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ANALYSIS

Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa

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Abstract

Soil nutrient depletion is considered as the biophysical root cause of declining per capita food production in sub-Saharan Africa (SSA). Data from 37 countries in SSA confirm a significant relationship between population pressure, reduced fallow periods and soil nutrient depletion (including erosion), indicating a generally unsustainable dynamism between population, agriculture and environment. It is estimated that nutrient depletion accounts for about 7% of the agricultural share in the average Gross Domestic Product of SSA with national values ranging up to 25%, indicating soil nutrient mining as a significant basis of current economic performance. With respect to increasing population densities, it is argued that more than proper soil management will be required to sustain food security. While soil scientists and farmers can reduce the speed of the dynamism only, policy-makers are requested to address also the demographic and economic root causes of soil degradation. Care should be taken that the 'obvious' simplicity of the dynamism will not provide the groundwork for corresponding blueprint solutions, ignoring the diversity of the biophysical and socio-economic environment of SSA.

Keywords: Population density; Soil nutrients; Economic growth; Sub-Saharan Africa

1. Introduction

Africa's population continues to grow at higher rates than on any other continent, and soil fertility depletion is considered as the major biophysical factor limiting per capita food production on the majority of African small farms (Sanchez et al., 1997). With economies mostly dependent on agriculture, especially in Eastern, Western, and Central Africa, soil degradation is a major threat to overall economic development (Scherr, 1999).

While there are many case studies from Africa on the costs of soil degradation in general or soil erosion in particular (see reviews by Bojö, 1996; Scherr, 1999), this paper describes the relationships between soil nutrient depletion, population

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density, and economic growth at the supranational or continental scale in sub-Saharan Africa (SSA). Nutrient depletion or nutrient mining in this context means the net loss of plant nutrients from the soil or production system due to higher nutrient outputs (through leaching, erosion, crop harvest, etc.) than inputs (e.g. through rainfall, manure, mineral fertilizer, fallow), resulting in a negative nutrient balance.

2. Materials and methods

A data bank comprising national statistics and projections of different sources, mainly FAO-AGL (2000), FAO (1986, 2000), The World Bank (1998, 1999), Winand Staring Centre/DLO (Stoorvogel and Smaling, 1990) and IBSRAM (Drechsel and Gyiele, 1999), was used. SPSS for Windows was utilized for data processing and graphics.

3. Results and discussion

3.1. Nutrient depletion in sub-Saharan Africa

On request of the Land and Water Development Division (AGL) of FAO, a landmark assessment on nutrient depletion in SSA was produced by the Winand Staring Centre/DLO (Stoorvogel and Smaling, 1990; Stoorvogel et al., 1993). A range of studies has followed this work, focusing primarily on fine-tuned estimates of nutrient flows and budgets (cf. Smaling et al., 1999). Most assessments showed that nutrient losses are only partially compensated for by natural and man-made inputs. The annual NPK balances estimated for SSA are negative with minus 26 kg N, 7 kg P_2O_5, and 23 kg K_2O ha^{-1} $year^{-1}$ in the year 2000 (Stoorvogel et al., 1993). As the authors aggregate differently available nutrient pools, a wide variety of land-use systems, crops, and agro-ecological zones in each country, these data are only approximations of the problem (cf. Scoones and Toulmin, 1998, 1999), but still the best general estimations available. On closer inspection of the different processes contributing to nutrient depletion in SSA, the data show that crop harvest (product and residues) plus erosion constitute about 70% of all N losses, nearly 90% of all K losses, and 100% of the P losses.

In comparison with erosion, nutrient leaching appears in general to be a minor contributor to N and K depletion, and is negligible in terms of P, but may become substantial in certain cases (eg. fertilization) and with respect to other nutrients (Pieri, 1992; Poss and Saragoni, 1992). If we calculate scenarios for upland SSA with zero erosion, zero runoff, and zero leaching, we still get a negative N and K balance through the amount of nutrients lost with the harvested crop and its residues. This means that although soil conservation is crucial, it can only reduce the speed of nutrient depletion under the current level of inputs. Corresponding empirical evidence is found in several case studies: While soil conservation measures are usually very effective in reducing soil erosion, a yield impact is often barely observed if no other inputs are simultaneously provided (Grohs, 1994; Steiner and Drechsel, 1998; Herweg and Ludi, 1999). An exception will be an increased availability of soil moisture in water constraint production systems.

