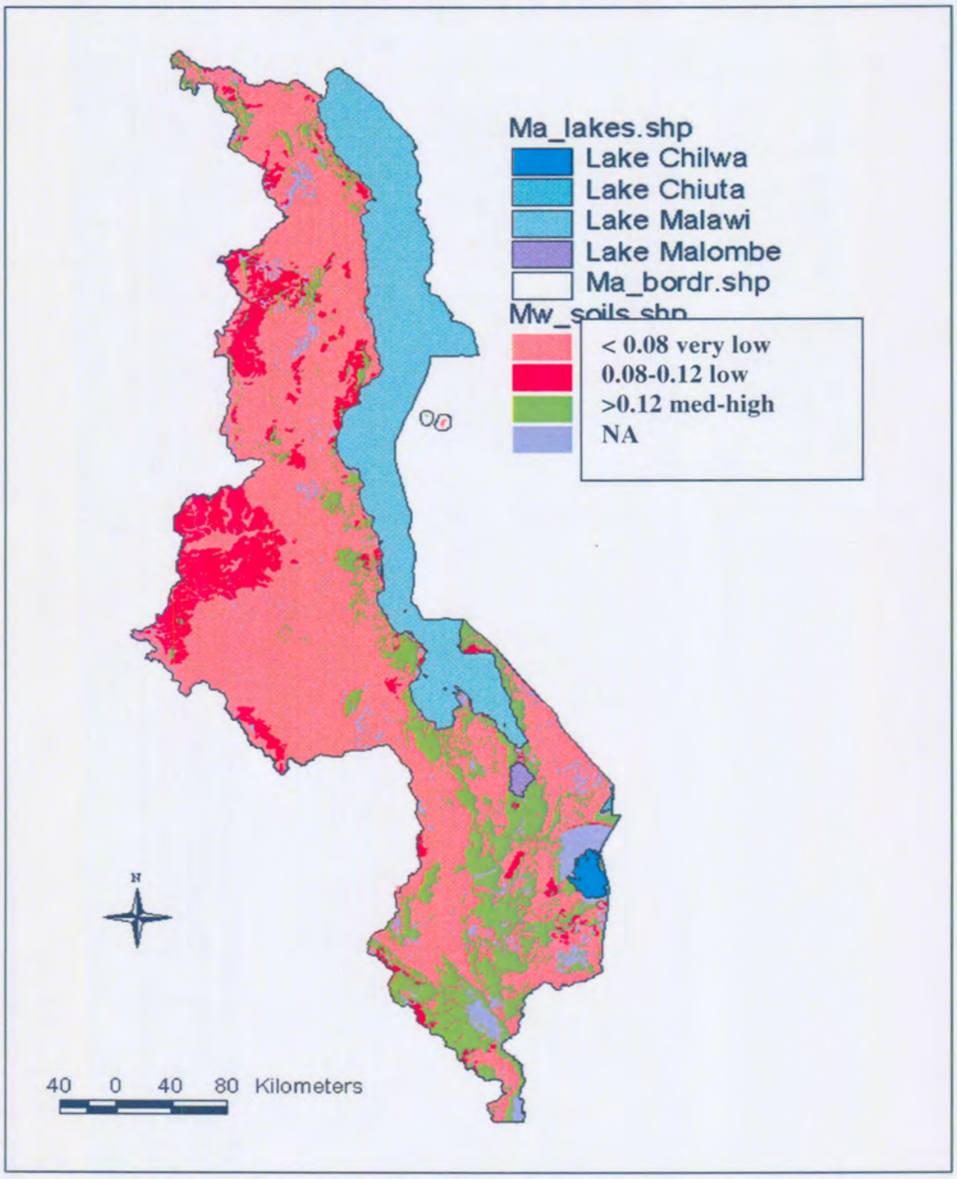

Figure 6: Distribution of Nitrogen (%) in Malawi Soils

Source: Mkandawire 2001 (data adapted from dept. of Land Resource, 1991)

Table 3 (a): Classification, physical and chemical properties of soils in the Northern Region of Malawi

Area ADD	Agro-ecological zone	FAO (1988) soil classfication.	Soil depth (cm)	Particle size (0-30cm)	Soil Chemical Properties (0-50cm)				
					pH	CEC[3]	N%	P (ppm)	K me/100g
KRADD[4]	Karonga (KA) Lakeshore plain	Vertic Cambisols	>150 very deep	Sandy clay to clay	5.5-6.5	>10 med-very high	<0.08 very low	<6 very low	>0.2 med-very high
	KA lakeshore, escarpment east	Haplic luvisol Eutric cambis	>150	Loamy sand to sandloam	5.5-6.5	5-10 low	<0.08 very low	<6 very low	0.1-0.2 low
	KA escarpment (E+C), Kyungu lowlands	Eutric and Haplic phaeozems	50-100 mod. deep	Loam sand to sand clay loam	5.5-7.0	5-10 low	>0.12med-very high	6-18 low	>0.2 med-very high
	KA escarpment, Misuku hills	Haplic lixisols	50-100	Sandy loam to clay	5.5-6.5	5-10 low	0.08-0.12 low	<6 very low	>0.2 med-very high
MZADD	Rumphi,Nkhata Mzimba (N+E):	Haplic lixisols	50-100	Sandy loam to clay	5.5-6.5	5-10 low	0.08-0.12 low	<6 very low	>0.2 med-very high
	Viphya	Haplic lixisols (Eutric Ferralic)	>150	Sandy clay loam to clay	5.0-6.0	5-10 low	<0.08 very low	<6 very low	>0.2 med-very high
	Nyika plateau	Haplic Acrisols	100-150 deep	Sandy clay loam	4.5-5.5	5-10 low	0.08-0.12 low	<6 very low	>0.2 med-very high

Source: MoA (1991)

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[3] CEC=cation exchange capacity; ppm=parts per million; me=milequivalent; P=phosphorous; K= potassium

[4] Karonga Agricultural Development Division (ADD) and Mzuzu ADD

Table 3 (b): Classification, physical and chemical properties of soils in the Central Region of Malawi

Area ADD	Agro-ecological zone	FAO (1988) soil classific.	Soil depth (cm)	Particle size (0-30cm)	Soil Chemical Properties (0-50cm)				
					pH	CEC	N%	P (ppm)	Kme /100g
LADD[5]	Dedza and Ntcheu Escarp	Eutric, Chromic Cambisols	50-100	Loam sand-sandy loam	5.5-6.5	5-10 Low	0.08-0.12 Low	<6 very low	>0.2 med-very high
	Ntcheu+Golomoti foot-slopes	Eutric Fluvisols	>150	Loamy sand to sand clay loam	5.0-6.5	5-10 Low	<0.08 very low	<0.6 very low	>0.2 med-very high
	Dzalanyama hill	Eutric cambisols	100-150	Loamy sand -sand loam	5.5-6.5	5-10 Low	<0.08 very low	<0.6 very low	>0.2med - very high
SLADD[6]	Nkhotakota, Dwangwa lowlands	Haplic & Chromic Luvisols	>150	Sand to sandy loam	5.5-6.5	5-10 low	<0.08 very low	<6 very low	>0.2 med-very high

Source: MoA (1991)

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[5] LADD is Lilongwe Agricultural Development Division

[6] SLADD is Salima Agricultural Development Division

Table 3 (c): Classification, physical and chemical properties of soils in the Southern Region of Malawi

Area ADD	Agro-ecological zone	Soil classification FAO (1988)	Soil depth (cm)	Particle size (0-30cm)	Soil Chemical Properties (0-50cm)				
					pH	CEC	N%	P (ppm)	Kme /100g
MADD[7]	Upper Shire Valley-Machinga	Eutric Fluvisols	>150	Sandy clay loam	5.5-6.5	>10 med-very high	0.08-0.12 low	6-18 low	>0.2 med-very high
	Chilwa and Chiuta lowlands	Eutric Fluvisols	>150	Loamy sand to SCL	5.0-6.5	5-10 low	<0.08 very low	<6 very low	
	Makanjila lakeshore plains	Cambic Arenosols	>150	Sand to loamy sand	6.0-7.0	<5 very low	<0.08 very low	>18 very high	>0.1-0.2 low
NADD	Chikwawa Escarpment	Eutric Cambisols, Haplic phaeozems	50-100	Loamy sand to SCL	5.5-7.0	5-10 low	>0.12 med-very high	6-18 low	>0.2 med-very high
	MidShireValley	Chromic Luvisols Cambisols	100-150	Sandy loam to sand clay	5.5-6.5	5-10 low	<0.08 very low	<6 very low	>0.2 med-very high
	Lower-Shire Mwanza Ftslop	Eutric Fluvisols Cambisols	>150	Loamy sand sandclay lm	5.0-6.5	>10	<0.12	>18	>0.2
	Mwabvi & Lengwe Upland	Eutric Cambisols Haplic Luviso	50-100	Sandy loam	5.5-7.0	>10 med-very high	0.08-0.12 Low	6-18 Low	>0.2 med-very high

