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Nutrient Flows in Agricultural Production and International Trade: Ecological and Policy Issues

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Abstract

This paper addresses the issue of environmental and ecological impacts of nutrient flows within and between countries by reviewing and presenting data on nutrient balances and global nutrient movements. The results for nutrient depletion in agricultural soils during 1996-1999 show that in most countries in Africa and Latin America and the Caribbean rates of depletion are so high that current land use is not sustainable. At the other end of the scale, nutrient surplus derived from agriculture is most serious in the USA and industrialized countries of Europe, but also occurs in some densely populated areas of countries such as India and China.

International net flows of NPK in traded agricultural commodities were estimated to total 4.8 Tg in 1997 and predicted to increase to 8.8 Tg in 2020. Flows vary widely across regions. Major net importers of NPK are West Asia/North Africa and China. Although soils in countries of Sub-Saharan Africa are widely known to be heavily degraded due to nutrient depletion, this region is nevertheless a net importer of NPK in agricultural commodities. However, the nutrients imported in food and feed commodities to Sub-Saharan countries are commonly concentrated in the cities creating waste disposal problems rather than alleviating deficiencies in rural soils. Countries with a net loss of NPK in agricultural commodities are the major food exporting countries – the United States, Australia, and some countries of Latin America.

A wide range of policy measures influence agricultural trade, nutrient flows and balances. The effects of agricultural trade liberalization and the reduction of production subsidies are briefly described, as well as more direct environmental policies like nutrient accounting schemes, eco-labeling, and nutrient trading. Our study highlights the need for environmental costs to be factored into the debate on nutrient management and advocates more inter-disciplinary research on these important problems.

Kurzfassung

Die vorliegende Arbeit stellt die Bedeutung von Nährstoffflüssen innerhalb und zwischen Nationen für Umwelt und Ökologie anhand von Nährstoffbilanzen und globalen Nährstoffflüssen dar. Die Daten für die Jahre 1996-1999 zeigen, dass aufgrund starker Nährstoffverarmung die Böden der meisten afrikanischen, lateinamerikanischen und karibischen Ländern nicht weiter nachhaltig genutzt werden können. Der durch die Landwirtschaft hervorgerufene Überschuss an Nährstoffen ist ein besonders ernstes Problem in den industrialisierten Ländern Europas und in den USA, aber auch in dicht besiedelten Gebieten Indiens und Chinas.

Internationale Nettoflüsse von NPK (Stickstoff, Phosphor und Kalium) variieren stark zwischen den Regionen. Die Nettoimporteure landwirtschaftlicher Handelsprodukte sind Westasien/Nordafrika und China. Obwohl Böden in afrikanischen Ländern südlich der Sahara bekanntermaßen durch Nährstoffverarmung stark degradiert sind, sind diese Länder trotzdem Nettoimporteure von NPK in landwirtschaftlichen Waren. Die Nährstoffe, die in Lebensmitteln und Tierfutter in die Länder südlich der Sahara eingeführt werden, konzentrieren sich aber normalerweise eher in den Städten und führen dort zu einem Müllproblem, als dass sie die Defizite in den ländlichen Böden lindern helfen. Länder mit einem NPK-Nettoverlust über landwirtschaftliche Produkte sind wichtige Lebensmittelexporteure wie die USA, Australien und einige lateinamerikanische Länder.

Eine große Anzahl von Politikmaßnahmen beeinflusst den landwirtschaftlichen Handel und damit die Nährstoffflüsse und -bilanzen. Die Auswirkungen der Liberalisierung des Handels und der Reduktion der Subventionen für die Produktion werden kurz beschrieben, sowie die direkteren ökologischen Politikmaßnahmen wie Aufrechnungsschemata für Nährstoffgewinne und -verluste, ökologische Zertifizierung und der Handel mit Nährstoffen. Unsere Studie unterstreicht die Notwendigkeit, Umweltkosten in die Debatte über den Umgang mit Nährstoffen einzubeziehen und befürwortet eine stärkere interdisziplinäre Forschung zu diesem wichtigen Thema.

1 Introduction

Human-induced changes to the cycling of nutrients in terrestrial ecosystems significantly affect the sustainability of food production, the state of the natural resource base, and the health of the environment. Agricultural expansion and intensification to meet the needs of the expanding population have amplified human dominance of the Earth's ecosystems to the point where between one-third and one-half of the land surface has been transformed (Vitousek et al., 1997). Moreover, Smil (2001) credits the synthesis of ammonia through the Haber-Bosch process as the most important technical invention of the twentieth century – without fertilizer nitrogen the Earth could not sustain 6 billion people.

The changes wrought by humans in nutrient cycling and budgets are complex and vary widely in magnitude across the globe. Vlek et al. (1997) estimate that 230 million tons[1] (Tg) of plant nutrients are removed yearly from agricultural soils, whereas global fertilizer consumption of N, P_2O_5 and K_2O is 130 Tg. In the case of nitrogen the fertilizer supplements are augmented by an estimated 90 Tg from biological fixation. Although developing countries now consume half the global fertilizer production, much is used on cereal crops grown on the irrigated lands of Asia or on cash crops. Large rainfed areas producing food crops in the tropics, particularly in Sub-Saharan Africa, receive little or no fertilizer. Low inputs and limited re-cycling of nutrients by poor small-holders in these areas lead to negative nutrient balances that render continued crop production unsustainable (Stoorvogel and Smaling 1990). This exploitation of native soil fertility is coupled to a decline in soil organic matter that contributes to climate change.

The negative nutrient balances due to inadequate external inputs, and the inequitable distribution of nutrients between and within countries, are exacerbated by the transport of nutrients in harvested products. At the global scale, Miwa (1992) showed that international trade in food commodities led to significant negative balances in exporting countries and accumulations in importing countries. The environmental impacts of inter- and intra-national nutrient flows are commonly concentrated in the burgeoning cities. For example, Faerge and Penning de Vries (2001) estimated that 20 000 Mg of nutrients were annually imported in food into Bangkok, and that large amounts of nutrients were lost, mainly to the waterways. Coping with high concentrations of nutrients in the environment is a major problem facing urban administrations, and the problems are likely to get worse with the continued trend to

