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LAND UNDER PRESSURE:
SOIL CONSERVATION CONCERNS AND OPPORTUNITIES FOR ETHIOPIA

by

B.G.J.S. Sonneveld
M.A. Keyzer

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Abstract

This paper evaluates the future impact of soil degradation on national food security and land occupation in Ethiopia. It applies a spatial optimization model that maximizes national agricultural revenues under alternative scenarios of soil conservation, land accessibility and technology. The constraints in the model determine whether people remain on their original site, migrate within their ethnically defined areas or are allowed a trans-regional migration. Key to this model is the combination of a water erosion model with a spatial yield function that gives an estimate of the agricultural yield in its geographical dependence of natural resources and population distribution. A comparison of simulated land productivity values with historical patterns shows that results are interpretable and yield more accurate outcomes than postulating straightforward reductions in yield or land area for each geographic entity. The results of the optimization model show that in absence of soil erosion control, the future agricultural production stagnates and results in distressing food shortages, while rural incomes drop dramatically below the poverty line. Soil conservation and migration support a slow growth, but yet do not suffice to meet the expected food demand. In a trans-regional migration scenario, the highly degraded areas are exchanged for less affected sites, whereas cultivation on already substantially degraded soils largely continues when resettlement is confined to the original ethnic-administrative entity. A shift to modern technology offers better prospects and moderates the migration, but soil conservation remains indispensable, especially in the long term. Finally, an accelerated growth of non-agricultural sectors further alleviates poverty in the countryside, contributing to higher income levels of the total population and, simultaneously, relieving the pressure on the land through rural-urban migration.

Section 1
Identifying priorities for soil conservation in Ethiopia[1]

The natural conditions on the Ethiopian Highlands generally offer a favourable environment for human settlement. The plus factors are mainly attributable to the physiographic abruptness that influences the prevailing winds and results in substantially higher rainfall than in the adjacent arid lowlands in the east, while the moderate temperature prevents the occurrence of tropical diseases that prevail in the low-lying humid pockets in the west. Moreover, the volcanic parent material supplies a rich diversity of nutrients that makes soils more suitable for agriculture than in most other parts of Africa (Voortman et al., 2000).

Land under pressure

However, the blessing gradually turned into a curse as population densities and herdsizes kept on augmenting to become the highest in Africa. At present, the Highlands carry 88 per cent out of a total population of 64 million people and 86 per cent of the labour force is employed in agriculture. This results in average population concentrations of 144 persons per square km that, under current agricultural production techniques, largely exceed the lands' carrying capacity (Higgins et al., 1982). Equally worrying is the increase of livestock population to 76 million head of which 86 per cent is managed in the Highlands where average stocking rates amount to 160 TLUs per square kilometre, while the recommended densities are in the range of 19-42 TLU per square kilometre for humid areas and 7-19 for semi-arid to arid areas (Jahnke, 1982). These high population density levels and the large scale overgrazing exert a severe pressure on the Highlands. Soil losses currently reach alarming levels of up to 100-200 Mt per hectare per year (Hurni, 1993, Herweg and Stillhardt, 1999), already affecting 50 per cent of the agricultural areas (UNEP, 1992).

The process of human-induced soil erosion in Ethiopia is by no means a recent phenomenon and its causes are deeply rooted in Ethiopia's unique geographic location and political history. The isolated agro-ecological position of the Ethiopian Highlands impeded an intensive exchange of agricultural technologies with its latitudinal equivalents, while insecurity on the land tenure and heavy taxation under the political systems were largely responsible for a complete alienation of land users from their own land (Tsighe, 1995; Gebre-Mariam, 1994). As a result, agricultural technology and soil conservation in Ethiopia was until the beginning of the 1990's practised at a low level of technology while the socio-economic conditions deprived the farmers of incentives to improve land husbandry.

[1] The authors thank Professor H. Hurni, of the Centre for Development and Environment (CDE), University of Berne, Switzerland, for allowing the use of the SCRP data set.

Furthermore, the high demographic growth rate of 2.7 per cent annually (World Bank, 2001) will double the population by 2030 to approximately 130 million (FAO, 2000) and this creates an enormous challenge for Ethiopian agriculture. Food supply has to grow by 3.6 per cent annually, if self-sufficiency is to be achieved, which means more than a twofold increase of the average growth rate of 1.4 per cent (FAO AGROSTAT) over the past thirty years. Currently, yields belong to the lowest in Africa and the possibility for expansion of the cultivated area is limited due to climatic and soil constraints (see Table 1). Therefore, a further yield increase should mainly come from an intensification of the arable areas and this becomes very difficult unless water erosion and soil degradation are brought under control.

Table 1. Areas share (in percentage) with soil restrictions for rainfed annual crop cultivation by Length of Growing Period (in days)

LGP (% of total area)		Drainage	Slope	Stoniness	Phase	Fertility	Shallow
Arid	(41)	5	32	16	44	23	34
Semi-arid	(25)	11	53	31	37	2	42
Sub-humid	(19)	20	49	29	37	1	31
Humid	(11)	14	58	19	24	3	18
Very humid	(5)	10	67	29	29	4	15

Source: FAO, 1998a; FAO, 1998b; Sonneveld, forthcoming.

The impact of this unprecedented population concentration on the environment is not clear and hotly debated in literature (e.g. Young, 1998; Sarre and Blunden, 1995; UN, 1987 Choen, 1995). The discussion broadly follows two opposite hypotheses, representing a Malthusian and a Godwin[2] perspective. In the Malthusian setting overpopulation will lead to a depletion of natural resources. The current soil degradation problem in Ethiopia would persist causing food insecurity and violent conflicts over scarce land as marginal groups seek to expand their settlements or migrate to other productive areas (Economy, 1997; Homer- Dixon et al., in press and Homer-Dixon, 1999; Barber, 1997). Ethiopia seems especially prone to this kind of conflicts (Zegahegn, 1999; Tuso, 1997), since approximately 60 per cent of the population belongs to a minority group at risk of ethnic conflicts (Easterly and Levine, 1996, Prendergast, 1997)[3] and the environmental pressure forces groups to leave their homelands (Coppock, 1990). The regional dissimilarities in population density illustrate these restrictions in land accessibility. Borders of overpopulated and underutilized areas often coincide with the ethnic-administrative boundaries that were formalized in 1992. The

[2] Reverend Thomas Malthus and his contemporary William Godwin started the first documented debate on the impact of population pressure on the environment. Godwin's ideas are nowadays better known through the recent work of Esther Boserup (1965, 1981).

[3] Ethiopia has a long record of ethnic conflicts (e.g. Abbink, 1993; Cohen, 1995). Ethiopia also scores a 3 for racial tension on a scale of 1 (high) to 6 (low) according to Easterly and Levine (1996). This is relatively high compared with neighbouring countries like Yemen (5), Egypt (4) and Somalia (4); only Kenya has a higher score (1).

alternative perspective of Godwin refuted the idea that man would succumb to imminent natural scarcities and pointed out that technological progress and self-regulation would counter this threat. Population concentration would improve land management as additional inputs of labour reduce production costs and favourably influence the efficiency of markets, communication and transport (Blaikie and Brookfield, 1987). Case studies elsewhere (Tiffen 1994; Shaxson and Cheatle, 1999; Mortimore, 1994) and in Ethiopia (Grepperud, 1996; Shiferaw et al., 2001) confirmed the positive influence of population pressure on land husbandry, rehabilitation of degraded soils and innovation of new technologies. Tanner and Payne (2001), Tarekegne et al., (1997) and Uloro and Mengel (1994) also show that new technologies can be responsible for spectacular crop production increases in Ethiopia (Howard et al., 1999). The higher value of scarce natural resources could also positively influence land markets and develop the underutilized areas to their full potential by a migration of labour from overpopulated areas. Moreover, population concentrations create favourable conditions for the development of other sectors, as was shown in Asia where the alleviation of rural poverty was to a large extent achieved through migration to urban centers, and employment in the service and industrial sectors.

Which pathway Ethiopia will take in the future remains uncertain especially since the latest developments are equivocal. First, the country witnessed a fast increase of agricultural production in the beginning of the 1990s under the new government, which gave reason to believe that the Malthusian perspective was too pessimistic. However, production stagnated in the second half of the 1990s, when Ethiopia became involved in a war with its neighbour and former province Eritrea. The famine that currently hits the region is also for many a reason to fear that sometime in the future the Malthusian prediction will really come true (Young, 1998; Brown et al., 1999).

Indeed, the current economic conditions do not allow for a large-scale application of purchased inputs that would compensate the loss of nutrients and ameliorate the physical damage that is caused by soil erosion. Consequently, the Ethiopian farmer, who on average cultivates one hectare of food crops while also keeping some livestock, is nowadays extremely dependent on natural conditions and cannot support further deterioration of soil productivity. Furthermore, the scope for raising employment in non-agricultural sectors is also restricted in view of the limited funds available for investment, the low degree of literacy and the instable political situation in the last decade.