Source: MoA (1991)

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[7] MADD is Machinga Agricultural Development Division, and Ngabu ADD

Table 4: Soil physical and chemical characteristics and fertility rating of the study areas (Nkhatabay and Mangochi Districts)

Soil origin	Crop trial	Depth	pH (H_2O	Soil pH rating	Sand %	Silt %	Clay %	Text Class	OM %	N %	Rating of N (Fertility)
Nkhatabay	Maize	0-20	5.0	Moderately acid	43	13	44	SC	0.52	0.03	Very low
		20-40	4.5	Acid	20	10	70	C	0.62	0.03	Very low
	Tobacco	0-20	4.9	Acid	37	7	57	C	0.58	0.03	Very low
		20-40	4.5	Acid	20	10	70	C	0.38	0.02	Very low
	Cassava	0-20	5.4	Moderately acid	7	27	67	C	0.89	0.04	Very low
		20-40	5.7	Slightly acid	7	7	87	C	0.65	0.03	Very low
	Control	0-20	4.6	Acid	33	20	47	C	0.84	0.04	Very low
		20-40	5.0	Moderately acid	17	10	73	C	0.41	0.02	Very low
Mangochi	Maize	0-20	6.1	Almost neutral	53	20	27	SCL	0.96	0.05	Very low
		20-40	6.1	Almost neutral	40	23	37	CL	1.82	0.09	Low
	Tobacco	0-20	5.7	Slightly acid	40	23	37	CL	1.13	0.06	Very low
		20-40	6.0	Almost neutral	30	23	47	C	1.62	0.08	Low
	Tobacco/ maize	0-20	5.5	Slightly acid	40	23	37	CL	0.89	0.04	Very low
		20-40	5.9	Slightly acid	40	13	47	C	1.24	0. 06	Very low
	Control	0-20	5.8	Slightly acid	33	23	43	C	1.72	0.09	Low
		20-40	6.0	Almost neutral	50	20	30	SCL	1.17	0.06	Very low

Survey data (2001). OM=organic matter

2.6 Soil Nutrient Balances

Soil fertility is not static. On the contrary, it changes constantly and its direction (accumulation or depletion) is determined by the interplay between physical, chemical, biological, and anthropogenic processes. This dynamism is also reflected in terminology such as nutrient cycles, budgets, or balances, referring to inputs and outputs in natural ecosystems and managed agro-ecosystems, to which nutrients are added and from which nutrients are removed (IFDC, 1999). As the world population keeps growing, balanced ecosystems are on the decrease and nutrient ledges all over the world have become increasingly imbalanced (Smaling et al, 1997). Malawi faced with one of the fastest population growth rate in SSA on one hand, and constrained by limited suitable arable land for agriculture on the other hand, is not exceptional to this predicament. Calculation of nutrient balances for Malawi is highly desirable. However, such literature for Malawi is not locally available. Hence this study relies mainly on the work done by IFDC (1999). In order to show what is happening to the soil nutrient resource in Malawi, the following sections present the nutrient balances based on the current levels of cropping and soil management, trend of the soil organic matter between the 1970s and 1990s and, maize response to nutrient *inter alia.*

Good soil management is crucial for maintaining and improving soil productivity in Malawi. In order to have a clear picture of what is happening to the physical accounts of the soil resource, calculation of nutrient balances becomes important (Smaling et al, 1997). Estimates of current rate of soil nutrient depletion are important in order to present a case whether indeed nutrient mining is a major contributor to land degradation in Malawi and therefore, a constraint to the sustainable intensification of agriculture production. Estimates of the amounts of nutrient depletion are provided as useful indicators for the design of soil and fertilizer management strategies that can be adopted to prevent land degradation and increase production. Estimates of nutrient depletion are analysed in the context of prevalent circumstances such as current levels of crop production, inherent soil fertility conditions and resilience (or fragility) of the soils, biophysical and agro-ecological environment and population density (IFCD,1999) (see Figure 7).

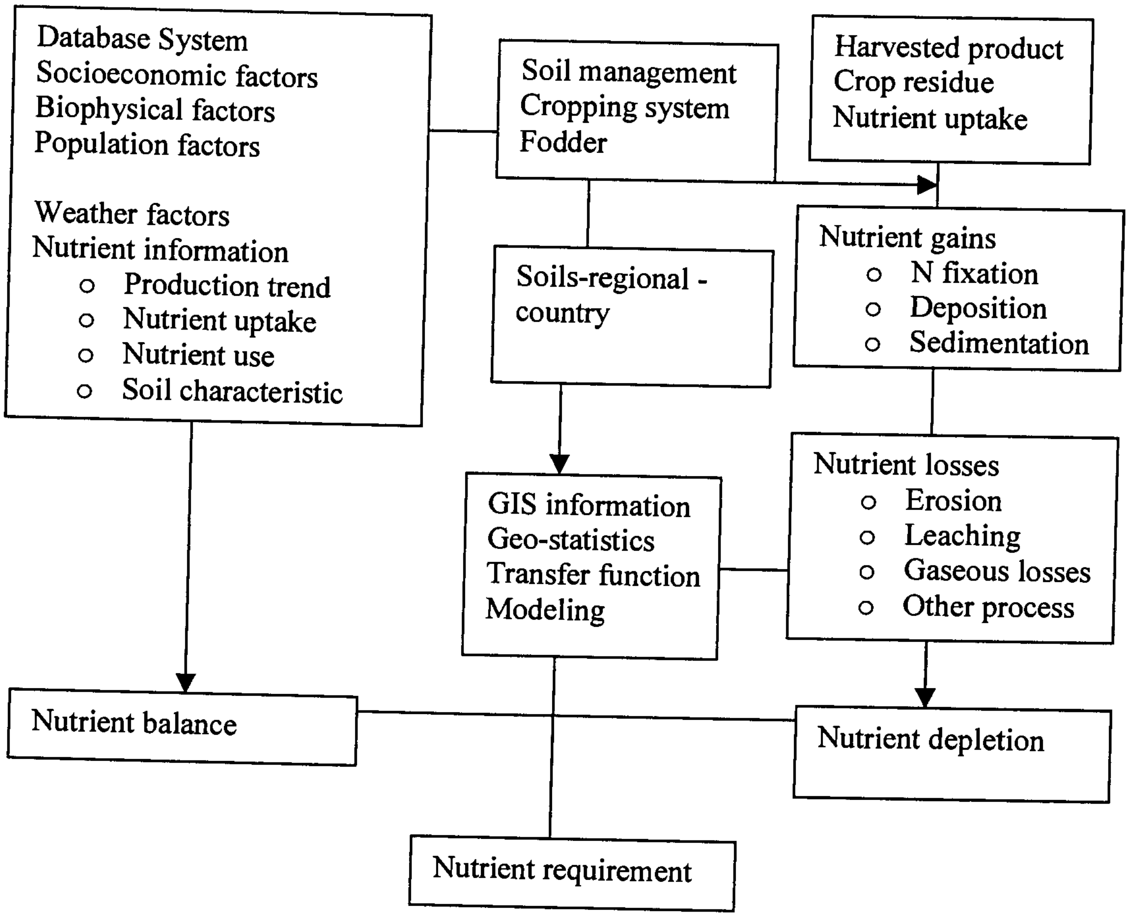

Figure 7: Geo-referenced System to Estimate Nutrient Depletion and Requirements

Source: (IFDC 1999).