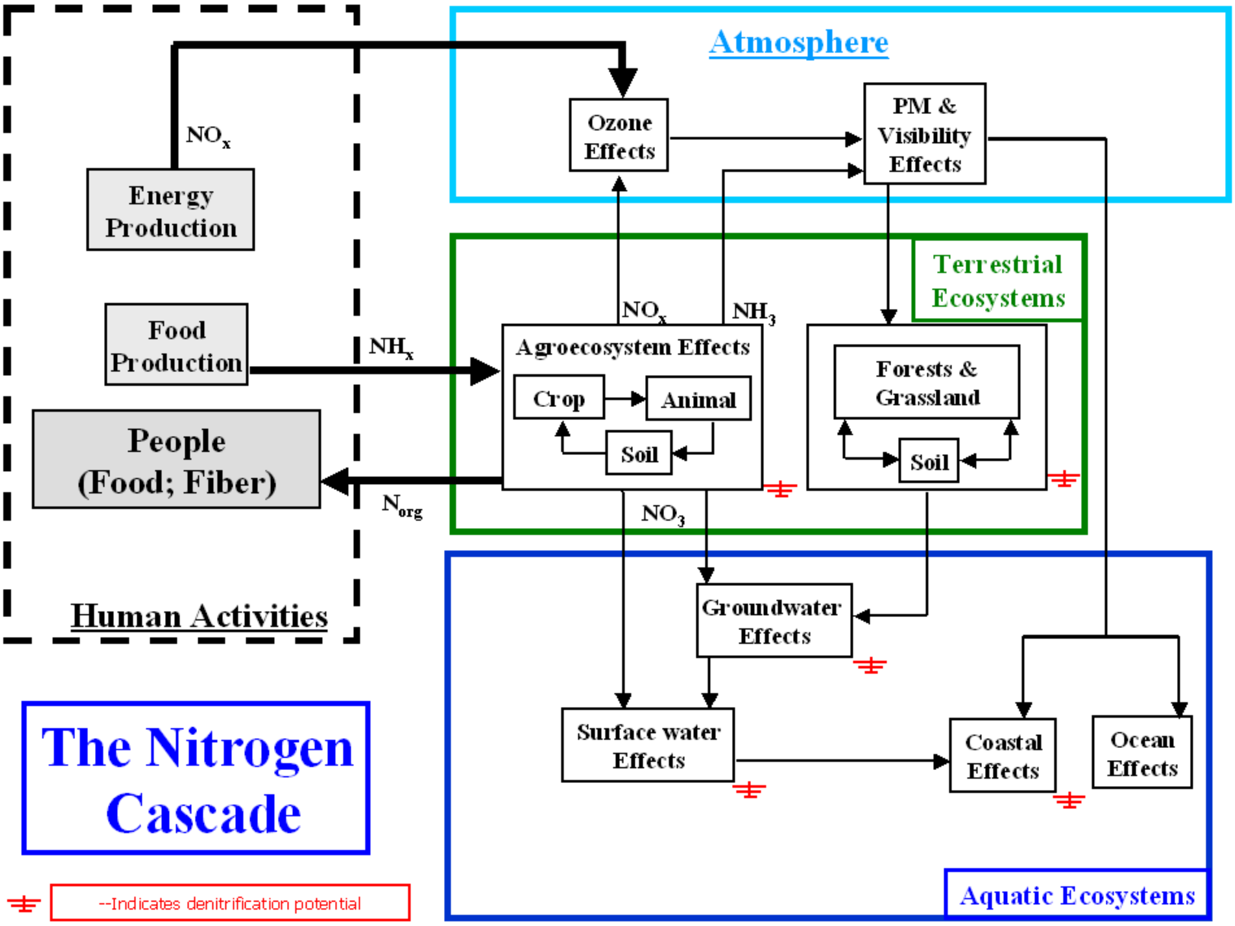
[1] This paper utilises SI units as follows: Mg = 1000 kg (1 metric ton); Gg = 1 000 000 kg (1000t); Tg = 1 000 000 000 kg (or 1 million t) – Unless specified as the oxide forms P_2O_5 or K_2O, and in Chapter II.2, amounts of P and K are expressed as uncombined elements.

urbanization. Similar problems occur in intensive animal production systems. Nutrients can be re-cycled through the application of wastes to crops and forages but, in spite of the obvious benefits, the extent of re-cycling is limited in most cities. Income growth and expanded demand for animal products in developing countries will increase international and intra-national trade in animal feed, aggravating the mining of rural soils and the environmental problems in animal production areas.

Environmental impacts on waterways of nutrient outflows from agricultural lands are widespread. In marginal areas, erosion of upper-catchment soil by water (and in some cases by wind) enriches surface waters with nutrients. Sediment is deposited and enriches lowland areas. However, annual net ocean outflows of sediments in Asia are as high as 7,500 Tg, representing a major loss of nutrients to the countries concerned (Milliman and Meade, 1983). Global net outflows of dissolved inorganic nitrogen to the oceans have been estimated at 18,291 Tg (Seitzinger and Kroeze, 1998). These flows of nutrients are in turn affected by human diversions of surface water, such as dams that collect silt and reduce flows to natural wetlands.

Other environmentally important human-induced perturbations of nutrient cycles include impacts on fluxes of nitrogen oxides that contribute to the greenhouse effect and ozone depletion and the accumulation in groundwater of nitrates and other nutrients that affect human health. Nitrogen has been more extensively studied than the other macronutrients, phosphorus and potassium, possibly because human impacts on the global nitrogen cycle extend to industrial perturbations, and atmospheric as well as terrestrial and aquatic phases (see Figure 1).

Figure 1: Human Impacts on the Nitrogen Cycle or Cascade



Source[2]: Galloway and Cowling (2002)

The above overview indicates that a substantial, though fragmented knowledge base is developing on the agricultural, ecological, and environmental aspects of alterations to nutrient flows and balances at different scales. The information and data vary in accuracy and are derived from a dispersed group of studies by authors from a wide range of disciplinary interests, including ecologists, soil scientists, and agricultural scientists. In contrast, the economic impacts and implications of these perturbations to nutrient cycling have been relatively neglected. One of the exceptions in the area of nutrient balances is the work of Drechsel and Gyiele (1999) who developed a framework for the economic assessment of soil nutrient depletion. Their data show that the cost of replacing nutrients lost from arable land in countries of Sub-Saharan Africa ranges from <1% to as high as 25% of the national Agricultural Gross Domestic Product. Related to the population engaged in agriculture, every farm member contributes about US$32 to the annual nutrient deficit. Related to the annual and permanent cropland in Sub-Saharan Africa, the average costs are about US$ 20 /ha and per year.

[2] If no source reference is cited, the data in the Table or Figure are derived from the present study.

At the other end of the scale, combating environmental pollution from imported nutrients in urban areas is a major multi-billion dollar industry in both developing and developed countries.