In addition, the physical soil loss from water erosion might lead to irreversible changes in soil productivity that directly affect the food security situation in Ethiopia. Even though this loss will often deposit as fresh sediments downstream, the areas that benefit from the transported soil are relatively small compared to those where it was detached. Hence, soil conservation is badly needed in Ethiopia. Where in flat areas low cost measures are presum-

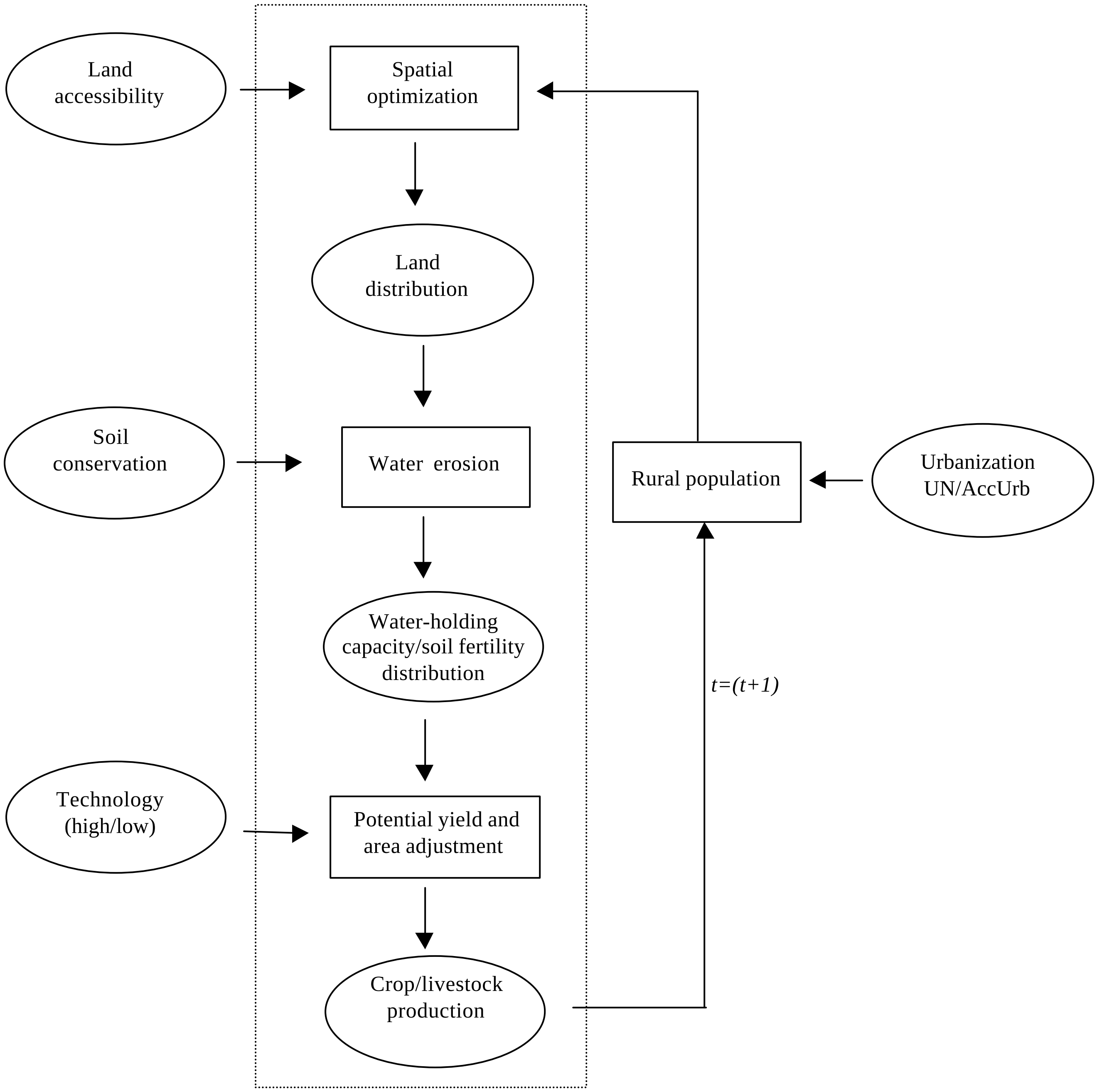

Figure 1 Cyclical process of soil degradation, agricultural production, demographic development and spatial optimization of land use. The dotted line surrounds the model, outside appear the exoenous variables.

ably adequate to counter the degradation process, this can be recommended without restrictions. However, for the major part of the mountainous Ethiopian Highlands the issue is far more subtle. Erosion control on steep slopes involves high cost programs and even requires complete bans on cultivation of currently occupied soils, with all associated controversies. Therefore, the development of tools that evaluate the impact of policy measures on soil productivity and food security is urgently needed. And this analysis should take place at a national scale, because this is the level where policy decisions affect land use and management most drastically and where soil conservation activities are generally planned.

In this paper, we evaluate the impact of soil conservation on food production in relation to future demographic developments and their impact on soil productivity at a national level. For this, we apply a spatial optimization model that maximizes national agricultural revenues in several prospective scenarios. We pay special attention to the effect of soil conservation, land accessibility, technology and development of non-agricultural sectors. The constraints in the model consists of bounds on land accessibility that determine whether people have to remain on their original sites, can migrate within their ethnically defined areas or are allowed a trans-regional migration. The key relationship in the optimization model is a spatial yield function that estimates the agricultural yield in its geographical dependence of natural resources and population distribution. Using a dynamic recursive simulation, we recursively link this optimization model to a water erosion model by adjusting the area of land suitable for cultivation and the yield potential, both location specific parameters of the spatial yield function. Figure 1 shows the cycle and steps in calculation of land cultivation, soil erosion, soil management and soil productivity.

Thus, in principle, the model gives for each year the spatially optimal locations to maximize agricultural revenues at a national level, based on the model outcomes of the previous year. However, calculations on an annual basis are cumbersome both numerically and when it comes to reporting of the results. Therefore, we only solve the spatial optimization for 2000 and 2010, i.e. only allow for migration in those years keeping population at fixed locations in other years. Simulation tests showed that the outcomes do not differ much from those of full annual simulations, essentially because most of the people are able to move to the appropriate locations in 2000 and 2010.

Soil degradation and productivity

We consider the linkage between soil degradation and production to be critical both for assessing the damages caused by land degradation, and for evaluating the benefits from soil conservation measures. Indeed, it is remarkable that the literature on the subject seems to focus on soil loss while neglecting the effect of these losses on crop yields. In fact, efforts in quantifying the yield effect have not been very successful (Ruttan, 1999; Kruseman and Van Keulen, 2001). So far, productivity loss from water erosion was mainly established through simulation models, notably the EPIC-model (Erosion Productivity Impact Calculator; Sharpley and Williams, 1990), the PI (Productivity Index: Pierce et al, 1983) and the latest versions of the WEPP (Water Erosion Prediction Project; Nearing et al., 1989). These models were designed for assessments at field level and are not suitable for application at a nationwide scale where data availability is inadequate for a proper validation (Pierce, 1991). Moreover, the soil loss estimates in EPIC and PI are calculated through the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978), whose application outside the ecological domain (East of the Rocky Mountains) that served for its calibration is even discouraged by its own designers (Wischmeier, 1976). In WEPP the soil losses are calculated with a process-based water erosion model, which is very data demanding, requires a long-term calibration and validation period and varies in its accuracy to predict soil losses and run-off (e.g. Jetten et al., 2000). Studies that concentrate on smaller study areas used field data to estimate a temporal soil degradation-production function based on a nitrogen balance (Aune and Massawa, 1998) that was later extended with soil depth (Shiferaw et al., 2001). However these models can not be extrapolated at national level.

In short, there is to date no relationship available describing the effect of water erosion on crop yields, which is both empirically robust and theoretically founded. Theoretical restrictions are needed because straightforward statistical estimation techniques are bound to be biased by data limitations (e.g. Openshaw, 1996; King, 1997). For instance, in our exercise the data give a detailed description of environmental conditions at every location but no information is provided on the type of cultivation that is practised on the different soil types, while the severity of soil degradation is known to depend heavily on the combined interaction of these biophysical characteristics and agricultural activities. Indeed, soil degradation appears to be particularly acute under very local, extreme conditions, that are by definition being averaged out in aggregated perspectives of larger landscapes. All this makes it difficult to explain empirically the variability of production levels in relation to soil degradation. In an earlier exercise (Keyzer and Sonneveld, 2001), at national level the data problem was addressed by estimating a nationwide relationship between soil degradation and productivity that concentrated on yield changes of crops which cultivation is known to provoke much erosion in Ethiopia. This exercise accepted the lack of a priori knowledge on the formal structure of this relationship and opted for a highly flexible functional form that closely follows the data, using a kernel density regression. The present paper follows a more comprehensive procedure in that it evaluates the impact of all crop cultivation and livestock activities on the soil productivity. We use an engineering approach, where soil loss is estimated independently from production levels and, subsequently, related to changes in one or more soil productivity characteristics to adjust estimations on yield levels. Smaling (1993) proceeds in a similar way for monitoring of nutrient balances in West Africa. Okumu et al. (1999) for relating soil loss to soil depth, Struif Bontkes (1999) for evaluating changes in organic and macro nutrients, Kruseman (2000) for calculating changes in organic matter and Kassam et al. (1993) for determining soil losses to be used in soil specific production functions. The advantage of this approach is that soil degradation can be simulated for each map unit at a disaggregated level that reflects the detailed level of the biophysical inventory, but there are two major limitations. On one hand, water erosion models are not designed to assess soil loss with the limited available information that prevails at the coarse scale of an exercise at national level. On the other hand, the results of simulated declines in productivity can not be verified against extensive data sets of time series and the simulated data have to be aggregated to correspond to the same geographic entity as the dependent variable, the effect of which on the final results remains unclear. In this paper we attempt to address both problems as follows. First, we apply spatial water erosion models, that were based on previous studies (Sonneveld and Albersen, 1999; Keyzer and Sonneveld, 1998) and the data set of the Soil Conservation Research Project (Sonneveld et al., forthcoming). The models were especially designed for a nationwide assessment in Ethiopia to calculate the soil losses in its geographical dependence of biophysical variables and land use. Second, we make a modest attempt to validate yield adjustments by comparing historical distributions of potential land productivity characteristics with the simulated values. We also evaluate the accuracy of the yield adjustments with regard to alternative approaches that assess the impact of soil degradation by downgrading the yields for the geographic entity as a whole, rather than calculating its impact at the detailed geographical level.