Table (5) shows the analysis of crop production and nutrient depletion estimates for the period 1993 to 1995 (IFDC 1999). There is a clear indication from Table (5) that soils in Malawi are losing large amounts of nutrients per year. Soil erosion and nutrient mining are blamed for much of the soil nutrient loss. A number of useful observations can be drawn from the nutrient balance and depletion estimates. Lack of application of required nutrients (NPK) is causing soil nutrient depletion and subsequent reduction of agricultural productivity.

Soil erosion, which is extremely high for Malawi, about 20tons/ha/year, is more likely to degrade soil quality further in the absence of soil conservation policies and if low adoption of soil conservation technologies among smallholder farmers persist. Low application of external inputs means that more nutrients are extracted from the soil than are replaced through external sources, hence soils in Malawi will become more and more unproductive. Since the country's economy is heavily dependent on agriculture, loss of soil productivity has significantly high cost on the well being of the population.

Table 5: Annual Nutrient Balance in Malawi (1993-1995)

	Area ('000ha)	NPK	N	P_2O_5	K_2O	NPK
	2,029	('000mt)	----------------(kg/ha)------------------------			
Annual nutrient requirement		263.8	38.9	37.0	54.1	130.0
Annual nutrient consumption		61.4	18.9	8.4	3.0	30.0
Nutrient balances		-220.8	-47.5	-16.0	-45.3	-108.8

Source: IFDC (1999)

2.6.1 Trend in Soil Organic Matter (SOM) Levels

Build up and maintenance of Soil Organic Matter (SOM) is an important source of fertility particularly when focusing on longer-term interventions. Declining SOM typically results in soils with lower nutrient holding capacities and lower levels of available plant nutrients (Giller et al., 1997). There is much anecdotal evidence that SOM levels in Malawi have declined. Benson (1998) reviewed data sets of Organic Carbon[8] analyses of soil samples collected under two separate programs. The first soil samples were from the Mass Soil Analysis Program carried out by the Soil Fertility Unit at Chitedze Research Station in the 1970s. The second data source was the nation-wide soil sampling exercise carried out in the

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[8] There is direct relationship between the Organic Carbon content of the soil and the Soil Organic Matter (SOM) content--the per cent of SOM is typically calculated as being 1.75 times the per cent Organic Carbon content.

early 1990s by the extension staff in each ADD. Comparable data sets from both programs could only be compiled for Blantyre, Kasungu, and Lilongwe ADDs. Table (6), provides evidence that SOM has been declining. Except for Blantyre, there is significant difference in the mean organic carbon for the two periods. Consequently, soil nutrients stock has been declining. This reinforces the findings according to calculations of nutrient balances indicating that at current cropping levels and management, soil nutrients are being depleted enormously (Table 5). Without additions of nutrients from external sources, it means productivity of the soils is rapidly declining.

Table 6: Trend in Organic Carbon Levels Between 1970 and 1990s

	BLADD		KADD		LADD	
	1970s	1990s	1970s	1990s	1970s	1990s
Mean Organic Carbon (%)	1.38	1.24	2.05	1.75	2.29	1.58
Signifcance of t-test comparing difference of means	0.096		<0.001		<0.001	
Sample % characterised as sandy (S or LS)	11	-	37	24	93	31
Sample % characterised as Loam (SCL or SL)	68	-	56	76	4	68

Source: Benson (1997), adapted from Hardy (1998)

Further evidence of declining soil fertility in Malawi is demonstrated using data from on-farm nutrient trials for the period 1972 and 1996 (Figure 8). Maize was cultivated continuously without any application of nutrient from external sources such as commercial fertilizers. The graph indicates a declining trend of maize yield over time. The yield decline has mainly been associated with deteriorating resource base (declining soil fertility). However, yield levels of smallholder farmers are usually lower than those of research stations. It is argued that effects of declining soil fertility on productivity will also obscure any potential gains from maize breeding (Hardy, 1998). Declining maize yield trend depicted in Figure 8 closely resemble yield trends of most of the smallholder farmers in Malawi for the fact that most of them also continuously cultivate maize crop on the same piece of land without any application of external inputs to replenish the soils.

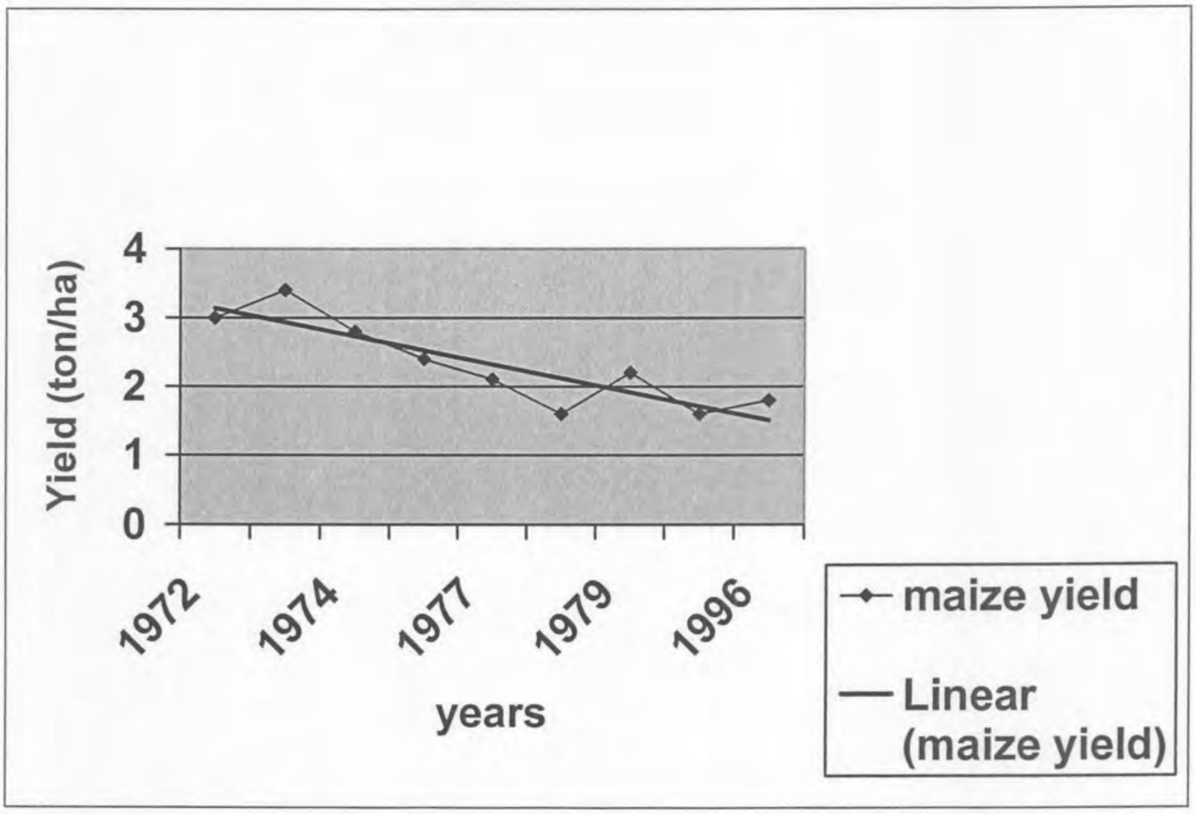

Figure 8: Mean maize yield/ha with no input application: Nutrient response research trials in Malawi.

Source: Data adapted from Benson (1998)

2.7 Concluding summary

Most of the arable farming in Malawi is done on Luvisols (Alfisols; Ferruginous soils), Ferralsols (Oxisols, Ferrallitic soils) and acrisols (Ultisols; Ferrallic soils). Among the soil physical properties, soil structure and effective depth are the most important for agriculture. Most of the soils in Malawi have deep effective depth. Of the upland soils, the Luvisols have good soil structure that is quite stable under proper cultural practices. However, under unimproved agriculture, continuous use of the soil, as is the case under smallholder farming, is bound to destroy the soil structure. Noteworthy, most soils in Malawi are of poor quality as evidenced by low levels of nitrogen and phosphorous, key elements for crop production in Malawi [Tables 3(a-c) and (4)].