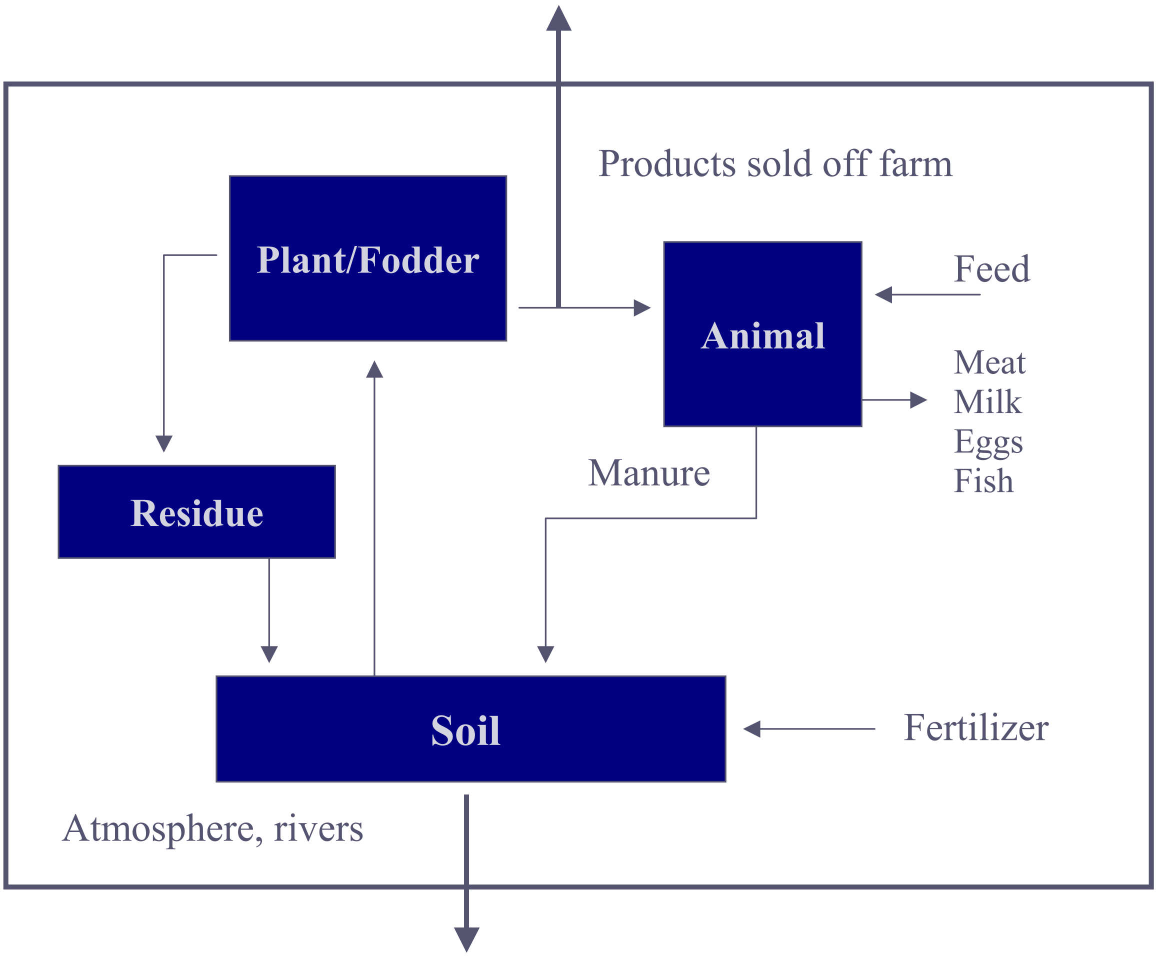
This paper focuses on three inter-related aspects of nutrient flows. Firstly, we review and present data on the nutrient balance of nutrient-rich and nutrient-depleted agricultural lands. Secondly, we present estimates of nutrient flows in internationally traded agricultural commodities in 1997 and IFPRI projections to 2020, and discuss the associated equity issues and environmental consequences. Finally, we consider the implications of current and possible agricultural, trade and environmental policies for nutrient flows and balances associated with international trade.

2 Nutrient Balances

2.1 Background

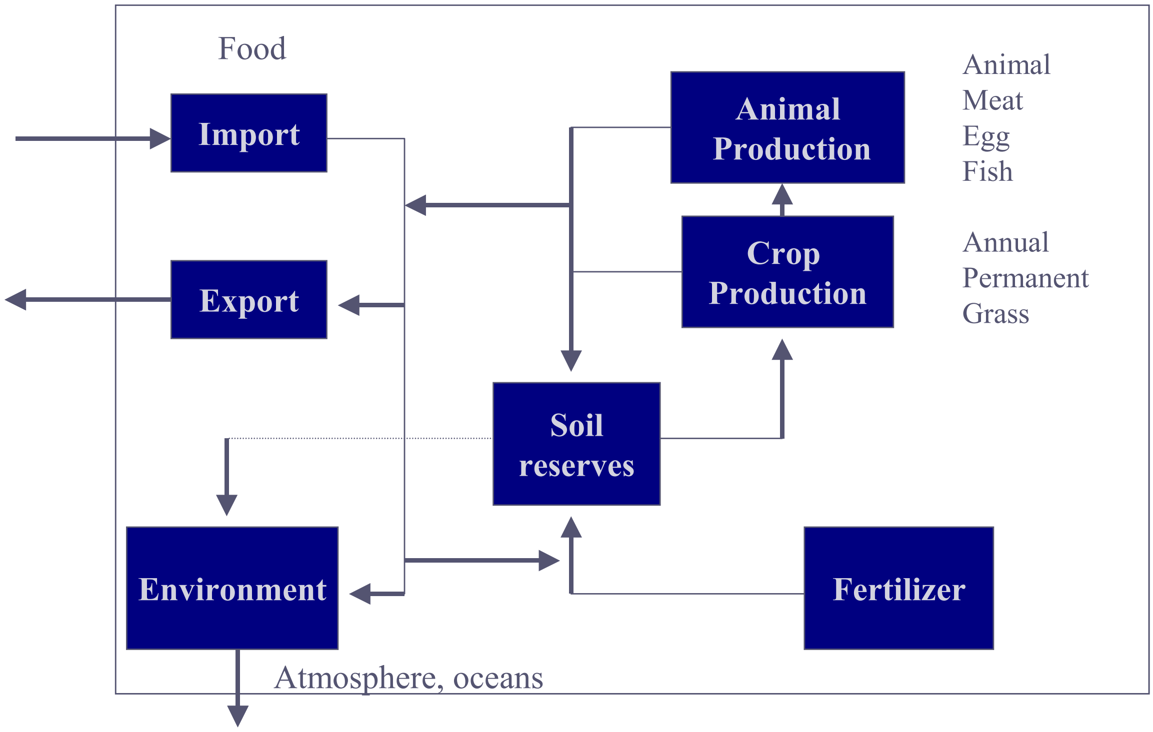
Nutrient balances provide invaluable insights into trends in the productive capacity of, and the potential for pollution from, agricultural lands (Bindraban et al., 2000; Parris, 1998). Since the pioneering work of Stoorvogel and Smaling (1990), many workers have studied the nutrient balances of farms in Africa, where the widespread depletion of soil nutrients, due to continuous cropping without the use of fertilizers, has become a major constraint to food production (Nandwa and Bekunda, 1998; Henao and Banaante, 1999). The methodology used for many of these balance studies is based on models such as NUTMON, that add gains, such as fertilizers, manure, biological nitrogen fixation, atmospheric deposition, and subtract losses, such as harvests, and estimates of gaseous losses, leaching and soil erosion (de Jager et al., 1998; Henao and Banaante, 1999). At the farm scale, the main components of the balance are shown in Fig. 2. Nutrient-rich areas represent the other end of the scale; the pollution potential of highly positive nutrient balances was recognized by the OECD, which developed a methodology to calculate surface soil nutrient balances in agricultural land (Parris, 1998). The OECD methodology is different from the NUTMON model and does not involve estimations of gaseous and erosion N losses, but includes calculations of biological nitrogen fixation by legumes and free-living organisms in the soil.