The paper proceeds as follows. After introducing the production model with migration (section 2), we specify the scenario runs (section 3) and compare the simulated impact of soil loss on agricultural production with the historically developed distribution of productivity and two alternative approaches (section 4). In section 5, we assess the economic performance of the sector under the various scenarios, in terms of agricultural productivity, food supply per kaput, value added per kaput and spatial distribution of the population with respect to the population density and occupation of degraded areas. Section 6 summarizes and concludes.

Section 2
The production model with migration

This section presents the model to be used for simulations. It introduces the agricultural production function that estimates agricultural output at every location as a function of the yield potential and the labour intensity. It also specifies the impact of water erosion on agricultural production as well as the program that is used to maximize agricultural revenues under the alternative scenarios.

Production function

The production function relates the agricultural output to labour productivity and potential yield of the area. We apply a cross sectional regression that distinguishes the 460 Cropping Production Systems Zones (CPSZ) of Ethiopia (FAO, 1998b), which correspond to administrative units (Auraja's), or subdivisions thereof in case a unit has steep ecological gradients.

For each CPSZ, we consider the observed crop yields (FAO, 1998b; CSA, 1997e) and livestock yields (CSA, 1998; Kruska, 1995), weighted according to the areas that are used for their cultivation and grazing, respectively. The potential yield of the CPSZ is not observed directly but calculated according to an Agro-Ecological Zones approach (FAO, 1978-1981; FAO/IIASA, 1993) based on empirical data on prevailing agro-climatic, land and soil constraints. For each CPSZ, an aggregate potential output is calculated in monetary units at constant base year prices, by choosing for every land type the crop or livestock product that is suitable according to the soil and climatic conditions and generates the highest value. Actual output is expressed in the same monetary units.

The data on rural labour availability are derived from a population density map (Deichman, 1994) after correction for the urban population living in the geographical unit. We can safely treat this variable as exogenous, because the ethnic-administrative subdivision determines the population distribution and site occupation in Ethiopia. The yield function does not include agrochemicals because detailed data are lacking and we assume the application to vary with the population density.

The production function has been estimated for rainfed areas where sedentary agriculture prevails and a relation between agricultural production, natural endowments, and labour force can be inferred. For the predominantly nomadic agriculture in the arid lowlands a more crude approach is necessary based on aggregated figures of livestock production (CSA, 1997c; FAO AGROSTAT) per labour unit (Deichman, 1994; CSA, 1997a), leading to a fixed production (USD 308 (Purchasing Power parity; PPP)) per person per year.

Approximately 9 percent of the rural population lives in such nomadic areas. As this productivity turns out to be very low, the marginal productivity can be taken to be fixed without running the risk of excessive migration to this area under a Free migration scenario.

The estimation distinguishes 756 GIS polygons that result from an overlay of the CPSZ areas and the administrative map and is done by cross section over these polygons, with a test about the absence of spatial correlation of residuals.

We opt for a Mitscherlich-Baule function as functional form for the yield relationship on rainfed areas, because of its convenient properties for an assessment of agricultural production (Llewelyn and Weatherstone, 1996). It has the potential yield as upper asymptote and fits well within a convex optimization model (Albersen et al., 2000). Formally, the yield function reads:

$$y_j(n_j) = \bar{y}_j \left(1 - exp\left(- a \frac{n_j}{\bar{y}_j A_j} - b \right) \right),$$

with $\bar{y}_j = \Sigma_g \hat{y}_{jg} p_{g0} a_{jg}$

where

y_j	=	annual yield expressed in quantity units per hectare of the land use types practised in area *j*
$\bar{y}_j$	=	potential annual output of area *j*,
n_j	=	population of area *j*
a, b	=	regression parameters
A_j	=	surface of area *j*
$\hat{y}_{jg}$	=	the potential (physical) yield of good *g* in quantity units per hectare of area *j*
p_{g0}	=	the price of good *g* in the base year divided by the price of the standard land use types practised in area *j* in that year
a_{jg}	=	area share (A_{jg} / A_j) of good *g* in area *j*

The r-square of the regression shows that the function explains 60 per cent of the yields variability. The potential yield ($\bar{y}$) represents in this function an asymptotic ceiling. The term $n_j / \bar{y}_j A_j$ gives the labour input per unit of potential agricultural production in area j; the exponential term produces smaller values if labour increases so that the estimated yield gets closer to its potential level. The values of the parameters *á* and *â* are 1.984192 and 0.079076 respectively and both are highly significant.

Simulations treat a multiplicative error term as fixed effect; hence, the model reproduces base year data.

Quantifying the impact of water erosion on agricultural production

Given the agricultural production function specified above, the impact of soil loss on agricultural production can be expressed via a reduction of potential yield and a reduction of the area under cultivation, in case the potential drops below a threshold value. For this threshold value we adopt the land evaluation criteria of the FAO (e.g. FAO, 1978-81), whereby land with a potential yield level that drops below 20 per cent of the maximum potential yield is considered unsuitable for production, basically because tillage operations become unfeasible due to rill and gully erosion.

To describe the effect of erosion on potential yields, we follow Kassam et al. (1993), who relate soil loss to the two most important soil productivity characteristics: fertility and water holding capacity. Soil fertility depends on soil susceptibility to erosion and regenerative capacity of the topsoil. The soils' susceptibility to erosion is classified as *least*, *moderately* and *susceptible*, implying productivity reductions of 1, 2 and 7 per cent per cm topsoil loss, respectively. With respect to the regenerative capacity of the soil we follow Hammer (1981), where development of the top soil is related to climatic variables. The water holding capacity of the soil controls the moisture availability for the crop during the growing season and is based on Batjes (1996) where total available water capacity (TAWC) is related to soil type, soil depth, phase and textural class. Effective soil depth (FAO, 1998a) is estimated by taking the mean value of the depth classes of the three most important soils, while missing values are replaced by the depth of the dominant soil except for Leptosols which are shallow by definition (30 cm). Further modifications of soil depth are made if phases occur.

Formally, we denote the combinations of biophysical characteristics and land use that belong to a map unit *j* by the index *k*, with $k = 1,...,K$, and the time points by t, $t = 1,...,T$. Hence, every map unit *j*, is subdivided into areas $A_{j,k,t}$ with yield potentials $\hat{y}_{j,k,t}$. The impact of the soil loss $s_{j,k,t}$, on agricultural production is expressed as a reduction of potential yield and, if the yield levels drop below a threshold of 20 per cent of the potential yield, the area is taken out of production.

$$\hat{y}_{j,k,t} = \hat{y}_{j,k,t-1}\left(1 - z_{j,k,t-1}\right),$$

where

$\hat{y}_{j,k,t}$ = potential yield

$z_{j,k,t-1}$ = percentage yield loss,

Furthermore, $z_{j,k,t-1}$, the percentage yield loss is modelled as in Kassam et al. (1991), whereby yield loss due to water erosion is determined by:

$$z_{j,k,t} = max\left(f_k\left(s_{j,k,t}\right), h_k\left(s_{j,k,t}\right)\right),$$

for

$f_k\left(s_{j,k,t}\right)$ = yield loss due to reduced soil fertility, under conditions k

$h_k\left(s_{j,k,t}\right)$ = yield loss due to reduced water holding capacity, under conditions k.

Finally, if $\hat{y}_{j,k,t} / \hat{y}_{j,k,0} \leq 0.2$, then area $A_{j,k,t}$ is taken out of production.

Migration

We use the production function and adjusted potential levels to calculate the spatial distribution of the agricultural labour force that would maximize agricultural revenue at national level, given the productivity of land in the geographic entities and subject to migration constraints that reflect different degrees of accessibility.

As before, the index j denotes the map unit, and to represent the constraints on migration we also define the index i, referring to the 52 ethnic-administrative areas in Ethiopia. J_i denotes the set of map units in area i.

In the 'Free' scenario, allowing nationwide admittance to all geographic entities, the following mathematical program distributes the population so as to maximize the national agricultural revenue:

$$max_{n_j \geq 0} \sum_j \left(P\, y_j\left(n_j\right) - C\left(y_j\left(n_j\right)\right)\right) A_j ,$$

subject to

$$\sum_j n_j = \bar{n},$$

where $y_j\left(n_j\right)$ is the production function, P is the price of the reference good, actually a quality index, whose change reflects the greater processing intensity of output (production of flour, cooking oil, etc.), as well as a shift to higher valued primary products. Furthermore, $C(\cdot)$ is a convex cost function per ha that increases with biophysical yield, and whose parameters are taken to be equal across areas and includes the production costs for the purchase of agricultural requisites. The 'Free' scenario equalizes the marginal productivity of labour across the country, i.e. people migrate until the addition of one unit of labour produces the same amount of agricultural output at every site.

To represent the population movement in the 'Restricted' scenario, which keeps people within their areas, we replace the constraint by $\sum_{j \in J_i} n_j = \bar{n}_i$ and $\sum_i \bar{n}_i = \bar{n}$. Marginal productivity is equalized within each of the administrative areas only. Finally, under the 'Stationary' scenario people have to stay within in their original map units, and the constraint becomes: $n_j = \bar{n}_j$ for given $\sum_j \bar{n}_j = \bar{n}$. Marginal productivity of labour will be different across map units.

It is important to remark here that the distribution of labour in this optimization exercise is compatible with revenue maximization by individual farmers and does not require government-orchestrated intervention, as people can move to places where they can earn higher returns to their labour. Of course, in practice government may have to stimulate the transition. The aim of our calculation is to locate the areas of destination that could accommodate the flow of population, and where specific investments or soil conservation programmes would be required, so as to avoid future conflicts over scarce land.