Nutrient balances indicate a negative balance, meaning that the current farming system is depleting the soil resource stock. Soil erosion and crop harvesting coupled with unbalanced nutrient application are the major causes of the soil quality depletion. Declining soil organic matter as calculated for the period between 1970 and 1990, confirms that nutrient stock is being depleted. Declining soil productivity as evidenced by continued reduction in maize yield over the years, is consequent to the depleting soil nutrient stock. Therefore, food insecurity among smallholder farmers will continue to worsen until there is a reversal to the current trend of land degradation.

CHAPTER III

MEASURING THE ECONOMIC IMPACTS OF SOIL DEGRADATION: Survey of the Literature

3.1 Introduction

Considering the important role of soil conservation techniques to the curtailment of soil erosion among the smallholder farmers in Malawi, the previous chapter dwelt on the analysis of factors that influence the incidence and extent of adoption amongst this category of farmers. However, the severity of soil degradation in Malawi can be much appreciated at both farm and policy levels if the true economic costs due to this problem are properly analysed. Hence, measuring the economic impacts of soil degradation, in particular soil mining and soil erosion, is the major thrust of this study. This chapter briefly reviews soil fertility and the soil degradation problems in Malawi. Models that predict soil erosion are also discussed. A discussion on linking land degradation and crop productivity is thoroughly presented. Finally, a detailed review of some approaches that have been used to measure the economic impacts of land degradation is also presented.

3.2 Soil Fertility and Soil Degradation

Soil fertility is a function of many physical, chemical and biological properties that, together with climate and other factors, determine the suitability and potential productivity of land for agricultural uses. The essential attributes of natural fertility include soil structure and rooting depth, organic matter and trace nutrient content, plant-available water reserves and soil biology (Lal, et al., 1989). Soil degradation can be described as a process by which one or more of the potential ecological functions of the soil are harmed. These functions relate to biomass production (nutrient, air, water supply and root support for plants) filtering, buffering, storage and transformation (e.g., water, nutrients and pollutants), and to biological habitat and gene reserves. Since total land area is fixed, using the land for agricultural production does not exhaust the physical land area but rather exhaust the quality of topsoil especially when agricultural production is coupled with imbalanced application of external inputs such as commercial fertilizers and manure. Also, erosion depletes land quality factor: depth of the topsoil and hence a loss of all essential nutrients and organic matter that support agricultural production. As a result yield drops or the same output levels are attained at higher costs (through extensive use of external inputs such as fertilizer). Soil degradation is therefore a process that lowers the current and /or future capacity of the soil to produce goods and services. Two categories of soil degradation processes are identified, displacement of soil material (e.g., soil erosion by water or wind forces) and in-situ soil deterioration covering chemical (loss of nutrients, salinization, acidification, pollution) or physical (soil compaction, water logging) soil degradation.

Soil degradation in Malawi is mainly due to water induced soil erosion (loss of topsoil) and loss of nutrients through crop harvest coupled with inadequate and imbalanced fertilizer application. Loss of topsoil results in soil nutrient loss but importantly also, destruction of soil physical structure. Soil degradation can be either the result of natural hazards, or of unsuitable land use and inappropriate land management practices. Unbalanced fertilizer use, deforestation of fragile lands, lack of soil conservation, and overgrazing are some of the human activities causing soil degradation in many parts of the world especially in developing countries. In measuring the economic costs of soil erosion and soil mining, we will confine ourselves to the impact of current smallholder soil and crop management systems on soil quality over time.

3.2.1 Causes of soil degradation

Evidence of exhaustion of arable land under agriculture is found throughout history and in all parts of the world (Brown 1981; Stocking 1984). Most soil degradation is related to effects of farming, though some may be due to long term climatic trends. A number of explanations have been offered as causes of soil degradation, which include population pressure, poverty and sheer ignorance. Whatever the underlying socio-economic cause of soil degradation, from an economic perspective, the effect is the same, that farmers behave as if they value short-term profits obtained from activities which degrade the soil more highly than they value the benefits of soil conservation (Bishop, 1992).

One of the most highly invoked explanations for land degradation in developing countries is high rate of population growth, leading to demographic pressure on land resources. In Malawi, it is reported that high population has put much pressure on the agricultural land resulting in small land sizes per household (World Bank, 1987). However, studies from around the world have failed to establish a direct causal link between population growth and degradation of soil and other renewable resources (Guizlo and Wallace 1994). Nevertheless, evidence from other studies explains why farmers may not choose an economically optimal rate of soil degradation (Bishop, 1992). The widespread prevalence of market, policy and institutional failures means that farmers do not always take into account the full costs of soil degradation to society. Such failures distort economic incentives, leading farmers to deplete soil assets at economically sub-optimal or inefficient rate, which may be too fast or too slow compared to socially optimal rates of soil exploitation. According to Bishop (1992), the underlying causes of inefficient land use are:

- the presence of non-marketed and uncompensated external impacts;
- high rates of time preference that diminish the present value of future yield losses;
- the availability of technical substitutes for natural soil fertility and alternative assets;
- inappropriate policy incentives that advertently discourage soil conservation; and
- technical and economic constraints that prevent farmers from adopting soil conservation practices.

A brief discussion of these factors is given below:

3.2.1.1 External impacts

External impacts or externalities are any costs or benefits that are not reflected in the market prices causing a divergence between private and social costs and benefits of actions of economic agents. For example, a typical negative externality resulting from soil erosion on agricultural land is the sedimentation of downstream reservoirs while protection of watershed provided by trees is a positive externality. Such off-site costs and benefits are not reflected in the prices of agricultural outputs and hence are not taken into account in decision-making. However, these represent real costs and benefits felt by other economic agents downstream.

Such externalities are not only difficult to measure in most cases, but also are rarely documented or understood.

3.2.1.2 Time preference

Time preference refers to the simple fact that most people prefer current income to future income. Pure time preference and marginal opportunity cost of capital are reflected in the discount rate, which is commonly used to compare present and future costs and benefits. Private individuals are often presumed to have high degree of time preference (impatient), thus employ higher discount rates, on average, compared to society as a whole. The reason is that society lives forever and that also, society can diversify investment to effectively minimize risk. This divergence between public and private rates of time preference leads individuals to discount future benefits excessively and thus to consume assets that society as a whole would have rather conserved (Markandya and Pearce, 1988). This leads to higher private than social optimal rates of consumption.

3.2.1.3 Substitutes

Technical innovation is largely devoted to devising substitutes for, or increasing the productivity of scarce factors. The depletion of scarce natural resources poses a threat when it is considered essential to future economic opportunities i.e., if there is no apparent substitute for the resource, if degradation is irreversible and/or if its future value is uncertain but believed to be high (Pearce et al., 1990). Natural resources may seem less essential in the industrialized nations, where fertilizer, irrigation and other technical inputs offer farmers some considerable flexibility, and where alternative economic opportunities are more widely available (Bishop, 1992).

3.2.1.4 Policy incentives

Most countries have instituted a host of policies affecting agriculture, including measures that stimulate production, and others which dampen output. Many of these schemes have significant impacts on land use and soil conservation practices, because of the way they modify relative returns to certain crops and relative costs of inputs or methods of cultivation. Policies may aggravate the problem of excessive soil degradation, or alleviate it. Changes in land use patterns can arise directly and intentionally, through policies affecting the price of farmland or incentives for conservation (e.g., land taxes or subsidies).

3.3 The Relationship Between Soil Properties and Productivity

Although erosion is considered the major agent of soil degradation worldwide [Dudal, 1982; Lal, 1990; Larson et al., 1983], the large-scale effects of erosion on productivity of soils are not yet well known. Quantifying the impact of soil erosion on crop productivity has not been easy because of the complexity of crop response to soil erosion (Pierce and Lal, 1994). The productive capacity of a given soil varies spatially due to variations in soil properties, climate, management, and plant genetics (Daniels and Bubenzer, 1990). Relating soil properties to yield is confounded by the fact that as management input increases or as agriculture becomes technologically advanced, the relative contribution of soil to crop yield diminishes (Pierce and Lal, 1994). Managed inputs can often mask soil erosion damage but to what extent inputs can compensate for soil erosion damage needs further investigation. However, considerable efforts have been directed toward quantifying the relationship between soil properties and crop productivity [Kang and Osimane, 1979; Huddleston 1984; Kayombo and Lal, 1986; Pierce 1990; Aune and Lal, 1995]. In fact, Lal (1984) summarized some of the traditional approaches used to measure the impact of soil erosion on productivity (Table 7). However, relating changes in soil properties induced by soil erosion (real, perceived, or simulated) to crop yield has been a common method for assessing erosion's impact on productivity [Cassel and Fryrear, 1990; Lal 1987; Pierce, 1990; Stocking, 1984]. Pierce (1990) came up with some general conclusions drawn from 50 years of soil erosion and productivity research in the United States (Table 8). Although complex, it is nonetheless important to assess soil erosion's impact on crop productivity in order to plan for agricultural development, to assess the adequacy of food resources for the world's population, and to evaluate agricultural policies at local, regional and national levels (Wolman, 1985). Knowledge of how soil erosion affects productivity is key to developing practices and policies for the restoration of eroded soils.