Figure 2: The Nutrient Flows at Farm Level



A number of other alternative schemes have been developed to assess nutrient balances, at a variety of scales and with associated uncertainties, biases and errors (see detailed discussion in Smaling et al., 1999). The main components of nutrient balances at an international scale are shown in Figure 3. Aside from the important matter of pollution of international waters, balances between countries have key characteristics that contrast with farm level balances. Firstly, the impact of gaseous losses, such as nitrous oxide emissions, may have a significant impact on global warming and, like the pollution of international waters, is a contentious matter for international relations. Secondly, the international import and export of nutrients in traded agricultural commodities may be a significant component of the overall nutrient flows. Thirdly, the domestic and international nutrient flows into and out of urban areas enter the equations. The first of these important issues is covered as part of an extensive literature on global change (Mosier and Kroeze, 2000), but is beyond the scope of the present paper. In contrast, the last two topics have been relatively neglected in the literature on nutrient balances, and are discussed in more detail below.

Figure 3: Nutrient Flows at the International Scale



Sheldrick et al. (2002) have recently proposed a conceptual model for calculating nutrient audits at national, regional and global scales. They used FAOSTAT data and applied their model to 197 countries. Their results reveal the sharp contrast between the nutrient surplus countries of Western Europe and Japan and the deficit countries, particularly those in Sub-Saharan Africa, where soil fertility is declining. In addition, Sheldrick et al. highlight and contrast the nutrient balances of Japan and Kenya representing nutrient surplus and nutrient deficient examples. However, this classification may be too simplistic, since many developing countries in regions such as Asia have relatively nutrient-rich areas where rice is grown intensively under irrigation, as well as nutrient-deficit marginal areas in the uplands or drylands (Craswell, 2001; Lefroy and Konboon, 1998). This chapter considers nutrient balances in deficit countries (focusing on Latin America/Caribbean and the African regions) and in surplus countries, and then discusses the urban-rural divide of intra-national nutrient balances.

2.2 Nutrient Balances in Deficit Countries[3]

Many developing countries are nutrient deficit countries. Although 80% of the population lives in the developing world, only half of the world's fertilizer is consumed there. A growing world population and increasing per capita incomes will likely require more intensive

[3] In the whole of Chapter 2.2, reference to NPK data implies the oxide forms P_2O_5 or K_2O.

agricultural production (FAO, 2000). Higher yields will in turn increase the demand for agricultural inputs, especially mineral fertilizers. About 50 % of the increase in agricultural productivity in the developing world is due to the adoption of fertilizers. In fact, maintaining adequate food supplies requires the supply of adequate nitrogen to plants.

A majority (50-85%) of the population in many developing countries depend on agriculture for their livelihood. Climate conditions, lack of land resources, and low soil fertility compounded by inadequate farming practices have, however, led farmers increasingly to cultivate marginal lands, further degrading the limited resource base for agriculture. With annual rural and urban population increases of 2 to 3 percent per year, food demand in many developing countries will continue to increase. Estimates indicate that in 2020, countries in Africa will need to produce or import more than 30 million tons of cereals each year to fill the gap between food demand and current supply. World population growth will cause a doubling on these nutrient requirements for the developing world by 2020, which, in the likely case of inadequate production will need to be met from soil reserves. Estimates of soil nutrient depletion rates for Sub-Saharan Africa are alarmingly high, and the reliance on nutrient inputs and their efficient use is bound to grow, also because expansion of the cultivable land area is reaching its limits (Vlek, Kühne and Denich, 1997).

Soil fertility degradation caused by nutrient imbalance and depletion is a major biophysical cause of declining crop yields and thus influences per capita food production in developing countries. On the other hand, in developed country areas with intensive agriculture, such as the irrigated areas of Asia, agricultural yields are well maintained through good farming practices and judicious management of both organic and mineral fertilizers. Areas with serious nutrient depletion are widespread in agricultural lands of Africa and Latin America, and in the marginal lands of Asia. Preliminary assessments by IFDC established that nutrient depletion in agricultural land in Sub-Saharan Africa ranges from 60 to more than 120 kg/ha of NPK per year. Likewise, in Latin America and some other developing areas in Asia nutrient depletion ranges from 30 to 120 kg/ha of NPK per year. In some cases, notably in West Africa, the rates of depletion are so high that even drastic measures, such as doubling the actual application of fertilizer and/or manure, or halving erosion losses, would not be enough to offset nutrient deficits. A study by Scherr and Yadav (1996) identified several sub-regions in Africa (such as the heavily populated areas in West and Central Africa) as areas where land degradation – in terms of nutrient depletion and erosion – pose a serious threat to food security and local economic activities.

In this section we present new estimates of nutrient balances and assess rates of current nutrient depletion in agricultural areas of Latin America and Africa in order to characterize regions where nutrient imbalances and nutrient mining are a serious, growing constraint to agricultural production. Based on the nutrient uptake of crops in grain and crop residues and certain assumptions regarding to nutrient losses and rates of nutrient return to soil in crop residue, net nutrient balances for nitrogen, phosphate, and potash were calculated for each major crop in agricultural regions and aggregated for each country.