3.2. Relation between nutrient depletion and land pressure

FAO estimates of the actual supporting capacity of land ranges from 10 to 500 persons km^{-2} (Henao and Baanante, 1999). The critical level is imposed by the reduced availability of or access to resources, such as fertile land, water, fuelwood, or off-farm capital and the growing needs of an expanding population. The results of these constraints are reduced fallow periods, limited soil fertility regeneration and an increased cultivation of marginal soils. Although case studies show that there are (temporary?) exceptions (for example, Pieri, 1992; Tiffen et al. 1994; Mazzucato and Niemeijer, 2000), the general picture is alarming. Under the current level of fertilizer and manure input, we can calculate the fallow periods necessary for natural N replenishment. On average for SSA, an R value[1] of about 0.2 would be required.

[1] R = years of cultivation/(years of cultivation + fallow years).

Today, this situation is rare in SSA, where the current average R value is estimated to be about 0.60. This implies most farming systems cannot afford the required fallow periods to prevent nutrient mining. The rapidity of soil degradation will depend on local soil fertility levels, and vary with farmers' possibilities and constraints for soil conservation and nutrient replenishment. There are interesting case studies that show farmers' ability to adapt to changing conditions. This includes increased fertilizer application rates with increasing population pressure at smallholder level (for example, Mazzucato and Niemeijer, 2000; Manyong et al., 2001). However, the quantities applied are often very modest due to problems of input availability and/or high costs. Moreover, increased (nitrogen) fertilization does not always improve the negative nutrient balance due to higher nutrient exports through leaching and crop uptake. In other words, food supply will be improved, but land degradation may continue, thus the mechanisms described by Boserup (1965) do not apply automatically to an intensification solely through increased fertilizer use on the poor (low cation retention) resource base of large parts of upland SSA. Complementary soil organic matter build up would be necessary to improve the situation; this, however, requires many years or illusory large amounts of organic fertilizers and related labour input (Diels et al., 2001).

Fig. 1 combines data on N and P depletion in SSA and rural population densities at the supranational level. The relationship seems to confirm the hypothesis of the unsustainable population–agriculture–environment nexus (Cleaver and Schreiber, 1994) that leads through a downward spiral into the poverty trap. However, nutrient mining is only one facet of land degradation: The carrying capacity of land in the Sahel, for example, can be reached under much lower rural population densities than 'implied' in Fig. 1. There are also other countries that do not follow this general trend: e.g. Malawi shows high erosion rates and severe nutrient mining due to its specific topography even under relatively low population density. In Lesotho, on the other hand, relatively high P fertilization rates on a small arable area keep the P stocks in balance. An even stronger case and example of Boserupian mechanisms is the French island Mauritius (not shown in the figure), where a high population density is accompanied by high fertilizer consumption. In fact, FAO (2000) data show an intriguing positive relation between average population density and fertilizer consumption also for the whole of SSA (Fig. 2), which, however, is mainly based on the support of export-oriented and input-intensive cash crops (cotton, cocoa, etc.).

Comparing nutrient depletion rates with total population densities results in a weaker correlation than comparing it with rural population densities as in Fig. 1, indicating a higher pressure through decreasing farm sizes and fallow periods on soil fertility than through aggregate product demand. The most affected countries, such as Burundi, Rwanda or Kenya, show at least in part high altitudes, which have been for many centuries favourite settlement areas because of a relatively healthy, mild climate and sufficient rains. Erosion is certainly a major nutrient depleting process in this area, but even under the assumption of zero-erosion, our models still show higher nutrient depletion rates in the East African highlands than other regions of SSA. One reason is that the highlands show regionally higher soil nutrient levels than soils in other regions of Africa and hence have more nutrients to lose. The major reasons are the general high population pressure and land-use intensity resulting in higher nutrient exports through crop removal with significantly lower percentage of arable land under fallow.

This is illustrated in Fig. 3, which combines data of different climates per country[2] and shows that regions where fallow periods are still common generally show less nutrient mining. Very high N depletion rates (>40 kg ha^{-1} year^{-1}), on the other hand, are widespread in areas with less than 50% of arable land under fallow. However, the relationship is not linear and fallow decline does not enhance nutrient mining in any case. Regression analysis shows that, among the biophysical variables, the percentage of slopes over 30% is able to explain additional variation of the negative nitrogen balance.

[2] Areas with large-scale irrigation or natural flooding are not considered.