Table 7: Traditional research approaches used to evaluate erosion's impact on crop productivity.

Method	Description	Comment
Artificial soil removal	manual removal of soil surface to different depths	erosion is selective: does not simulate natural condition
Greenhouse	comparative productivity evaluation under greenhouse conditions for surface vs. subsoil horizons	provides information on fertility but cannot simulate soil structure in field; should be validated under field conditions
Long-term variable management	long-term field trials comparing different soil surface management or cropping systems	difficult to separate management effects from erosion effects
relating soil properties to crop yield	relating erosion-induced alterations in soil properties to crop yields	alterations in soil properties can be caused by intensive cultivation
Topsoil depth/crop yield	relate crop yields to remaining depth of topsoil	natural pedogenic factors can produce differential topsoil thickness in landscape
Reconnaissance survey	relate crop performance and yield to qualitative assessment of past soil erosion (e.g., soil erosion class)	assessments are subjective ;degree of past erosion difficult to quantify
Erosion simulation	rain and wind simulators used to accelerate rate of soil removal	does not address long term soil changes; equipment expensive
Modelling	prediction of erosion's impact on soil properties and productivity	existing models poorly validated in field

Adopted from Pierce and Lal (1994)

Table 8:General conclusions drawn from 50 years of erosion and productivity research in the United States

- yield levels of many of these studies were low relative to present production levels and study durations were for few years only
- management inputs were sufficient to restore production to levels of undisturbed soils and that the degree to which that was possible was related to the characteristics of sub-soils
- under limited or no fertiliser amendments, yields were often highly related to depth of topsoil
- there is a relationship between crop yield and soil depth
- the ability to find uneroded sites is uncertain and limits assessment of past erosion
- other effects of erosion have been largely ignored
- the effects of erosion on soil productivity are hard to visualise. They are long-term and, at least temporarily, often masked by technology.
- the spatial relationship and variability of soils within the landscape have generally been ignored in soil erosion studies

Source: Pierce (1990)

In modelling soil erosion and productivity loss, soil properties such as soil organic carbon (SOC), acidity (pH and Al saturation), nitrogen, available phosphorous (P), exchangeable potassium (K), soil bulk density, rooting depth, and weed infestation have been chosen because of their importance in determining productivity of Oxisols, Ultisols, and Alfisols, which are the common soil groups in the tropics (Stewart et al., 1991). One major shortfall of many models linking soil erosion to productivity losses is that they are usually site-specific [Pierce and Lal, 1994; Aune and Lal, 1995]. However, there is no prescription for what comprises an appropriate model (Pierce and Lal, 1995). Stocking (1984) suggested that an appropriate or effective model should have (a) readily available inputs, (b) an output that can link directly to economic or conservation planning decisions, (c) physical/ mathematical expressions to link the steps connecting erosion to yield losses/fertility decline/productivity. A brief explanation of some soil properties that influence productivity is given below.

Nutrient availability

Nutrient availability is an important soil property for productivity and is significantly altered by soil erosion (Pierce and Lal, 1994). Erosion induced changes in the nutrient supplying capacity of soils can be significant. Nitrogen (N) is one of the most important soil nutrients influencing maize production in SSA. However, soil N is a highly labile property and no single soil analysis is adequate to predict its supply to crop over the growing season. For this reason, the effect of N on crop productivity should not be calculated using soil analysis but rather be base on long-term data of crop response to N-fertiliser (Aune and Lal, 1995). Other critical nutrients in the tropics are phosphorous and potassium.

Rooting depth

Rooting depth is an important physical factor in soil productivity because it determines soil reserves of water and nutrients (Aune and Lal, 1995). Other than subsoil acidity, poor soil aeration and presence of hardpans, accelerated soil erosion reduces rooting depth. Admittedly, there is no direct method for measuring the effect of rooting depth on productivity. However, experimental data available from studies designed to evaluate the effects of factors limiting rooting depth are useful in establishing the functional relationship. These experiments include sub-liming, sub-tillage, and soil surface removal studies. Noteworthy, the critical value of rooting depth for maize is 23cm. Mean water holding capacity of soils in the tropics is about 1.3mm /cm soil (Lal, 1987). This implies that soil depth of 23 cm has an available soil water holding capacity of 30 mm (Aune and Lal, 1995).

Bulk density

Bulk density is an important soil physical property because it influences crop productivity in the tropics (Stewart et. al., 1991). It affects water infiltration, root growth and uptake of nutrients and water (Babolola and Lal, 1977).

3.4 Predicting Soil Erosion Impact on Productivity

While there is agreement on the need for predictive capabilities, there is no consensus on which of the varied approaches used to predict soil erosion's impact on productivity is most appropriate (Pierce and Lal, 1995). There are two basic approaches to developing predictions: statistical models and biophysical simulation models. Cassel and Fryrear (1990) cite three classes of statistical models:

- regression models in which crop yields are regressed against one or more variables including soil properties, landscape characteristics, and climate variables;
- multivariate and factor analyses, which use data transformation within multivariate data sets. These often delineate cause and effect relationships not detectable with other statistical techniques and identify soil properties significant in defining crop productivity (Bruce et al., 1989);
- geostatistical models, which analyse the variance structure of spatially distributed data (soil properties and erosion processes) and use the knowledge of spatial variation to predict the areal distribution of properties.

Multiple regression models are the most commonly used, particularly in developing countries, to relate measured soil properties to crop yield for specific environment and cultural conditions (Pierce et al., 1983). The Universal Soil Loss Equation (USLE) and SLEMSA are examples of regression type parametric models that have been used widely to predict long-term erosion impacts on soil productivity [Pierce et al., 1983; Kiniry et al., 1983; Stockings 1986; Arens 1989; Bishop 1992; Brekke et al., 1999]. This section gives a thorough review of both the empirical statistical models and the biophysical simulation models.

3.4.1 Empirical models for predicting impact of soil erosion

Erosion research as known today started in the United States of America (USA) in 1917 and the first model for predicting soil erosion was proposed by Baver in 1933 (Lal, 1990). However, the Universal Soil Loss Equation (USLE) [Wischmeier and Smith, 1978] and Productivity Index (Kiniry et al., 1983) are examples of regression type parametric models that have been used widely to predict long-term erosion impacts on soil productivity [Pierce et al., 1983; 1984]. The USLE is a deterministic (or an empirical) method for estimating average soil loss in tons per hectare as a function of five composite variables: rainfall erosivity index, the inherent susceptibility of the soil to erosion by water, a combined slope length and steepness factor, crop cover and management, and a correction factor for 'supplemental' conservation practices. Although USLE is one of the most extensively used erosion predictive models in the USA and other parts of the world [Lal, 1990; Morgan, 1988; Foster et al., 1982a; Williams, 1981; 1975; Onstad and Foster, 1975], it has some major shortfalls. Among the major shortcomings of the USLE are the following:

- its failure to account for re-deposition;
- the model is designed to predict soil loss from small plots and, therefore, extrapolation to national level attracts a lot of errors and limits the reliability of the results;
- use of USLE in regions with conditions different from those where it was developed (USA) encounters problems limiting its prediction power [Elwell, 1978a,b; Foster et al., 1982b; Wendelaar, 1978; Wischmeier, 1976].