2.2.1 Assessment of Nutrient Depletion

Our study estimated nutrient balances based on approaches followed by many researchers (Pieri, 1983; Gigou and Pichot, 1985; Stoorvogel et al., 1993; Smaling and Fresco, 1993; van Duivenbooden, 1990; and van der Pol, 1992, Henao and Baanante, 1999). The nutrient balance approach is a simple method that allows quantification of nutrient outputs and inputs based on a broad assessment of nutrients pathways in soil-crop systems. One shortcoming of this approach is that it is a relative indicator of nutrient stock changes and gives no information on the size and variability of the different stocks of available soil nutrients (Drechsel and Gyiele, 1999). A generalized simple specification of the balance approach for the macro nutrients (N, P, and K) in crops, regions and countries is given by the following equation:

$$R_t = \Sigma^t (SP + AR - RM - L) \qquad (1)$$

Where R_t is the nutrient balance in the country/region at time t; SP_t represents the available soil nutrients present at time t; AR_t is the mineral and organic fertilizers added or returned to the soil during the time interval Δt. The RM_t is the plant nutrients removed with the harvested product and residue management during the time interval Δt and L_t is the nutrients lost from the soil/system during the time interval Δt. The time series used included a range of data from 1980 to 2001 and the time interval for series indicators was five years.

The main assumption in using equation (1) was that, in the long run, nutrient depletion will be determined mostly by the degree to which nutrient gains due to the application of mineral and organic fertilizers, and to biophysical processes of nutrient deposition, sedimentation, and fixation, are balanced by nutrient exports due to crop harvest and to other factors such as crop residue use, leaching, erosion, runoff, ammonia volatilization, and denitrification. Data and information on weather, soil constraints, and agro-ecological zones were used as proxies to estimate soil nutrient losses due to erosion, leaching and volatilization (gaseous losses). Nutrient gain and loss estimates in specific countries and regions were developed from assumed soil-nutrient transfer functions, and from empirical and mechanistic models (Larson and Pierce, 1991; van Diepen et al., 1991; Bouma and van Lanen, 1987; Smaling et al., 1993; Stoorvogel et al., 1993, Henao and Baanante, 1999).

Our study used information on agricultural production and agricultural areas from secondary sources. The baseline data was integrated into a monitoring information system to produce attribute and geographic information on agricultural land resources, nutrient balances, and nutrient requirements. This information can be periodically updated because of changes overtime in the management of agricultural land, interventions, and variability in the use of fertilizer inputs across areas, countries, and regions. A summary of the data used for the database management system is presented in Appendix 1.

2.2.2 Extent of Nutrient Depletion in Latin America and the Caribbean

In each of the Latin American and the Caribbean countries, between one-fourth and one-third of the total population of almost 300 million live in rural areas. In these areas, approximately half of the farms are located on steep hillsides with slopes more than 20 percent, whereas about 80 percent are on hillsides where erosion control is a major concern for the farmers. The agricultural land ranges from altitudes near sea level in the Caribbean basin, with emphasis on root crops, to 4000 meters or more in the Andes, with emphasis on producing quinoa and indigenous crops. Land characteristics include forest areas, highly intensive agricultural areas, and extensive savannas. Many of these areas receive little rain, as in the central and eastern regions of the Andes, the Mexican highlands, the Cerrados in Brazil and the lee zones, while others have abundant rainfall, as in the Atlantic zone in Central America, the Caribbean, western zones of the Andes and extensive savannas in Argentine, Paraguay, and Uruguay.

Principal constraints affecting agricultural lands are drought stress, erosion, and deficiencies of nitrogen and phosphorus. Because of the topography and soil physical properties, erosion is a major problem for sustaining agricultural production in the Andean regions. In these areas, approximately 18% of the cultivated lands are subject to different degrees of erosion, that varies widely by country. Other constraints are water availability and low soil fertility. These two factors have become a problem on more than 3.3 million ha out of a total of 15 million ha in Latin America. In the Caribbean basin, large areas of agricultural land have been degraded due to very low use of inputs, making rehabilitation and conservation of some areas essential measures for economic growth. Latin America and the Caribbean have large areas of acid infertile soils. On the other hand, large areas of high base status soils with good moisture supply occur along the Andean chain, coastal and alluvial regions, and in most of the Central America and Caribbean production areas. Proper soil management based on adequate nutrient use and efficiency is rather generally low by most standards.

Farming systems in Latin America and the Caribbean are extremely diverse across the fertile high base status soils, with generally intensive land use, and the low fertility acid soils in the savannas. Although the geographic characteristics vary widely, agricultural areas have many things in common. For instance, the highland farmers play an outstanding role in the production of important export crops, such as coffee and citrus. They also produce the principal basic food crops, including rice, wheat, barley, maize, beans, potatoes, vegetables, and most of the wood for domestic and industrial use. Lowlands are mostly dedicated to livestock for beef, milk, and wool, and for more extensive cash crops such as bananas, cereals, soybean, oil palm, and sugar cane production systems.

The preceding discussion of farming systems leads into a discussion of crop productivity in the context of fertilizer consumption and the nutrient balance situation of agricultural land in countries of the region. Average maize productivity during 1996-1999 was about 2.4 t/ha and varied from 1 t/ha in Guyana to 9 t/ha in Chile; average sorghum yield was 2.5 t/ha and ranged from 1 t/ha in Honduras to 5 t/ha in Peru. Average wheat production was 2 t/ha and varied from 1 t/ha in Honduras to 4.5 t/ha in Mexico. An important crop such as potatoes averaged about 12 t/ha and yields varying from 5.7 t/ha in Bolivia to 25 t/ha in Argentina.

About 65 percent of applied fertilizer was used in cereals, with rice alone accounting for one-third of the total use and maize and wheat about one-sixth. The allocation of fertilizers to cereals roughly corresponds to the share of cereals in total harvested area (57 percent), though some of the coarse grains, especially sorghum, received little fertilizer. The share of non-food crops and of fruits and vegetables in total fertilizer use is large relative to the share of these crops in harvested area. Sugarcane, cotton, banana, and oil-palm are also major consumers accounting for about 4 to 6 percent of the total fertilizer use. Roots and tubers, and in particular pulses, receive little fertilizer relative to their share in harvested area. The average annual rate of nitrogen use during the years 1991 to 1999 was 69.4 kg/ha and ranged from 1.6 kg/ha in Bolivia to 216 kg/ha in Costa Rica; the average rate for phosphorus (P_2O_5) was 32.8 kg/ha and ranged from 2.1 kg/ha in Bolivia to 138 kg/ha in Chile. The average rate for potassium is low (27.5 kg/ha) and ranged from 0.5 kg/ha in Bolivia to 130 kg/ha in Costa Rica. Typical fertilizer response ratios (kg of additional crop produced per kg of additional plant nutrient applied) in countries with middle yield levels and areas not subject to severe water constraint, ranged from 10 to 16 for cereals, 6 to 10 for oil crops and 30 to 50 for root tubers.