The cost function

The cost function refers to purchased agricultural inputs, and was calibrated as a quadratic function based on national and international statistics of agricultural inputs per hectare:

$$C(y_j) = max(\alpha y_j^2 + \beta y_j + \gamma, 0)$$

where the parameters á, â and ã had the values of -0.0000008, 0.0035 and -250 respectively. If the sum of the first two terms is smaller than 250 the costs were put on zero. These values were calibrated to correspond cost elasticity of about 5 and 30 per cent to the output value for low and high input agriculture, respectively. Cost assessments for Ethiopia were taken as a representation of low input agriculture while the African countries Zimbabwe and South Africa were examples for the high input alternative.

We further assume that the implementation and maintenance of soil conservation measures is separate from these inputs and mainly require manual labour combined with educational services and technical assistance.

Section 3
Scenario specification

The first, ‘Stationary’ scenario evaluates the situation under the prevailing land occupation and technology levels and with an uncontrolled progressive soil degradation. The second, ‘Control’ scenario assumes a perfect erosion control that relies on soil conservation measures, and can preserve the land’s productivity. The third option, ‘Migration’, appraises different options in land accessibility, with a ‘Free’ alternative allowing trans-regional migration to all productive areas and a ‘Restricted’ alternative where people are confined within their ethnic-administrative areas of origin. This scenario also considers variants with and without tropical disease control that determine whether migration to new settlements in Western Ethiopia is possible. As a fourth alternative, ‘Technology’, we assume gradual adoption of new technologies, less labour intensive technologies in agriculture and accelerated growth of non-agricultural sectors that absorb labour from rural areas.

The scenario specification requires assumptions on exogenous variables concerning (a) the pattern of rural to urban migration, (b) the prospects on technological innovations and (c) the growth in the non-agricultural sector. It is implemented in the model through exogenous adjustment of the productive area (A), the quality index (P), the potential yield ($\hat{y}$) and the population level ($\overline{\mathrm{n}}$).

Demographic and non agricultural sector development

The growth of the rural labour force will follow two scenarios: the medium UN growth option and an alternative that presents a higher outflow from the agricultural sector to industrial and service activities (AccUrb). Table 2 shows the population development under the two alternatives. The AccUrb assumes that after 30 years the urbanization rate is equal to that of countries with an average medium human development level (UNDP, 1997), whereby urban population growth is adjusted for the expected changing fertility rates (POPIN Ethiopia, 1997).

Table 2. Population (x 1000) in the scenarios

	Rural				Urban		Total	
	UN*		AccUrb					
Year	Nomadic	Sedentary	Nomadic	Sedentary	UN	AccUrb	UN	AccUrb
2000	4535	46988	4535	46988	11042	11042	62565	62565
2010	5428	56245	5351	55452	18271	15552	79944	76355
2030	7279	75427	6187	64112	45110	51732	127816	122031

* Source: FAO Agrostat.

Technological development

The assumptions on technological development of agricultural production are controlled via two parameters: the potential yield and a quality index expressing the monetary value of a biophysical unit. We consider two technological alternatives: a Medium and High Technology level.

Regarding the yield potential, for Medium Technology, the potential yield for crops is taken to reach a maximum of 50 per cent of the attainable yield, while for livestock the current yield levels per TLU under the carrying capacity of the land are taken as a reference. High technology assumes the adoption of agronomic innovations and agricultural requisites like fertilizer and pesticides, thereby increasing the potential yield for crops to 100 per cent of the attainable yield, while the quality index increases due to the greater processing intensity of output (production of flour, cooking oil, etc.) and through a gradual increase in the area share of the cultivation of higher valued crop varieties, occupying up to a maximum of 50 per cent of the arable land. TLU yields, in sedentary and nomadic agriculture, increase under a high technology scenario to levels comparable with more developed countries like South Africa.

With respect to quality, the index P_t is expressed as the monetary revenue per unit of biophysical output, and defined as:

$$P_t = p_{10} \frac{\sum_j \sum_k p_{k,t} \tilde{y}_{j,k,t} a_{j,k,t}}{\sum_j \sum_k p_{k,0} \tilde{y}_{j,k,t} a_{j,k,t}}$$

where $p_{1,0}$ = price of reference commodity $k = 1$ in the base year $t = 0$

$\tilde{y}_{j,k,t}$ = imputed biophysical yield of good k at time t,

$a_{j,k,t}$ = area share of good k in year t

$p_{k,0}$ = price of good k in year 0

$p_{k,t}$ = price of good k in year t

and where the imputed yield $\tilde{y}_{j,k,t}$ is obtained as $\left(y_{j,k,0} / \hat{y}_{j,k,0}\right)\hat{y}_{j,k,t}$, which is used as a proxy for the actual yield, that is only determined at aggregate level within the model and depends on P_t itself.

The Medium Technology scenario assumes that $p_{k,t}$ retains the base year value for existing crop and livestock systems. For the High Technology alternative, P_t rises because we assume that $p_{k,t}$ increases due to the greater processing intensity of output (production of flour, cooking oil, etc.) and through a gradual shift in $a_{j,k,t}$ over time, towards the cultivation of higher valued primary commodities up to half of the arable land, assuming that farmers maintain cultivation of traditional crops on the other half, basically for security reasons. The four scenarios are summarised in Table 3.

Table 3. Scenarios for 2000, 2010 and 2030

Scenario	Erosion control	Migration	Disease control	Accelerated urbanisation	Input
Stationary	no	no	no	no	low
Control	yes	no	no	no	low
Migration	yes/no	yes	no	no	low
Technology	yes/no	yes	yes	yes	high

Section 4
Impact of water erosion on land productivity

In this section we validate the soil degradation/yield adjustment procedure and verify the accuracy of the assessment after the aggregation of the results determined for combinations of biophysical characteristics and land use (*k*) to map unit (*j*). Since no extensive time series are available for an empirical verification of the results, we only carry out a modest attempt in this context. First, we compare the historical distribution of potential land productivity characteristics with the simulated values. Second, we evaluate the accuracy of the results with regard to alternative approaches that downgrade the yields at the level of map unit *j*.

Validation by comparison of land productivity patterns

When comparing the land productivity patterns we assume that the aggregated data on potential yield of our geographic entities (app. 2,000 square km) are representative for the productivity of the landscape, which underwent an age-long process of natural and human induced water erosion. This potential productivity can be considered to be rather stable, not only because the landscape is consolidated in its geomorphologic structure that largely determines the potential possibilities and constraints of the land for cultivation, but also because of the partial deposition of the detached soil within one and the same map unit that compensates for productivity losses upstream, or in other words, because of the averaging within a map unit. Therefore, one might expect that the impact of water erosion at this aggregated level progresses with a 'geological' slowness, suggesting that long term trends in land productivity and their spatial distribution should not differ too dramatically from historical ones.

The curves in figure 2 compare land productivity distributions for the years 2000, 2010 and 2030 and are calculated as means of a kernel density regression on the logarithm of the yield levels in all areas. It appears that the shape of the distribution curves remains more or less constant over time while the area under the curve decreases with progressive water erosion. The shift to the left of the top of the curve after 10 years of erosion indicates an average loss in potential yield. As land becomes unsuitable for cultivation, the total area under the 30-year curve becomes smaller. This curve also stretches out to the right and shows a slight increase in the yields at the mode. This is because better areas gain in relative importance as the degraded ones are taken out of production. We tentatively conclude that the simulated distribution pattern of the land productivity characteristics is interpretable.

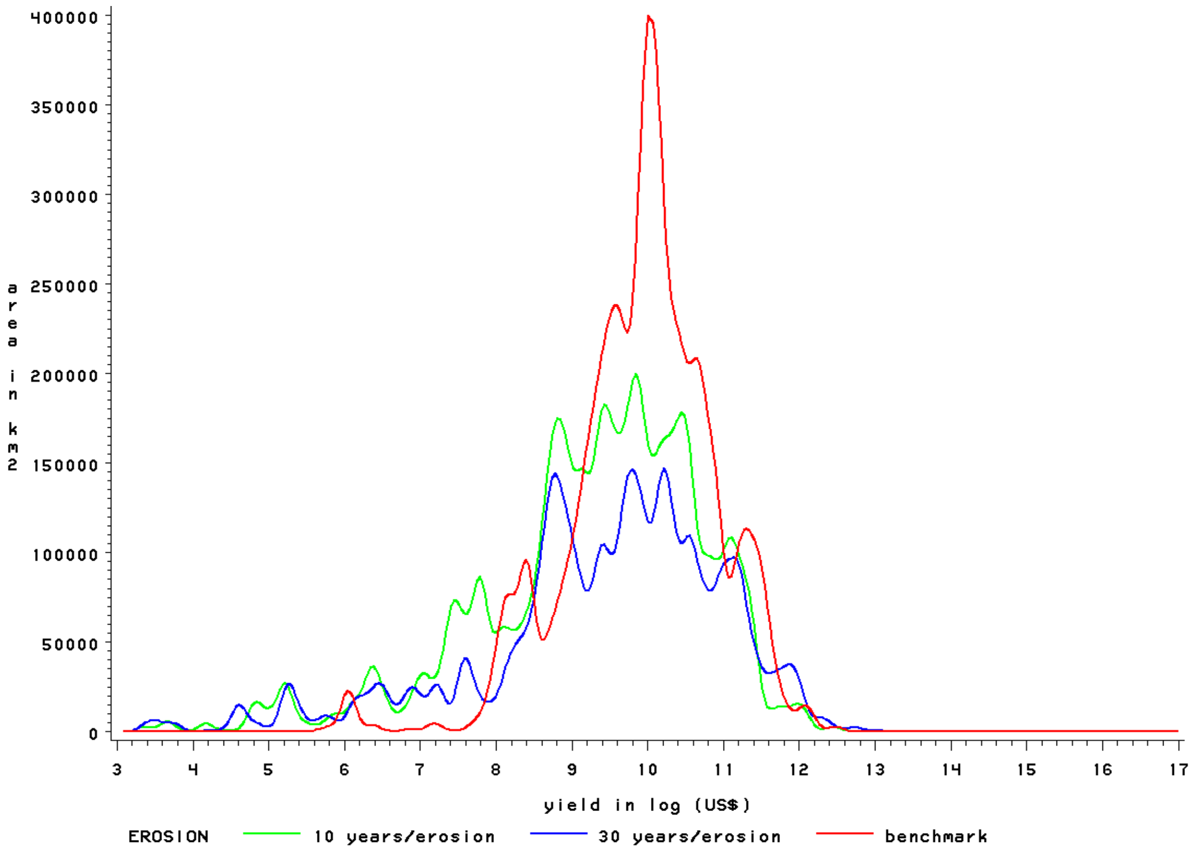

Figure 2. Distribution of yield by area for the benchmark year and after 10 and 30 years of degradation