Accordingly, some researchers have disputed the predictive ability of this model under tropical conditions (Stockings, 1987). Some improvements to the USLE have been made to come up with a revised Universal Soil Loss Equation (RUSLE). Integrated changes included seasonal variation in soil erodibility, new methods of calculating cover management factors, new conservation practice values, rainfall runoff erosivity for western rangelands, and computerisation of the algorithms. RUSLE is also capable of accounting for rock fragments in and on the soil. However, an important limitation in both the USLE and RUSLE is that they do not explicitly represent fundamental hydrologic and erosion processes (Renard et al., 1991). Most importantly, in order to use either model outside the USA, it requires that the models be calibrated to local conditions.

Elwell and Stocking (1982) developed an alternative model for Southern Africa. The Soil Loss Equation for Southern Africa (SLEMSA), was designed for use in countries with limited capacity to generate the physical data required by USLE and other models. Unlike USLE, SLEMSA only requires three input parameters: the rainfall energy interception of each crop, the mean soil loss on bare fallow plot of known slopes and a topographic factor for other slopes. Malawi and Zimbabwe share common climatic and soil conditions. As such, the parameters for Zimbabwe would be applicable for Malawi.

A modified version of SLEMSA was developed for reconnaissance level evaluation of erosion hazard (Stockings et. al., 1988). The methodology was designed to make relative assessment of the risk of erosion over large areas, expressed in Erosion Hazard Units (EHU). The latter model uses precipitation data to estimate rainfall energy, which is combined with an index of soil erodability to calculate an erosion index (I_b). The protection provided by vegetal cover is also incorporated, along with average slope.

3.4.2 Simulation models for predicting impact of soil erosion

Erosion prediction is moving away from empirical models like USLE to physically based erosion prediction models in order to describe more accurately the various erosion processes and thereby improve prediction of soil erosion. Simulation models have become important. Since1980s alternative approaches to measure soil erosion impact on crop productivity have involved the use of biophysical simulation models. This approach relies on computerized mathematical models of physical and biological processes linked together in a central system. Some of these models focus heavily on the physical processes of soil erosion and/or sediment movement. Other models focus on the physiological development of a specific crop. The Erosion Productivity-Impact Calculator (EPIC) was the first simulation model developed for the sole purpose of simulating erosion's impacts on crop productivity (Williams et al., 1984). Developed in the mid-1980s, the model has been widely used to assess soil erosion and crop productivity on virtually every continent in the world [Grohs, 1994; Barbier, 1996]. Because soil degradation can take many decades to impact on crop productivity, the EPIC model was originally designed to achieve the following four goals:

- ❖ develop a realistic physically based erosion prediction model with readily available inputs;
- ❖ include the capability of simulating processes over long time horizons;
- ❖ produce valid results over a wide range of soils, crops, and climates;
- ❖ provide a model that is computationally efficient.

The physical components of EPIC include weather simulation, surface and subsurface hydrology, erosion process, nutrient cycling, plant growth, tillage and management and soil temperature. The model is characterized as a lumped parameter model because the drainage area considered, usually around one hectare, is assumed to be spatially homogeneous. The model is designed to consider vertical variation in soil properties associated with different soil types and conditions (Lal, 1997).

Another important model that has been used to assess erosion's impact on productivity is the Nitrogen-Tillage-Residue Management (NTRM). NTRM model was developed by Shaffer et al. (1983) to evaluate the effects of soil, climatic and crop factors that limit crop yield through soil erosion. This model is especially useful for identifying management alternatives to alleviate erosion-caused constraints to crop yields. In general, if a crop model effectively describes the important soil-related processes that regulate crop production, then a crop model, along with information about the rates of soil erosion and their effect on soil properties, will allow prediction of erosion's effect on productivity.

Other simulation models include the Productivity Index (PI) developed by Pierce et al. (1983). Pierce et al. (1984) used PI to predict the long-term erosion impacts on soil productivity for soils in the Corn Belt regions of the U.S.A. This model is based on assumption that reduction in potential crop yield by erosion is due to adverse changes in soil profile characteristics to 1-m depth. Soil properties considered include pH, available water capacity, soil bulk density, and soil organic carbon content. However, extensive validation is desired for this model under diverse soil profile characteristics, plant rooting depth, and climatic conditions.

Although biophysical simulation models, such as EPIC, have proved to be valuable research tools for assessing the potential impact of soil erosion and management practices on crop productivity, they are not substitutes for agronomic research. The reliability of the results of simulation models depends on the accuracy and availability of the input data, validity of the assumptions, and application of the model within the boundary conditions in which it was developed (Pierce and Lal, 1994). Most simulation models generally demand substantial data. Most developing countries in SSA, such as Malawi, do not have detailed databases. In addition, some of these models have not been adequately validated using scientifically defensible data (Cassel and Fryear, 1990). According to Pierce (1990), the whole process of quantifying and predicting erosion's impact on crop productivity requires:

- a clear identification of soil properties that regulate crop productivity;
- a coordinated monitoring program that quantifies the rate and extent of erosion induced change in soil quality, erosion damage to crops, and indirect effects on crop productivity discussed earlier;
- a coordinated research program designed to support and/or validate the models; and
- a standardization of field and laboratory methodologies that would allow the establishment of minimum data sets for evaluating erosion effects on soil productivity, regionally or even globally.

3.5 Approaches to Measuring the Economic Costs of Land Degradation

Implicit in the concept of land degradation (soil erosion and soil mining) is the notion that agricultural land use removes some useful nutrients from the land bringing about deterioration in its quality and reducing its productivity. Models for predicting soil land degradation's physical impact on crop yields have been discussed in the previous section. However, physical impacts of land degradation on crop yield entail economic costs. The economic costs of soil erosion are usually separated into two, on-site and off-site costs. On-site refers to the direct effects of soil degradation on the quality of land resource itself, often expressed in terms of reduced agricultural productivity. Off-site costs refer to the indirect effects of soil degradation, which take the form of externalities such as siltation. These downstream damages impose costs on the other members of society not directly involved in causing the erosion.

Most economic analysis of soil erosion has been carried out in the US, where since the 1970s the issue has received much public attention (Ervin and Ervin, 1982). Earlier work on this subject mainly concentrated on conservation and adoption. Dating back to the late 1950s, literature in this area ascribes a key role to institutional factors, information and attitudes (Ciriacy-Wantrup, 1952). Researchers emphasized the need to solicit farmers' perceptions and monitor their decisions (Ervin, 1982). However, since the 1970s, more formal modelling such as linear and dynamic programming techniques as well as optimal control models gained importance and appeal to analysing the economic costs of soil erosion [Brekke et al., 1999; Eaton, 1996; Pagiola, 1993; McConell, 1983; Seitz and Swanson, 1980]. Other approaches included the replacement cost approach and the productivity loss approach. This section reviews the approaches that have been used to measure the economic costs of land degradation.

The approaches that have been used to measure economic costs of land degradation can be separated into two groups: those that are static in nature and those that are dynamic. A static analysis seeks an optimal number or finite set of numbers. Static optimisation models do not trace effects or changes over time. In contrast, dynamic optimisation models generate solutions for a complete optimal time path of each choice variable and not just a single optimal value (one period) (Chiang, 1984). Examples in this category include the optimal control and dynamic programming models.

3.5.1 Static models of valuing impacts of soil degradation

Static models for valuing impacts of soil degradation can be grouped into two: direct valuation methods such as the replacement costs method (RCM) and productivity loss method, and static optimisation models such as linear programming (LP[9]).

3.5.1.1 The replacement cost method (RCM)

The replacement cost approach calculates the loss of major nutrients (e.g., N, P, and K) as a result of any degrading processes such as erosion or crop harvesting and assign a value to it by using the equivalent cost of replenishing the soil fertility through the application of external inputs such as commercial fertilizers. Empirical soil erosion predictive models like USLE and SLEMSA have frequently been used to estimate levels of erosion. Regression analysis is then used to establish a statistical relationship between soil erosion and losses of

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[9] LP models are often extended to handle temporal aspects in multi-period formulations

major soil nutrients such as N, P and K. The value of such losses is then determined through the RCM.