Most of the countries show negative nutrient balances on an annual basis. In the semiarid, arid and very dry areas that are more densely populated, average nutrient depletion ranges from 60 –to 100 kg of nitrogen, phosphorus (P_2O_5), and potassium (K_2O)/ha each year. The soils of these areas are shallow with low water retention capacity, highly weathered, and subject to intensive cultivation but with low rates of fertilizer application. These areas have restricted crop diversification and short growing seasons contributing to additional pressure on the land.

In other important agricultural areas, such as those located in the sub-humid and humid regions, and in the savannas and forest areas, annual rates of nutrient depletion vary from moderate (30 to 60 kg NPK/ha) in the humid forest and wetlands in southern and Central America and South America, to high (more than 60 kg NPK/ha) in the Andean Highlands in Bolivia, Ecuador, Peru and Colombia.

Most South American countries, particularly those located in the sub-humid to dry savanna like in Brazil and Argentina, fall into the high nutrient depletion range. The nutrient imbalances are highest where fertilizer use is particularly low, and nutrient losses, primarily from soil erosion, are high. The inherently low mineral stocks in some soils in Brazil, and the harsh climate of the interior plains and plateaus, aggravate the effects of nutrient depletion on crop yields.

The net annual losses of nutrient vary considerably among countries (Figure 4a and 4b). Specific calculations of nutrient inputs and outputs for agricultural areas in selected countries in Latin America in 1996-1999 showed the following annual changes in nutrient balance: -152 kg/ha in Paraguay, -31 kg/ha in Uruguay, and +188 kg/ha in Chile. An assessment of the different processes (pathways) contributing to nutrient depletion, for these three countries, reflects that the two main factors are erosion as well as crop plus residue removal, which constitutes about 70% of all N losses, nearly 80% of all K losses, and 95% of all P losses.

Figure 4a: Annual NPK Balance of Arable Land for Central American and Caribbean Countries (1996-99)

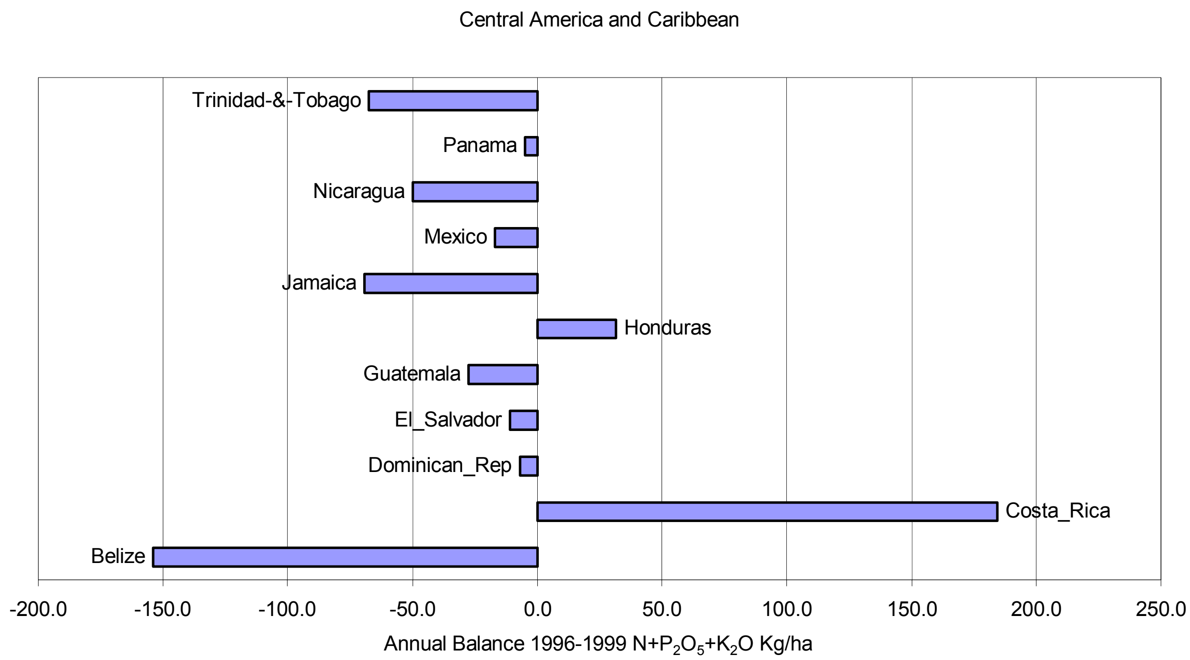
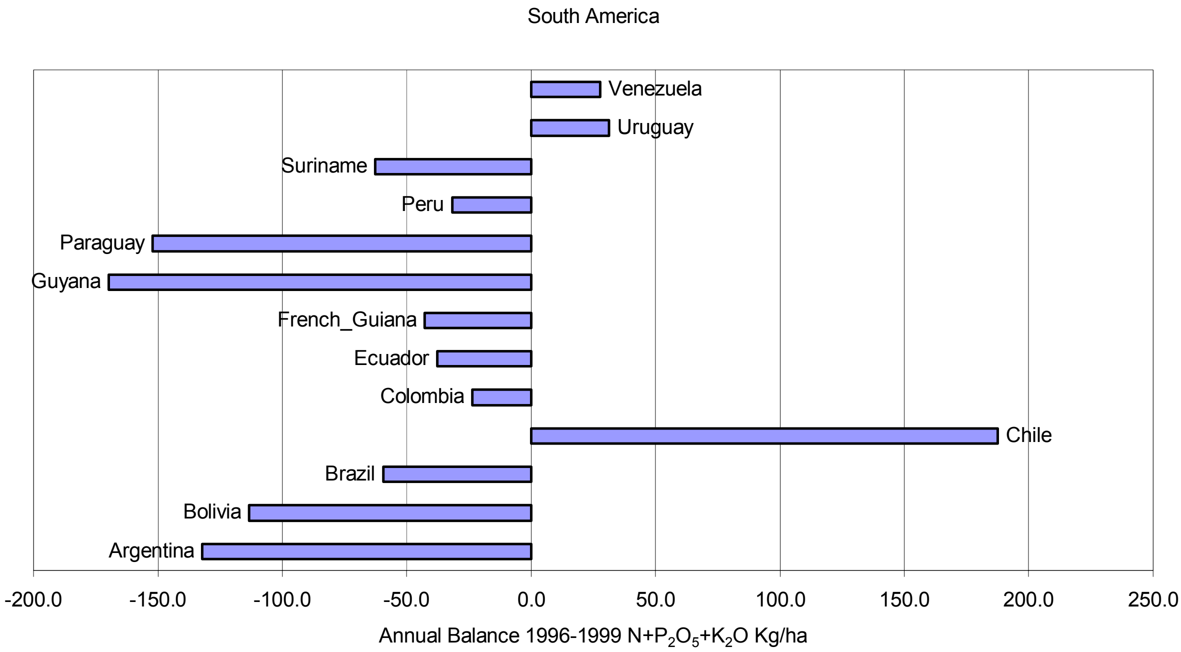