Accuracy and data aggregation

The increased cultivation of marginal areas and reduction of fallow periods inevitably leads to productivity losses, the details of which should be clearly reflected in the changing patterns. We will therefore compare the results with downgrading procedures that are applied elsewhere and that take the map unit as one entity without discriminating between the different soils in association. Figure 3a and 3b show the results of two alternatives. The first alternative (Figure 3a) refers to a general reduction of the yield of one per cent per year and was, for example, applied by Hurni (1993) and Dyer et al. (2001), the second (Figure 3b) refers to a reduction of 1 per cent per year which is derived from projections made by UNEP (1980), Dudal (1981) and Kovda (1983).

The patterns for the 10- and 30-year curve in figure 3a replicate the historical patterns with a slow shift to the lower yield values. Compared to figure 1, erosion has less impact on agricultural production. This also holds for the 10-year curve in figure 3b, although, the 30-

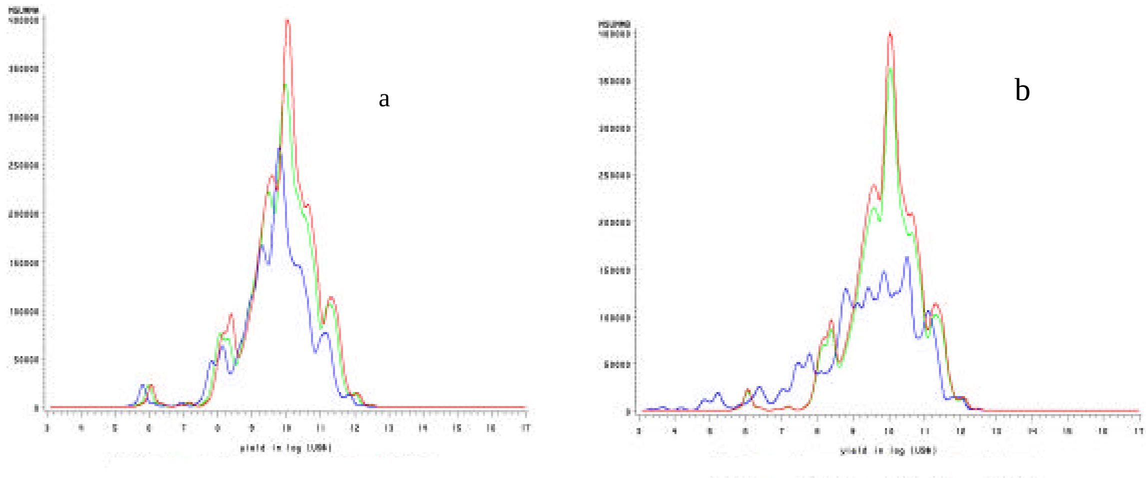

Figure 3. Distribution of yield by area for the benchmark year (red line) and after 10 (green line) and 30 years (blue line) of progressive soil erosion for: (a) annual yield reduction of 1 per cent and (b) annual land reduction of 1 per cent.

year curve shows here a sudden decline of the peak and an increase in areas with lower yields.

To seek an explanation for these differences we analyse the differences between the curves of Figure 2 and Figure 3 (a and b), against the prevalence of erosion vulnerable soils, defined here as soils that are shallow (less than 30 cm) and low in organic matter (OM) (less than 0.5 per cent). The relation between soil erosion and these vulnerable soils is, after all, supposed to be a distinguishing characteristic between the more detailed approach followed in this study and the overall downgrading procedure.

For the analysis we use the mollifier program (Keyzer and Sonneveld, 1998 and 2001) to produce 3-D graphs that depict the non-linear error trends in association with both soil characteristics. The error term is estimated by kernel density regression. The mollifier program also provides us with statistics on the accuracy of the estimate which we use here to zoom in on the reliable areas.

Figure 4 shows the error terms as a colour shift for the 10- and 30 year differences in the surface curve and plane, respectively, against the area share of the vulnerable soils. The classified frequency distribution of error values appears on the upper right side of the graphic and as contour lines in the surface curve. It indicates that the yield reduction rule overestimates agricultural production in areas with a high share of shallow soils and those where low organic matter prevails. Areas with a high share of both characteristics are less affected by this rule basically because the yields were very low already and the relative reduction has less influence. The error term for the thirty year differences shows a similar pattern except for the lower area shares where soils have a higher resilient capacity to withstand the erosion and the yield rule underestimates productive capacity.

Figure 5 shows the same dimensions but now for the land reduction rule. The 10 and 30 year error terms indicate that for areas with higher shares of low organic matter and shallow soils the land rule overestimates the productivity as these areas are not downgraded enough by a simple reduction of the area. The error term after thirty years have in general a smaller deviation from the applied procedure except for the high area shares where it overestimates the productive capacity.

Thus it appears that the procedure applied in Figure 1 is not affected by data aggregation and therefore provides a more accurate reflection of yield declines compared to the overall downgrading of agricultural production for the whole map unit.

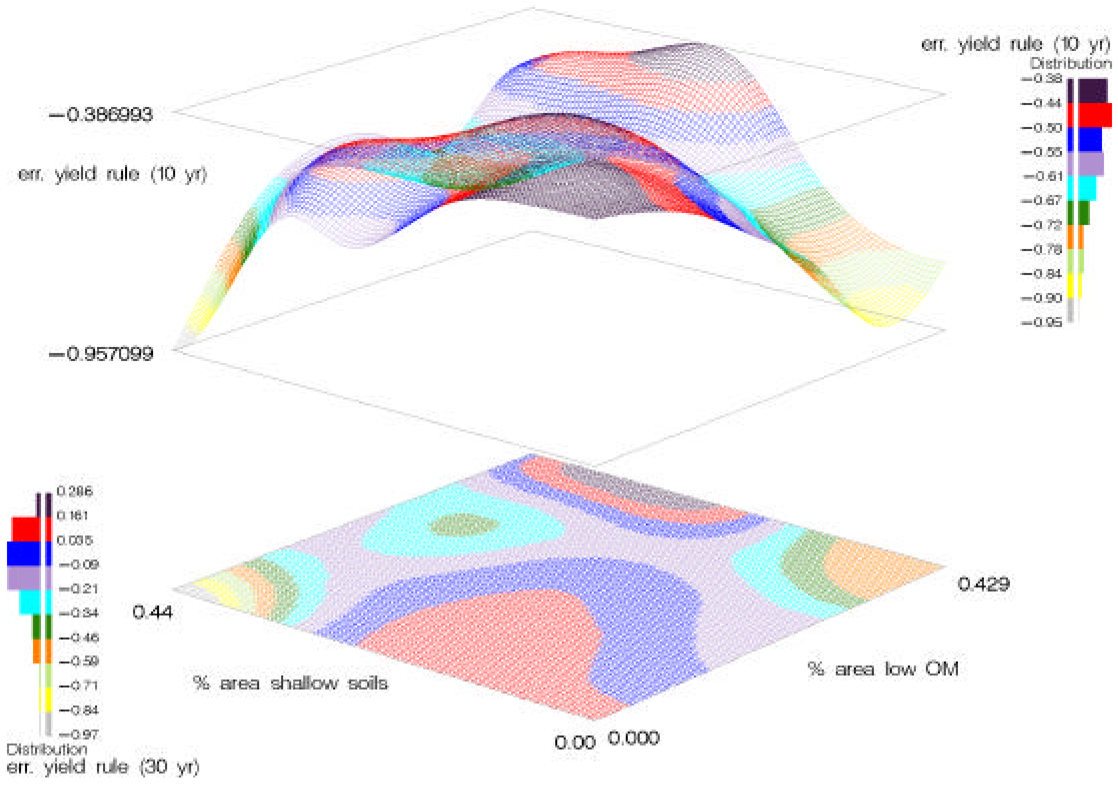

Figure 4. Error of yield reduction rule against share of shallow soils and soils with low OM.