The replacement cost method has been widely used due to its ease. Solorzano et al., (1991) examined effects of soil erosion in Costa Rica and found that annual replacement costs were equal to 5.3-13.3 per cent of annual value-added in agriculture. Stocking (1986) working in Zimbabwe, estimated nutrient loss in terms of nitrogen, phosphorous and organic carbon, and calculated the cost of replenishing these nutrients. A set of data taken from experimental plots during the late 1950s and early 1960s was used. The data represented over 2000 individual storm soil loss events on four soil types and numerous crops, treatments and slopes. Regression analysis was employed to establish a statistical relationship between soil erosion and losses of the three nutrients. Assuming an average rate of sheet erosion for each of the four major farming systems in the country (crop and range-land on communal and large-scale farming land), the amount of nutrients lost per year was calculated. Stockings (1986) then extrapolated the experimental data to the country as a whole for both communal and commercial farming systems engaged in grazing and arable land production. This study assumed that all nitrogen and phosphorous losses were to be replaced by fertilizer every year in order to maintain soil fertility.

However, Norse and Saigal (1992) summarized the pioneering work of Stocking (1986) and concluded that Stocking's study overestimated the costs of soil erosion in Zimbabwe by almost 20 per cent due to its neglect of nutrient input sources. The replacement approach used by Stocking may over-state on-site costs since it is based on replacing the entire mineral stock, whilst the rate at which nutrients become available for crop growth and the low actual uptake of minerals means that fertility may be maintained without complete replenishment (Bishop, 1992). The replenishment cost approach does not take into account the thresh-hold beyond which the effects of erosion are irreversible and cannot be rectified. Soil erosion affects several yield determining parameters, such as soil depth and nutrient availability [Hailu and Runge-Metzger, 1992]. Thus, when soil erosion has destroyed the soil physical structures like rooting depth, nutrient replenishment approach may under-state effects of soil erosion. Another major weakness of this approach is that it is a cost-based rather than benefit based valuation. This approach is remedial in focus unlike the benefit-based valuation e.g., computing the marginal value of soil quality. The latter approach instils in the user a sense that soil is an asset and has a value. The speed of the asset depreciation will thus depend on the way the asset is used and cared for. Comparably, where one is concerned with sustainable use of soil resource, the benefit-based valuation, which indicates a marginal value of soil quality, is more proactive in approach. For example, if producers are made aware of the marginal value of their land's quality they would protect and put it to the best use possible.

3.5.1.2 The productivity loss method (PLM)

In developing countries, productivity loss approach has been widely used to measure economic losses due to erosion. Practically, the widely used empirical predictive models like USLE and SLEMSA have been used to predict levels of soil erosion. Based on previous research in Nigeria, carried out at the International Institute for Tropical Agriculture (IITA), physical soil loss in tons per hectare per year can be considered a proxy for declining soil fertility (Bishop, 1992). Multiple regression analysis of data from controlled experiments at IITA revealed that soil loss measured in tons per hectare was a reliable predictor of changes in soil nutrient content, soil pH, and moisture retention (Lal, 1981). Aune and Lal (1995) working on erosion research data from Kasama region in Zambia established a functional relationship between erosion and crop productivity loss. Thus, the empirical erosion predictive models are linked to the multiple regression models to establish the functional relationship between erosion and yield productivity losses.

Among the well-known studies that have used the crop productivity loss approach are those by Bishop and Allen (1989) on Mali, Bishop on Malawi (1992), Magrath and Arens (1989) on Java, and Pierce (1984) on Corn Belt in the U.S. Bishop and Allen (1989) estimated cropland erosion in an area comprising about one-third of Mali's most productive cultivated cropland. They then used regression models of erosion-yield loss relationships developed by Lal (1981) at the International Institute for Tropical Agriculture (IITA) in Nigeria. The IITA equations allowed the prediction of the effects of cumulative natural soil loss, in tons per hectare, on yields of degraded soils relative to yields on newly cleared (uneroded) plots (Lal, 1987). To derive crop productivity losses due to soil erosion, net returns "with erosion" were subtracted from net returns "without-erosion". Bishop and Allen's (1989) approach has its own problems. For example, if net returns computed on the plots supposedly to be "with erosion" includes some costs which represent farmers' efforts to counter effects of erosion, then the method understate the true cost of erosion. Also, the requirement to subtract net returns from land "with erosion" from net returns from land "without" erosion is another limiting factor where land is scarce i.e., virgin land may not be available.

Grohs (1994), working on a case study in Zimbabwe, linked estimated soil erosion to crop yields using two empirical models of erosion-yield relation. First, average annual sheet erosion on cropland was estimated for every district using SLEMSA. Yield impacts were then calculated using CERES and EPIC models. The former links erosion, expressed as a reduction in depth of the fertile horizon, to soil water holding capacity and thus to maize yield. Yield losses for maize per centimetre of soil loss were estimated at 0.3-1.4 percent. EPIC links erosion to changes in both soil chemical and physical properties (i.e., nutrient losses as well as depth) and accordingly generates slightly higher estimates of yield loss (0.7-3.3 percent per cm soil loss for maize). Calculated yield losses are combined with farm enterprise budgets and data on average yield and cultivated area to derive estimates of on-site costs of erosion, reported as USD0.7-2.1 million in 1989. Another study is Sutcliffe's (1993) work on Ethiopia who related data on productivity declines to erosion estimates based on the USLE, and combined a soil-life model with a water requirement satisfaction index.

Bishop (1992) used the productivity loss method to measure economic costs of soil erosion in Malawi. This is the only existing study in Malawi that has tried to estimate economic losses due to erosion in the country. This study adapted results from the erosion hazard in Malawi carried out by Khonje and Machira (1987) using SLEMSA. The study converted the Erosion Hazard Units (EHU) into expected soil loss, by simple regression analysis. A database of land use was compiled. A mean rate of soil loss by rural development project (RDPs) and by districts was calculated from gross arable land. For Malawi, a mean rate of soil erosion was estimated to be 20 ton/hectare/year on gross arable land. Using crop budgets, yield losses arising from soil erosion were used. The author made an assumption that farmers reduce the use of variable inputs in the same proportion as gross revenue declines. Applying the estimated percentage yield loss directly to gross crop margins, the study came up with an estimate of economic losses arising from erosion. Gross margins were defined as gross revenue per hectare (mean yield multiplied by the prices offered by the Agricultural Development and Marketing Corporation, ADMARC), less the total cost per hectare of using all recommended inputs (seed, fertilizer, and pestcides) but not including labour inputs. Labour was assumed fixed. However, it is worthwhile to note that input application levels (fertilizers, pesticides) in Malawi are by far below the recommended requirements. Further, the ADMARC prices used in this study were not market determined but rather were fixed (and usually stayed unchanged for long periods) and therefore, would not offer any incentive for farmers to apply recommended inputs. Reduction of gross margins over a period of time should not therefore be specifically linked to the decline in land productivity as the authors assumed because it could also result from the effects of the fixed producer prices (ADMARC prices), hence farmers failed to offset the high cost of production as input prices increased over the years.

3.5.1.3 The hedonic pricing method (HPM)

Hedonic pricing is the indirect approach to valuing soil degradation. It compares the sale of or rental price of plots that differ only in the extent of physical degradation. In principle, the difference in productive capacity will be reflected in prices, which in turn reflect the present value of net returns over time. Hedonic pricing has been used to value effects of soil degradation on agricultural land in North America, with mixed results (Bishop, 1995). Hertzler et al. (1985) evaluated the loss of future productivity due to soil erosion on farmland in Iowa at over USD400 per hectare, but found that this cost was not reflected in land prices. Gardner and Barrows (1985) using data from Wisconsin demonstrated that conservation is only capitalized into land prices when the need for such investment is obvious. The implication of these studies is that soil degradation is not automatically reflected in land prices, even where land markets are relatively well developed, due to lack of information on the extent of erosion and its effect on productivity. Hedonic pricing is generally not applicable where land markets are poorly developed, or when land markets are distorted by speculation or public policy (Bishop, 1995). These constraints are acute in most developing countries such as Malawi.