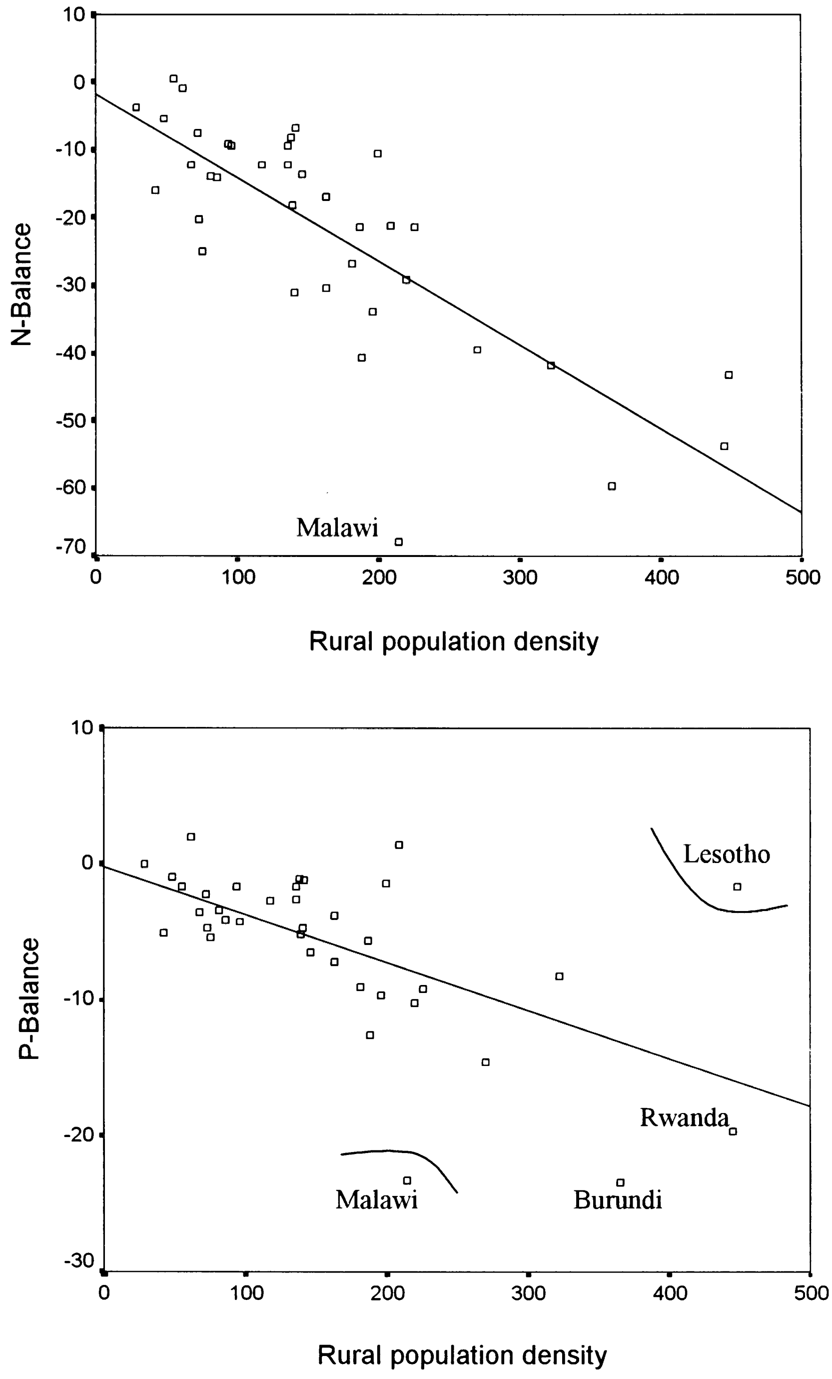

Fig. 1. Increasing nutrient depletion with increasing population density. Population density refers to the rural population per square kilometre annual and permanent cropland; annual nitrogen (above) and phosphorus (below) balances are in kg ha^{-1}. Projections for 37 SSA countries ($R^2 = 0.70$, $P < 0.001$ (above); $R^2 = 0.35$, $P < 0.001$ (below)).