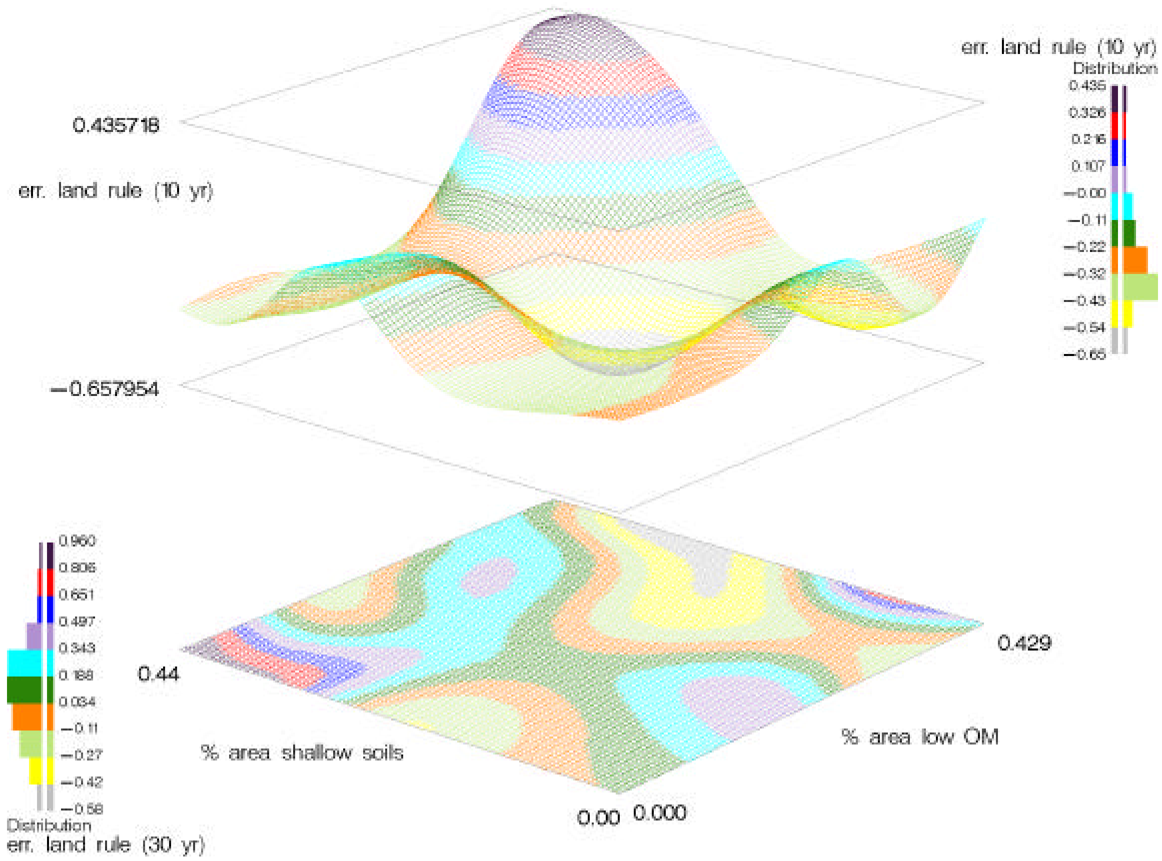

Figure 5. Error of land reduction rule against share of shallow soils and soils with low OM.

Section 5
Scenario results

We are now ready to report on the results of the four scenarios.

Stationary

Not surprisingly, the outcomes of the ‘Stationary’ scenario are dramatic (see Figure 6). Water erosion reduces the potential production of the land by 10 per cent in 2010 and even by 30 per cent in 2030. The total national agricultural revenues stagnate over this period, whereby the increase in the labour force, from 47 to 75 million people, more or less compensates for the decline in production. Consequently, the value added per capita per annum in the agricultural sector drops from 372 US$ in 2000 to 162 US$ in 2030, which is below the poverty line as defined by the World Bank (income of less than one USD (PPP[4]) per day). Likewise, food availability per capita plunges from 1971 Kcal per day to 686 Kcal per day, falling far below another threshold which is defined by the World Health Organization, where a minimum of 2600 Kcal per day for adults and 1600 for children is recommended. [5]

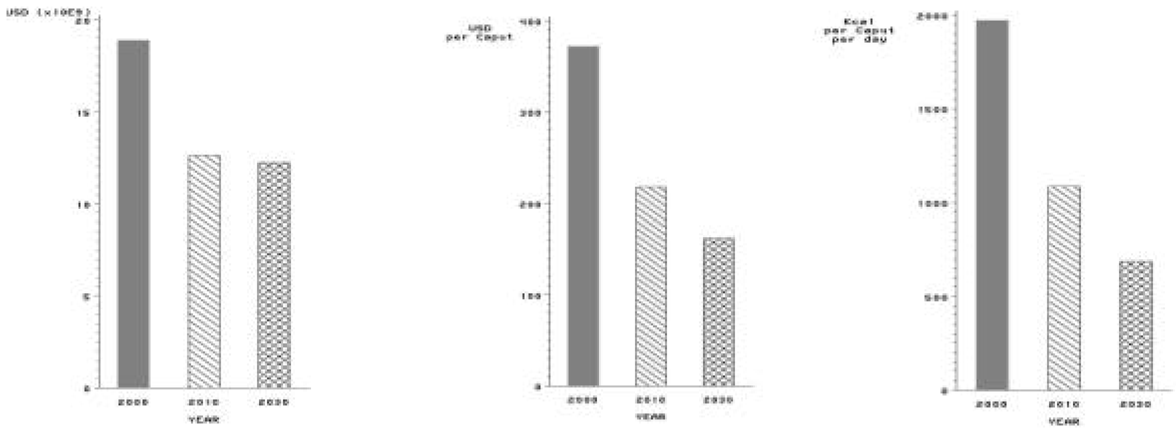

Figure 6. Developments under the Stationary scenario in (a) national agricultural revenues, (b) value added per capita per annum of rural population and (c) food availability.

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[4] Purchasing Power Parity refers to the currency conversion after correcting for the differences in price levels between countries.

[5] Biophysical output is converted to calories using the food balance sheets of the FAO and the production figures for agriculture of the World Bank for the years 1994 to 1996. In this period an average of 32 000 billion Kcal was produced[5] corresponding to a monetary gross value of 14.2 billion US$ (PPP) or a 2227 Kcal per US$ (PPP) produced food and a level of 1774 Kcal per capita per day.

Control

The Control scenario (see Figure 7) conserves soil productivity and prevents the decline in potential production. Agricultural revenues at a national level increase modestly by 3 per cent in 2010 and 9 per cent in 2030. The value added of the labour force, however, still declines, although less sharply compared with the Stationary scenario, to 324 USD in 2010 and 260 USD in 2030. Likewise, the per capita food supply improves relative to the Stationary scenario, from 1085 to 1611 Kcal per capita per day in 2010 and from 669 to 1085 in 2030. However, both food supply and value added remain significantly below the minimum for poverty and Kcal intake threshold levels.

Since under the Control and Stationary scenarios, population is not allowed to migrate, and grows at exogenously specified rates, both have the same population density. In the rainfed agricultural areas this density increases from an average of 116 persons per square km to 199 persons per square km in 2010 and 318 persons per square km in 2030. These figures greatly surpass the carrying capacity of the land which even under the Control scenario produces enough food for only 123 and 132 persons per square kilometre in 2010 and 2030, respectively.

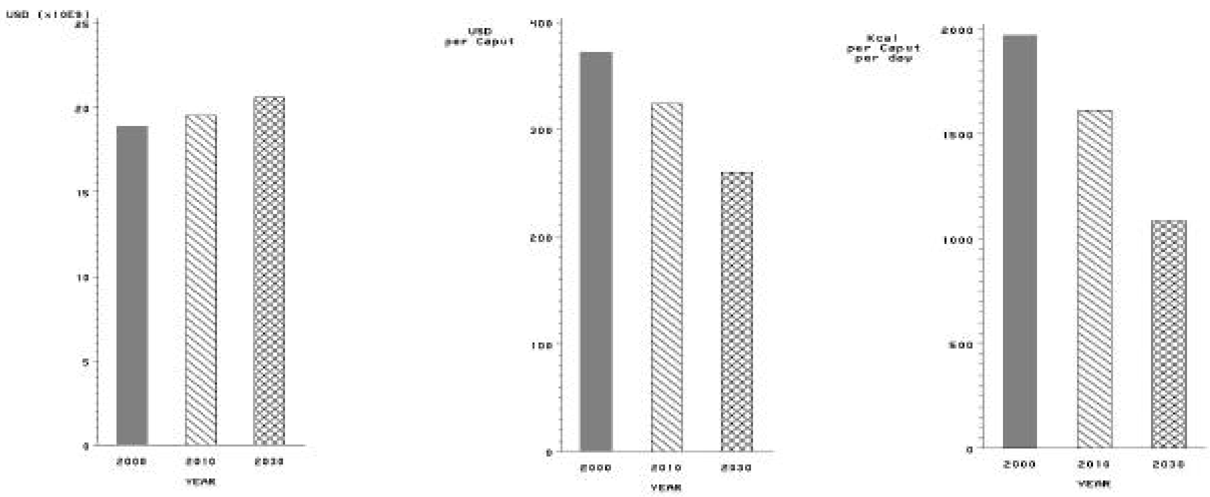

Figure 7. Developments under the Control scenario in (a) national agricultural revenues,(b) value added per capita per annum of rural population and (c) food availability.

Migration

In the migration scenarios (see Figure 8) productivity loss due to soil degradation under the ‘Restricted’ and ‘Free’ migration alternatives is partly compensated by the occupation of more productive and less affected areas. The ‘Restricted’ option shows an improvement of 16 per cent in the agricultural revenues, in 2010, compared with the stationary scenario in that year and an increase of 19 per cent for 2030, whereas the Free scenario increases food production by 24 and 21 per cent for the same years. However, compared with the base year, 2000, losses in per capita revenues are still considerable. For the years 2010 and 2030, reductions amount to 22 and 24 percent for the Restricted scenario and 17 and 18 per cent for the Free alternative and, consequently, food supply remains far from the required demands. Under the Restricted alternative, approximately 1242 Kcal and 786 Kcal per capita per day is available for 2010 and 2030, respectively, while the Free scenario is only slightly higher with 1317 Kcal and 833 Kcal, respectively, for the same years. The value added per agricultural worker decreases equally sharply, from approximately 258 USD per year in 2010 to 195 USD in 2030.