Figure 4b: Annual NPK Balance of Arable Land for South American Countries (1996-99)



More nitrogen and potassium than phosphorus is normally depleted from cultivated soils. Nitrogen and potassium losses primarily arise from soil erosion and leaching. These soil problems result mainly from widespread poor crop management practices such as continuous cropping of cereals, few crop rotations, inadequate soil conservation practices, and insufficient fertilizer use. Losses due to erosion range from 25% to 55% of the total NPK loss for N, 35% to 65% for P, and 30% to 40% for K. In comparison with erosion, leaching appears to be a minor contributor to NPK depletion.

Nutrient depletion in most countries has a far-reaching impact that extends beyond the farm into community, region, and national scales. It affects the environment and national economies. In Latin America and the Caribbean nutrient depletion represents a total of US$2.5 billion (based on 2000 fertilizer prices) per year in terms of the replacement cost of nutrients as fertilizers. Forfeited yields cause additional financial losses. Most crop yields in the region did not change substantially between 1991 and 2000, remaining close, in most countries, to the average obtained by smallholders with rainfed land and moderate to low soil fertility.

Nutrients gains in Latin America and Caribbean agricultural lands come about mainly through mineral fertilizer application, nutrient deposition, and nitrogen fixation. The negative nutrient balances clearly indicate that not enough nutrients are being applied in most areas. The 1996-99 data series shows that annual use of nutrients averages about 60 kg of NPK /ha for the region. Fertilizer use ranges from nearly 234 kg of NPK /ha in Chile to 46 kg in Mexico to less than 10 kg in most countries in the Caribbean.

Fertilizer tends to be used mostly on cash and plantation crops because of the high profitability of fertilizers in the production of export crops. Food crops get less fertilizer because of unfavorable crop/fertilizer price ratios and financial constraints faced by farmers.

To maintain current average levels of crop production without depleting soil nutrients, Latin American and Caribbean countries will need approximately 20 million t of NPK each year. Total nutrient requirements per ha and year in this sub-region range from Bolivia's 32 NPK (350 percent above current usage) to Chile 250 NPK (about 20 NPK /ha less than the country consumes). Ecuador and Guatemala, for example, would have to increase their NPK consumption more than 12 times to maintain crop production levels without depleting soil nutrients.

Although increasing the use of mineral fertilizer may be the centerpiece of the strategy to balance nutrient depletion and improve soil productivity in most countries, it should not be taken to mean that fertilizer levels should be increased beyond basic requirements. Indeed, surpassing recommended levels for less-responsive varieties and in poorly managed cropping systems can lead to high nutrient losses, soil acidification, salinization, pollution, and low yields. Moreover, to achieve intended goals, fertilizer use must be combined with a broad spectrum of complementary practices, such as soil conservation, recycling of crop residues, livestock management, and the use of organic fertilizers. Such practices could reduce the mineral fertilizer required to maintain current average yields by as much as 44 percent in some countries.

2.2.3 Extent of Nutrient Depletion in Africa

African countries show great diversity in their endowment of agricultural resources. The total area of land in Africa potentially suitable for production of one or more crops is estimated at 874 million hectares, about 27 percent of the continent's landmass. It has been estimated that about 196 million hectares are presently cultivated, out of which—taking into account requirements for fallow—about 108 million are harvested yearly. One-third of Africa's land area is too dry to support rain-fed agriculture. Most of the unused agricultural land in Africa lies in the central humid region. This is a region where infrastructure is particularly poor, where the incidence of human, livestock and plant diseases is high, and is subject to exceptionally variable rainfall, which can severely limit agricultural production.

Soils with low nutrient retention capacity are widespread and many are heavily leached and eroded. Superimposed on these constraints is the removal through harvest of much more plant nutrients than are being returned to the soil in mineral or organic fertilizers. Cases of soil degradation have been documented in highly populated regions of dry land areas in West and East Africa. In the Peanut Basin of Senegal, continuous cultivation with low use of mineral and organic fertilizers and inadequate soil management practices has exhausted the soils (Charreau, 1972; GDPA cited by Pieri, 1983). In the highly populated Mossi Plateau of Burkina Faso, millet areas were degraded by continuous cropping (Broekhuyse, 1983), and many farmers migrated to sub-humid regions of coastal areas of Benin, Ghana, and Côte d'Ivoire. In Northern Nigeria, around Kano, where population density is very high, soil fertility has been depleted due to poor crop management practices (Smith, 1994). This has been a major factor influencing food security in the area and the economy of the country.

Mali, Niger, Benin, and North Togo are among the Sahelian countries often referred to as examples where trends for maize, millet, and sorghum yields have been stagnant or decreasing due to continuous cropping, poor soil management, and low use of mineral and organic fertilizers (IFDC, 1992; FAO, AGROSTAT, 1994). In Central and South Sudan, Ethiopia, and Western Kenya, highly populated areas in East Africa with naturally fertile soils, the continuous cropping without external inputs has decreased production and severely depleted the land (Hoekstra and Corbett, 1995). A long-term trial in Western Kenya indicated that after 18 years of cultivation of continuous maize and common beans (*Phaseolus vulgaris* L.) in rotation, in absence of nutrient inputs, the soil lost about 1 t/ha of soil organic nitrogen and 100 kg of organic phosphorus /ha. Maize yields decreased from 3 to 1 t/ha during that period (Swift et al., 1994).

Compounding the current socioeconomic concerns, land degradation in West and Central Africa is damaging to the resource base for agriculture. The soil management and the agricultural systems are based on low use of external inputs and continued cultivation leading to soil mining processes. The most used land -the interior plains and plateaus- have low mineral nutrient stocks and soils difficult to manage due low organic matter content and the presence of clay fractions dominated by kaolinite, halloysites, and/or iron aluminum oxides (Ssali cited by Rhodes et al., 1995). The soils have become strongly weathered and leached and the cation exchange capacity of the soils is dominated by the organic fraction that is generally at a low level. This implies that essential elements such as phosphorus, potassium and calcium rapidly become scarce and acidity increases if proper management is not used. Nutrient balance studies performed by van der Pol (1992) and by Stoorvogel et al. (1993) showed that nutrient depletion has been severe in densely populated areas in Mali, Nigeria, Ghana, Côte d'Ivoire, and Chad where agriculture is intensive and less than 30 percent of the land is reserved for fallow.