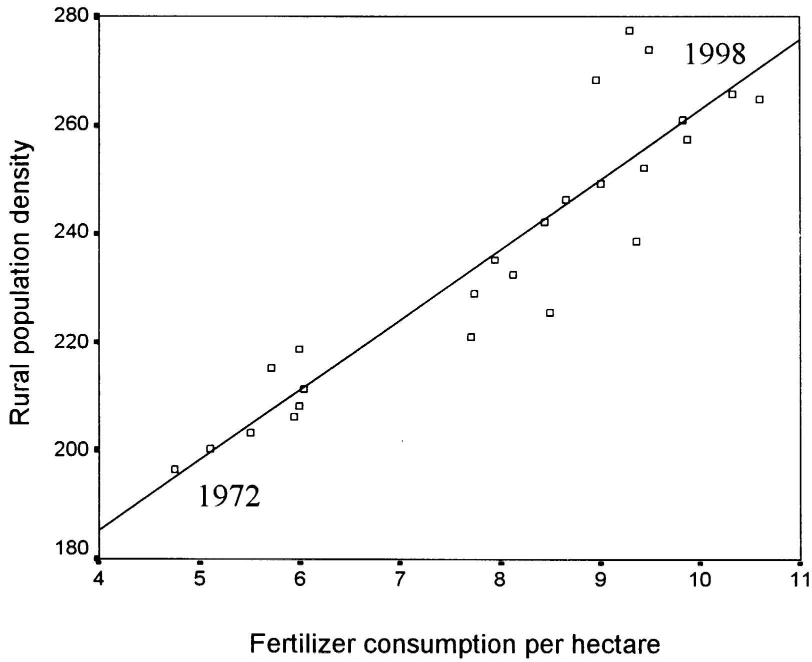

Fig. 2. Increasing fertilizer use (kg ha^{-1} arable land) and rural population density per square kilometre arable land between 1972 and 1998 in Sub-Saharan Africa ($R^2 = 0.85$, $P < 0.001$). Data adapted from FAO (2000).

3.3. The costs of nutrient depletion

The impact of nutrient mining on economic growth can be assessed with the replacement costs approach (RCA), which assigns monetary value to the depleted nutrients. This is often based on the cost of purchasing an equivalent amount of nutrients in chemical fertilizers. The RCA is simple to apply when the nutrient balance has been calculated (Drechsel and Gyiele, 1999).

Our assessment of the on-site replacement costs of annual NPK depletion is based on the national nutrient balance predictions by the Stoorvogel–Smaling team for the year 2000 (and its strengths and weaknesses) and a national fertilizer retail price survey by IBSRAM in 1999. Replacement costs of non-available nutrients, e.g. in eroded soil material, have been excluded[3] because they are not directly related to productivity and difficult to compare with nutrients in fertilizers (cf. Bojö, 1996). Thus, the economic on-site impact of erosion becomes much smaller, and the total cost assessment more conservative if available nutrients are valued higher than non-available nutrients. This narrows the gap usually observed between assessments made with the RCA and the productivity loss approach (cf. Bojö, 1996; Drechsel and Gyiele, 1999). The adjustment for nutrient availability by using the RCA mostly affects countries with high nutrient depletion rates through erosion, such as Malawi. In such a case, high (total) nutrient losses do not automatically represent high on-site costs. However, the economic off-site impact would be worth studying (Enters, 1998).

In certain countries, such as Rwanda, Tanzania, Mozambique and Niger, nutrient depletion accounts for up to 25% of the Agricultural Gross Domestic Product (AGDP), indicating nutrient mining as a significant basis of economic growth (Table 1). For the whole of SSA, nutrient mining accounts for about 7% of the sub-continental

[3] We assume that, in most cases, a maximum of 6% of the total NPK contents in eroded soil material is available. For further details, see Drechsel and Gyiele (1999).