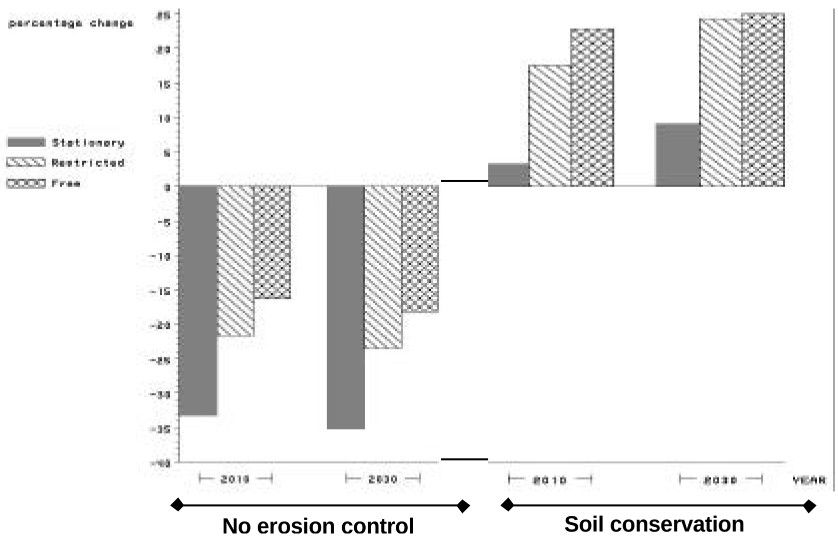

Figure 8. Changes in total agricultural revenues under the Stationary, Restricted and Free migration alternatives; without erosion control and with soil conservation.

When soil conservation measures are taken, the migration scenarios give much better results. Compared with the base year, under the Restrictive option, food production increases by 17 and 23 per cent for the years 2010 and 2030, respectively, and under the Free alternative by 23 and 30 per cent for the same years. However, increases in total food production are cold comfort if one looks at the per capita figures. For the Free option, the value added per worker decreases for the years 2010 and 2030 from 392 USD to 314 USD per year, while food availability per capita reduces in this period from 1878 Kcal to 1264 Kcal per day.

The introduction of a tropical disease control programme, whereby access is gained to west Ethiopia, also gives little solace. Food production increases only slightly, by 1 per cent on average, as compared with the no control programme. This is basically due to the agro-ecological constraints that prevail in the humid tropics. Soils are more leached and in general poorer in nutrients compared with soils in the sub-humid and semi-arid areas. Furthermore, crop diseases are difficult to combat and post-harvest losses are high due to unfavourable storage conditions.

Table 4. Population distribution (in percentage of total) by land degradation class.

Degradation class	Stationary	No erosion control		Soil conservation	
		Restricted	Free	Restricted	Free
Low	32.4	33.9	54.3	34.0	50.4
Slight	36.5	31.0	23.6	33.4	26.1
Moderate	14.7	20.8	16.6	18.6	15.3
Severe	9.6	8.3	3.3	9.1	5.1
Very severe	6.8	6.0	2.2	5.9	3.2

Table 4 presents the population distribution of the migration alternatives with respect to the occupation of degraded areas. In the Free scenario people exchange the degraded areas for the less affected ones. which shows their higher productive capacity as compared with the soils in the higher degradation classes. Population movements in the Restricted alternative, on the other hand, are limited and the population distribution over the classes is comparable to the Stationary situation, indicating that the administrative boundaries strongly impede movement to areas not affected by degradation, thereby largely continuing the cultivation of already substantially degraded areas.

The outflow of people presented in Table 5 indicates that a soil conservation programme would save on migration costs, since more people continue to live on their original sites. However, as soil erosion progresses, more people have to seek refuge in other, less degraded areas.

Table 5. Outflow (in million persons) according to erosion control and land accessibility alternatives in 2030

Migration\erosion control	Erosion	Conservation
Free	45.2	39.6
Restricted	39.8	32.4

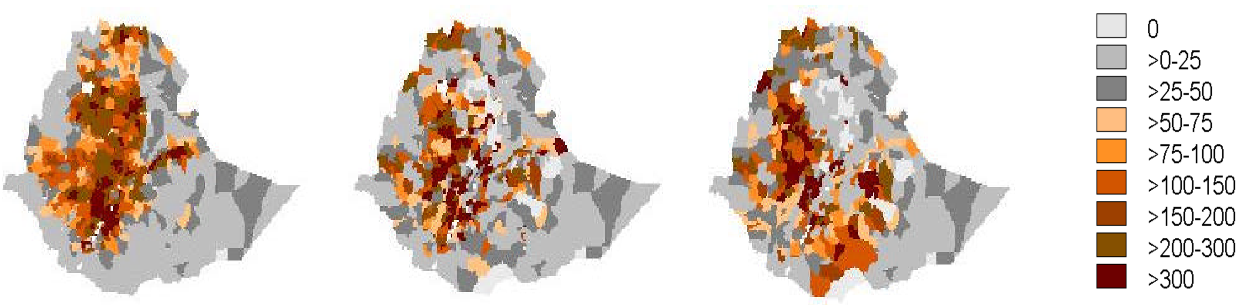

Figure 9. Population distribution (persons per square km) for the a) stationary, b) restricted and c) Free migration alternatives, without erosion control

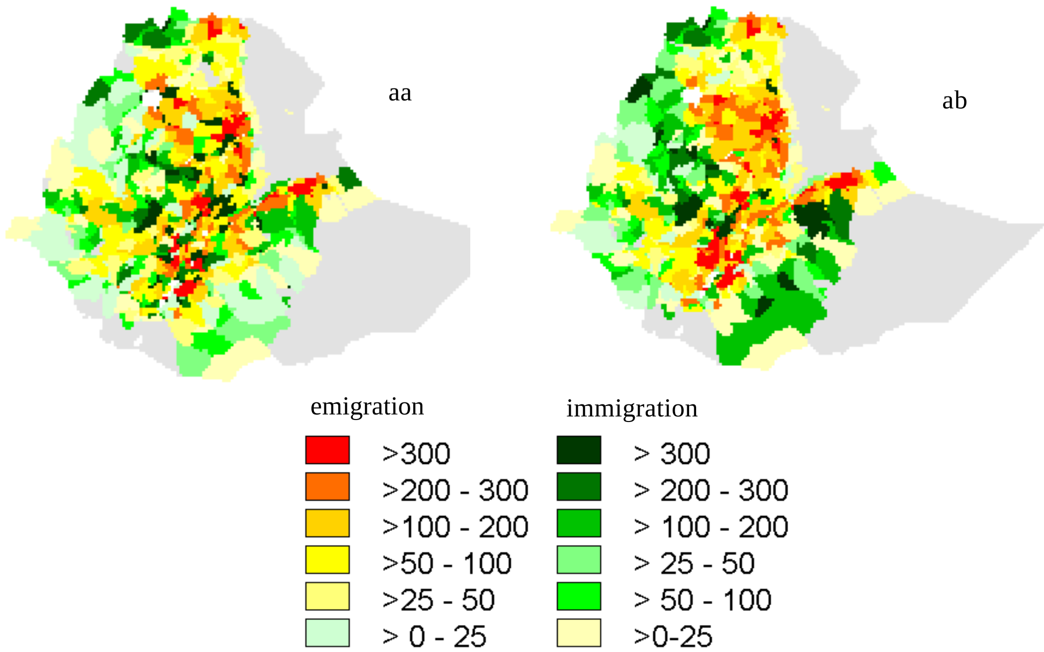

Figure 10. Migration patterns (in persons per sq. km) under the (a) Restricted and (b) Free alternative under no erosion control

Figure 9 shows the population distribution in 2030 for the Stationary, Restricted and the Free alternatives for the case where water erosion control is absent. The pattern is, as we would already expect from the discussion on table 4, similar to the soil conservation alternative.

We discuss the movements under the two migration scenarios, on the basis of the spatial distribution of net migration as shown in Figure 10. In general, we observe a dramatic emigration from the area along the Central Northern axis and in the southwestern part of the Highlands. Most of this emigration is absorbed in the southeastern fringes of the Highlands and along the mountain chain towards Somalia. The Free scenario allows more migration towards the extremities in the south east and the north west, whereas the ethno-administrative boundaries in the Restricted scenario force the people to concentrate within these boundaries.

Technology

The Technology scenarios assume a better quality produce and higher yields potentials. They allow agricultural revenues to increase above the poverty line and even compensate for loss of productivity due to the soil degradation. Agricultural revenues in absence of soil conservation and compared with the Medium input alternative, increase by approximately 160 to 230 per cent for the Stationary and Free migration alternative in the year 2010 and by 180 to 250 per cent, respectively, for the year 2030. Also the value added per person increases in 2010 to 706 USD and 824 USD for the Stationary and Free scenarios, or more than twice the value compared with the Medium input scenario. Under the High input alternative, a surplus of food is produced in 2010, even without water erosion control, that could possibly stimulate the export of agricultural products. However, by the year 2030 the effect of soil degradation on the productivity and the increasing population finds expression in a decreasing value added per capita that declines to 518 USD to 702 USD, respectively, while food supply decreases from a large surplus of 7040 Kcal to 3200 Kcal per capita per day in 2030 under the ‘Free’ scenario and even reaches a critical level 2600 Kcal in the ‘Stationary alternative’. Malaria control leads to a modest increase on agricultural revenues of approximately 2 to 3 per cent as compared with the situation when such a program is absent. This level is slightly higher than under the medium input scenario where growth was in the order of 1 per cent.

The future Technology scenario is less weak when the soil conservation programmes become effective. Agricultural revenues now increase by 280 and 305 per cent for the Stationary and Free alternative, respectively, in the year 2010 as compared with the medium input scenario and further increases by 360 and 430 per cent for the year 2030. The value added per capita in agriculture also helps to shift the per capita income further away from the poverty line and reaches levels of 1160 USD in 2010, increasing further to 1305 USD by 2030. Food supply no longer is of concern since the available Kcal (7000 Kcal per capita per day in 2010 and 6000 in 2030), by far surpasses the expected food demand, which offers possibilities for export of agricultural products. Migration movements also diminish compared with the medium input alternatives. For example, under the ‘Free’ alternative, with soil conservation, approximately 27 million people will migrate which is 13 million less compared with the medium input scenario. In the absence of erosion control, migration figures are higher, 36 million, which is still 9 million lower than under the medium input scenario.