3.5.1.4 Normative approaches: Static optimisation models

Static optimisation models such as linear programming have also been used in land degradation studies. Barbier (1998) carried out a study on induced innovation and land degradation in Bukina Faso using a linear programming model (LP) of economic behaviour with a biophysical model of plant growth and the condition of the soil. The LP was specified at village level, and had its objective the aggregate welfare of the community, measured as discounted value of future monetary income and opportunity cost of leisure, subject to constraints on the level, quality and distribution of key production factors (livestock numbers, land, capital, soil condition) and on market demand for food. It was assumed that all resource allocation and production decisions were made on the basis of a three year planning horizon. Simplified production functions were used to represent farmers' yield expectations for cotton, sorghum and irrigated rice. In the LP model, yields depended on type and fertility of soil, amount of input application (fertilizer). It was also assumed that insufficient soil depth and insufficient soil organic matter (SOM) depletes yield. Parameters for the production function were obtained from the results of the EPIC model developed by Williams et al., (1987) which was calibrated with real data from different sources (see Barbier, 1996). Barbier (1998) used the Target MOTAD (minimizing of total absolute deviation) method to simulate farmers' aversion toward risk. The model is multiperiodic, but limited by the duration of the assumed planning horizon. Since yield and soil erosion outcomes are affected by stochastic weather events a recursive framework allowed adjustments to be made between expected and actual outcomes each year. The multiperiod model was solved for each year and assumed that farmers held expectations about most likely outcomes for relevant random variables. The model was solved 40 times representing 40 future years. Given the model's solution for the year *t* and its optimal cropping pattern and yields, and associated level of soil erosion, EPIC was then run to simulate random weather outcomes, and to generate 'actual' outcomes for yields and erosion that year. The actual values were then used to adjust total production and income, and to recalibrate the closing stock of cash and grain and the level of soil erosion that entered the constraint set for the multiperiod model in year *t*+1.

In another study, Shiferaw and Holden (1999) applied a whole-farm linear programming model that contained multiple production activities and a number of behavioural constraints to understand the question of soil erosion and smallholders' decisions in the Highlands of Ethiopia. This model assumed the following four major goals: maximisation of net income, self-sufficiency in major staples, generation of cash to meet various needs, and achievement of acceptable levels of leisure. Model constraints included limits on owned and rented land, labour, oxen power, subsistence needs, animal feed requirement, capital/credit for fertiliser, cash income, and restriction on crop rotations. The effect of soil erosion on crop yield (productivity) was estimated from a production function estimated for the major crop (teff) based on time series data collected by the Soil Conservation Research Project (SCRP) in other similar areas in the highlands. Although Shiferaw and Holden's model was able to examine long-term effects on resource use and conservation behaviour of smallholder farmers, the steady-state equilibrium would not give guidance on the optimal control path for the extraction of the soil stock.

.3.5.2 Dynamic optimisation methods

In a dynamic optimisation problem, current output levels do not only affect current returns, but also future output and future net returns. Current extraction level will influence future extraction levels and net benefits. The problem faced by the decision maker in dynamic optimisation is, therefore, to extract given levels of resource at each period of time that will maximize the total net returns over time. The solution of a dynamic optimisation problem would thus take the form of an optimal time path for every choice variable (Chiang, 1992). There are three alternative approaches to dynamic optimisation: calculus of variation, dynamic programming and optimal control. This study presents examples of some studies that have used these approaches, precisely, the dynamic programming and the optimal control using the maximum principle.

3.5.2.1 Dynamic programming

One of the early influential models in dynamic optimisation for economic costs of soil erosion was the one developed by Burt (1981). Burt presented a formal inter-temporal model of soil use for farms in Palouse area of the northwestern U.S.A. He used a dynamic programming formulation with two state variables: depth of topsoil and the percentage of organic matter in the soil; and the percentage of land devoted to wheat as a control variable. However, according to Chiang (1992), dynamic programming models are known to suffer from two shortcomings:

- primary attention is focused on the optimal value of the function (optimal value function) rather than on the properties of the optimal control path as in optimal control theory;
- solution of continuous-time problems of dynamic programming involves the more advanced mathematical topic of partial differential equations which do not often yield analytical solutions.

3.5.2.2. Optimal control methods

Given the limitations of dynamic programming approach, techniques provided by the optimal control method are more powerful for the inter-temporal analysis (Chiang, 1992). One of the early key studies using optimal control is that of McConell (1983), who developed a simple model using optimal control theory in which soil depth and loss were incorporated into a single production function. The focus was on the inter-temporal path of soil use including the conditions under which private and social optima diverge. The paper also gave insight into some effective instruments of erosion control. In the tradition of natural resource economics, McConell(1983) argues that soil is an asset that must compete with other assets. The returns to the farmer are characterized by two elements. First, the value of soil as input to agricultural production in both current and future periods, which thus contribute to profits. Second, the amount and productivity of the soil at the end of the planning period will affect the potential resale value of the farmer's land, reflecting a capital element. One objective of McConnell's model was to explain circumstance under which it is optimal for a profit-maximising farmer to tolerate soil erosion. The first order conditions yield the normal profit maximizing result: farmer should use soil up to the point at which value of its marginal product equals its marginal cost. This value is simply the additional current profit while the cost is the foregone future profit from depleting the soil in the current period plus the capital loss at the end of the planning period. McConnell's model generates results similar to other natural resource management problems and helps us understand the inter-temporal trade-off that farmers make (explicitly or implicitly) in their decisions on soil erosion (Eaton, 1996). The first order conditions show that any change that would increase the costs of soil loss or decrease the benefits would lead to reduction in soil loss, and vice-versa. However, McConnell's paper ignores effect of soil quality on productivity by assuming that soil quality is constant.

Another useful study utilizing the theory of optimal control for economic cost analysis of soil erosion is that of Hertzler et al., (1985), who computed user costs of soil erosion and their effect on agricultural land prices. The study considered whether land markets efficiently capture the degradation in soil quality caused by erosion. Using a dynamically optimal adoption of soil-conserving technologies, crop rotation and pesticide regimes, they calculated differences in land prices observed in a completely inefficient and perfectly efficient markets. Total user cost of erosion measured the present value of decreases in static rents over time because of declining yields and increasing operating costs. The user costs of erosion included the costs of soil, phosphorous and potassium. Dynamic rents were measured as static rents minus total user costs. Productive value of land was calculated as the present value of the stream of static rents that equalled to dynamic rents capitalised at the discount rent. This allowed total user costs, as one component of dynamic rent, to be capitalized separately, showing the effect of erosion on the value of land in a perfectly efficient market. An important finding in this study was that soil erosion significantly reduces the productive value of land per acre by USD170. This value would double if user costs of phosphorous and potassium were added, except that the loss of nutrients does not permanently degrade the soil as can be replenished by application of fertilizers. The study was, nevertheless, not conclusive on whether inefficient land markets influence farmers to over-exploit the soil. The impact of land price is of particular interest to economists examining soil erosion in the U.S. or anywhere else where private property rights and markets for agricultural land are fairly developed. In Malawi, however, property rights and markets for agricultural land are poorly developed and lacking in many aspects. This approach is, therefore, less applicable.

Brekke et al. (1999) used optimal control theory (maximum principle) to calculate soil wealth for Tanzania. In their approach, they combined SLEMSA model and other soil scientific model (The Tropical Soil Productivity Calculator) developed by Aune and Lal (1995) to link crop productivity and soil degradation into an inter-temporal optimisation framework. The approach by Brekke et al. (1999) is unique in that there is a clear distinction between soil-mining and soil erosion problems. In the soil-mining model, land productivity (land quality) is a function of nutrient stocks. Hence land productivity is constrained only by nutrient levels. Erosion model captured the negative effects of soil erosion on crop productivity due to reduction in rooting depth i.e., soil depth within which crop roots are able to utilize nutrients and water. Unlike extraction of nutrients, rooting depth reductions are irreversible. A key assumption in this study was that the government's objective was to maximize soil wealth. Smallholder farmers chose labour, capital investment and level of input (fertilizer) to maximize soil wealth i.e., present value of soil rent.

3.6 Concluding Summary

In spite of the overwhelming recognition that erosion is the major agent of soil degradation worldwide, still, large-scale effects of soil erosion on productivity of soils are not well known. Pierce and Lal (1994) acknowledged that quantifying the impact of soil erosion on crop productivity has not been easy because of the complexity of crop response to erosion. However, considerable effort has been directed towards quantifying the economic costs of soil degradation.

Soil degradation has long-term consequences and static models, which form the bulk of studies that have so far been carried out in Africa to quantify economic costs of soil degradation, do not account for the inter-temporal dimension of optimal resource management. To deal with this shortcoming, an inter-temporal optimisation framework, which considers soil in a time-dependent resource extraction perspective, is regarded as a better approach in quantifying the economic impact of soil degradation.