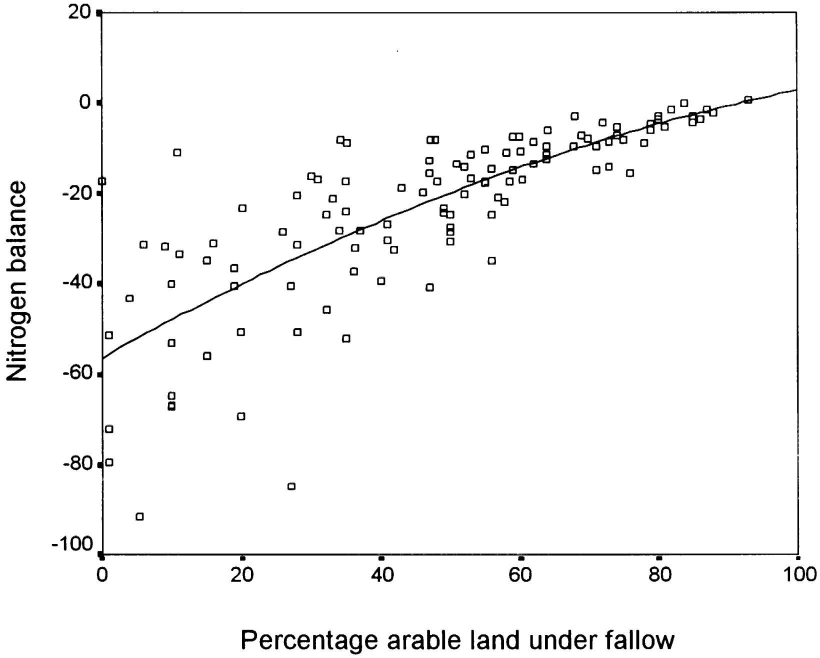

Fig. 3. Relation between N balance (kg ha^{-1} year^{-1}) and the percentage of arable land under fallow in SSA (data from up to four rainfall zones per country; $n = 115$, $R^2 = 0.61$, $P < 0.001$).

AGDP. This amount (US$4 billion year^{-1}) exceeds the annual external assistance to the development of African agriculture in the past decade by about 30–50%, which gives an indication of the financial dimension, also with regard to blueprint solutions (e.g. large-scale fertilization) to the depletion problem.

4. Conclusions

The comparison of regional and national data from SSA shows increasing land degradation through nutrient depletion related to population pressure and land-use intensity, a nexus so far mostly known from case studies at lower scales. This relation should be acknowledged in the political agenda as it could have a significant economic dimension. This is often ignored due to the difficulty of providing a generally acceptable assessment. The difficulties concern less the economic approach than the extrapolation of nutrient balance data to larger scales (cf. Scoones and Toulmin, 1998, 1999). Hence, the results presented in this paper might only sketch reality, but show possible magnitudes to encourage debate between scientists and policy-makers.

The question remains: What can be done to counteract nutrient depletion and to minimize the negative population-degradation nexus? First of

Table 1
Sub-Saharan Africa nations grouped according to on-site nutrient depletion costs in percentage of the Agricultural Gross Domestic Product (AGDP)

Country	% of AGDP
Benin, Botswana, Cameroon, Central African Republic, Dem. Rep. Congo, Rep. Congo, Gabon, Ghana, Guinea, Kenya, Mauritania, Mauritius, Sierra Leone, Swaziland, Zambia, Zimbabwe	≤5
Angola, Burkina Faso, Burundi, Chad, Côte d'Ivoire, Ethiopia, Lesotho, Madagascar, Malawi, Mali, Nigeria, Senegal, Togo, Uganda	6–11
Mozambique, Niger, Rwanda, Tanzania	>11
SSA (average)	7

all, we should take care not to translate the 'obvious' simplicity of the nexus (cf. Fig. 1) into corresponding simple solutions, ignoring the diversity of the biophysical and socio-economic environment of SSA.

Second, we should accept that the continuously shrinking resources base per capita will set limits to many technical improvements, especially to often highlighted indigenous adaptations and low external input agriculture (Drechsel et al., 2001). In fact, it will require more than proper soil management to escape from the population-degradation nexus towards food security. There are at least three areas that should receive equal attention.

1. Agricultural research remains important to find together with farmers site-adapted measures for both soil fertility conservation, nutrient replenishment, and yield increase in general. The technologies are in principle known; the task is determining which one fits best into each local context. Bottleneck: Spectacular yield increases usually remain the exception.
2. Socio-economic analysis of the circumstances of soil degradation could help to identify location-specific (market) conditions that could encourage farmers to invest in their soils. Bottleneck: It will remain in many cases difficult to change these conditions.
3. Policy advice addressing demographic–economic developments at the macro-level with special attention on rural out-migration, urbanization, and rural–urban interactions, but also on strategies to narrow the gap between the private and social interest in fertility reduction.

Cleaver and Schreiber (1994), FAO (1995), Donovan and Casey (1998), Scherr (1999), Scoones and Toulmin (1999) have extensively discussed these and other areas of concern and required intervention, in part from different but largely complementary points of view.

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