The maps in Figure 11 represent the population density for the Free scenario in the presence and absence of water erosion control. The pictures clearly indicate that the implementation of water erosion control results in less migration, thus avoiding future conflicts over scarce land.

Finally, we discuss the impact of urbanization under the Technology scenario. It appears that urbanization eases the pressure on the land, by assuming that a higher share of the labour force can be employed in non-agricultural sectors. In the Urbanization scenario we suppose that, during the period 2000-2030, the composition of the Ethiopian labour force gradually changes into one that is comparable for a middle income country (UNDP, 1999)

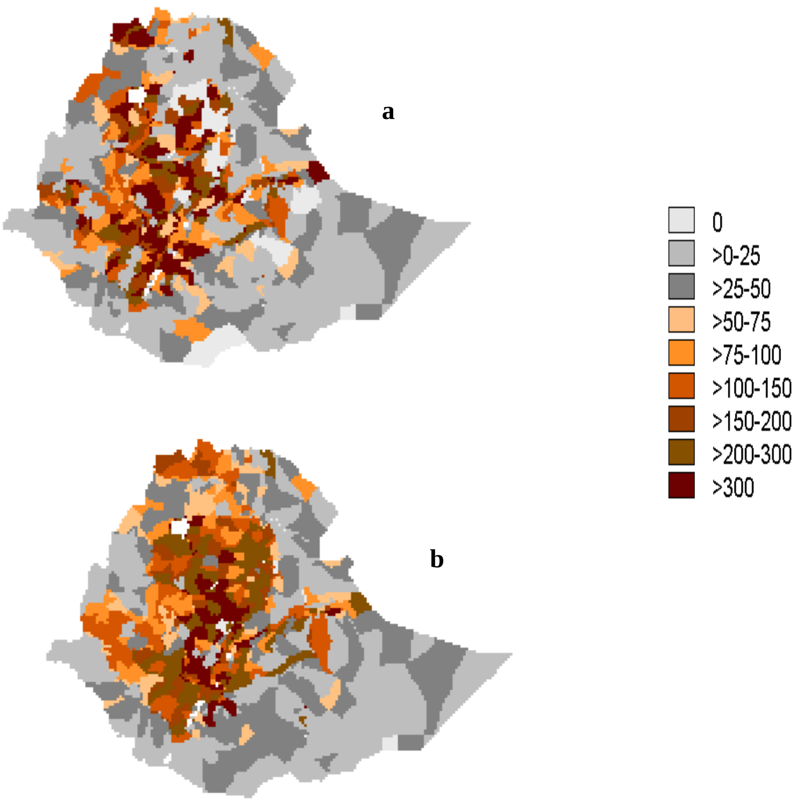

Figure 11. Population density under (a) absence and (b) presence of water erosion, under the Free migration alternative of the Technology scenario.

The differences between the accelerated urbanization (AccUrb) alternative and the population developments under the UN predictions are especially noticeable for the two input levels. Total agricultural revenues under the (AccUrb) are, under the medium input option, about 9 per cent less as compared with the UN population development and drop in 2030 to the lowest levels of this exercise with 599 and 759 Kcal for the Stationary and Free alternative, respectively. However, food supply differences are negligible under the high input option and the values added per capita of the rural population are in general higher under the AccUrb scenario then the UN population development scenario.

Equally important are developments at the national level. The Gross Domestic Product and value added per capita under the AccUrb alternative increase in 2010, by 2 per cent compared with the UN option, but for the year 2030 the difference between these two options is on average 60 per cent. The assumed higher earnings in the non-agricultural sector are the major cause of this large difference, and hence not attributable to erosion control.

Under the AccUrb option the population density in rainfed agricultural areas amounts in 2010 to 114 persons per square km, slightly lower than the UN projections (116). The difference becomes more pronounced in 2030 when densities under AccUrb are 270 persons per square km while the UN-predictions give 318 persons per square km.

Section 6
Summary and conclusion

This paper evaluates the implications for future food supply in Ethiopia under alternative scenarios of erosion control, land accessibility, technology levels and non-agricultural sector development. It uses spatial water erosion models that are based on Ethiopian data to adjust future potential yields of the affected areas. The validation of this adjustment is known to be problematic. Here we apply a rule commonly used in the literature and determine the implied distribution of land productivity in Ethiopia, at different points in time, and compare it with the historically observed pattern. The rule appears to produce an interpretable drift in the distribution. We also found that the applied rule reflects the degradation process more accurately than yield reduction rules that are applied at more aggregated level, without discriminating between the soil types. Furthermore, we estimated an agricultural production function with land, labour, and the yield potential as input variables, and study the effect of soil conservation measures including erosion control and intensified application of agrochemicals. We also apply the production function in an optimization model that maximizes national agricultural revenue under different assumptions with respect to the possibilities for the rural population to migrate to other rural areas with better prospects. Table 6 summarizes the results of the four scenarios by presenting: the total value added of the national agricultural production, food supply per kaput, value added for the rural population and the value added for the total population.

The simulations confirm that the Ethiopian agricultural sector has to increase its production significantly to meet the future food demands of its fast growing population. An expanding rural labour force, even in combination with the implementation of a soil conservation programme will not sustain a satisfactory level of food supply. Rural-to-rural migration increases the national agricultural revenues, whereby trans-regional migration generates slightly better results compared with a movement within areas of ethnic origin. Nevertheless, even free migration within the country, combined with increased accessibility to the humid western part of the country, by controlling tropical diseases, does not result in adequate per capita revenues.

As regards the spatial distribution, under free migration the highly degraded areas are exchanged for less affected sites, whereas under restricted migration, where the population has to stay within given ethnic-administrative boundaries, cultivation continues on already substantially degraded soils. The Free scenario generally involves moving to zones of a

Table 6. Summary of scenario results

Scenario		Soil Conser-vation	Net Food production (in billion USD; PPP)		Food per caput (in Kcal)		Value added per caput: rural population (in USD; PPP)		Value added per caput: total population (in USD; PPP)	
			2010	2030	2010	2030	2010	2030	2010	2030
Stationary		No	12.4	12.0	1083	685	218	162	627	1267
Control		Yes	17.8	18.7	1611	1085	324	260	709	1330
Migration	Restricted	No	15.9	16.1	1242	786	263	198	662	1290
		Yes	23.2	25.0	1801	1213	383	307	754	1360
	Free	No	16.9	17.1	1317	833	279	210	674	1298
		Yes	24.2	26.0	1878	1264	399	320	767	1368
Technology	Stationary/ UN	No	43.5	42.9	3978	2681	706	519	1004	1497
		Yes	65.4	42.1	6228	5852	1060	1038	1277	1833
	Stationary/ AccUrb	No	43.5	46.4	3968	2605	705	508	1021	1661
		Yes	65.3	84.4	6212	5682	1058	1021	1366	1992

different ethnic entity. Hence, it would require reforms of the ethnically-restricted land tenure systems so as to avoid conflicts over scarce land.

Obviously, a shift to higher technological levels gives better prospects also on a per capita basis, and when combined with soil conservation activities this significantly moderates the need for migration. Concentration on higher input levels without erosion control is not a sustainable path either. The new technologies may initially mask the productivity loss, especially because less land needs to be cultivated due to increased yield. Yet, the continuing soil erosion inevitably results in a decline of food production, whereby food supply gradually drops to critical levels after some years. Basically, the short-term measure of substituting soil loss by higher inputs cannot conceal the reality of the increasingly shallow soils, which have lost their vital role as a medium for plant growth.

The model results further clearly indicate that value added per worker decreases over time, even for the high input alternative, indicating the limited possibilities for future employment in the agricultural sector. The accelerated growth of non-agricultural sectors would alleviate the poverty in the countryside and contribute to higher revenues for the total population. Therefore, the development of non-agricultural activities is of utmost importance to, simultaneously, absorb a surplus of the rural labour force and further relieve the pressure on the land.

Finally, we mention as limitation of this study that we have presented different scenarios without attributing a probability to any of these, and without indicating how Ethiopia could effectuate a transition to the more favourable ones. In particular, the 'Stationary' scenario impedes a further use of agricultural inputs, thereby trapping the population in a downward moving poverty spiral without any possibilities to escape. Many case studies (Tiffen et al., 1995; Shaxson et al. 1999) show that these poverty and pressure situation stimulates the development of innovative techniques making the situation less dramatic compared with the scenario results. The ‘Technology’ scenario, on the other hand, supposes that both yields and quality of the produce improve so as to create a surplus of agricultural products. These products will have to be sold, to urban areas, and possibly exported. This requires an infrastructure most of which still has to be developed and the costs of which were not explicitly dealt with. Finally, the assumed increase in output and earnings in the non-agricultural sector, possibly including remittances from Ethiopian workers abroad, is questionable but this scenario serves to illustrate that an escape from poverty cannot build on agriculture alone.

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The Centre for World Food Studies (Dutch acronym SOW-VU) is a research institute related to the Department of Economics and Econometrics of the Vrije Universiteit Amsterdam. It was established in 1977 and engages in quantitative analyses to support national and international policy formulation in the areas of food, agriculture and development cooperation.

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Centre for World Food Studies
SOW-VU
De Boelelaan 1105
1081 HV Amsterdam
The Netherlands

Telephone (31) 20 - 44 49321
Telefax (31) 20 - 44 49325
Email pm@sow.econ.vu.nl
www http://www.sow.econ.vu.nl/