Most Sudano-Sahelian and Southern Africa regions with intensive mixed farming systems are located in pasture and savanna areas with low soil nutrient content where nutrient depletion is a major constraint. About 50 percent of the vast grazing lands in the Sahel, located on sandy soils with very low soil fertility, are affected by high nutrient depletion rates (Breman, 1994). The low nutrient stocks of the soils and the low water availability of the area limit the agricultural potential of these lands. Agro-forestry based systems in the Sudano-Sahelian of West Africa are also limited by the very low nutrient reserves of the soils. Breman and Kessler (1995) quantified the nitrogen and phosphorus balance of these systems in West Africa, and concluded that competition for water and light constrains the agro-forestry systems that could prevent nutrient losses (leaching and erosion) and land degradation.

In the tropical moist forest and savannas, characteristic of the humid and per-humid areas that are predominant in Cameroon, Congo, Ghana, Nigeria, Gabon, Congo, and part of Uganda, intensification of agriculture with low use of inputs and forest clearing are major factors causing degradation. Slash-and-burn practices, combined with ever shortening fallow periods, and low recycling of crop residues, characterize the agriculture of these regions. Most soils are very fragile and particularly low in plant nutrients. The nutrient recycling mechanisms through fallow systems that sustained the soil fertility are being disrupted, land is being degraded, and soil fertility is dropping to levels that cannot sustain even a marginal level of productivity (Lal et al., 1986; Kang et al., 1990).

Cropping intensification and poor crop management practices have made the mountain and hilly areas of Sub-Saharan Africa prone to excessive water runoff, soil erosion, and soil nutrient depletion. Specific areas identified by UNEP (1991) as warranting special consideration included the Fouta Djallon mountains in West Africa (Guinea), the East African highlands (Kenya, Burundi, Ethiopia, Rwanda, Tanzania, and Zimbabwe) and the highlands of southern Africa (Botswana, Lesotho, and Swaziland). Stocking (1986) estimated the economic costs of the nutrient loss (N, P, and K) by soil erosion in Zimbabwe. The annual losses of N and P alone amount to US$1.5 billion/year. Because of severe shortages of energy and fodder, and the continuous cropping on steep slopes, and the low use of fertilizers and crop residues, the land has been severely degraded in some areas principally in Rwanda, Burundi, and Lesotho. Recycling of plant nutrients is highly desirable in these regions, although competing forces for firewood and fodder to feed animals prevent a significant quantity of nutrients from being returned to the soil.

The average application rates for mineral nutrients on agricultural land in most countries of Sub-Saharan Africa are still below 10 kg/ha. Fertilizer nutrient use varies widely among countries, ranging from nearly 234 kg/ha in Egypt to 99 kg/ha in Swaziland, 46 kg/ha in Kenya, and less than 10 kg/ha in some countries in south of Africa. North Africa, with about 20 percent of the continent's surface area, accounts for about 41 percent of the fertilizer consumption. A few countries, Nigeria, Zimbabwe, Kenya, Sudan, and Ethiopia account for about 75 % of the total fertilizer use in Sub-Saharan Africa. Fertilizer in these areas tends to be used mostly on cash and plantation crops (cacao, cotton, coffee, groundnuts, tobacco, tea, sugarcane, and oil palm). This is due to the high profitability of fertilizers in the production of export crops. Unfavorable crop/fertilizer price ratios, particularly for food crops, and financial constraints are key factors explaining the current low levels of fertilizer use. As in Latin America, crop yields are generally low in Africa and within the range of average rainfed smallholder yields with moderate to low soil fertility in other tropical areas.

Figure 5a: Annual NPK Balance of Arable Land for Central and East African Countries (1996-99)

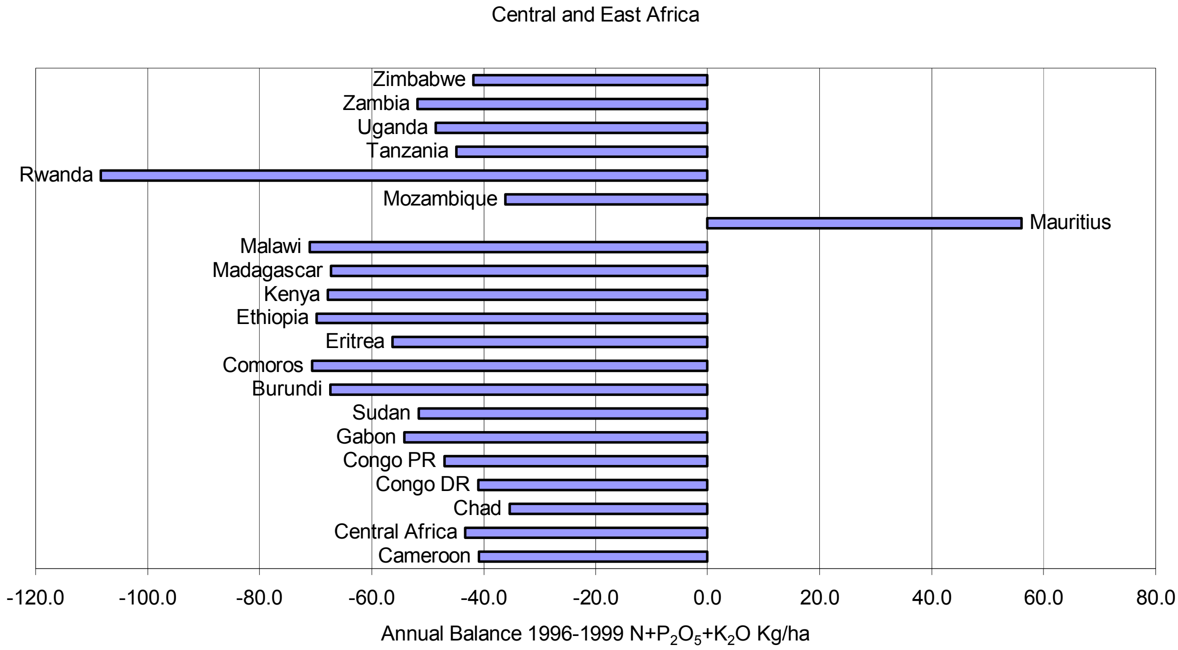
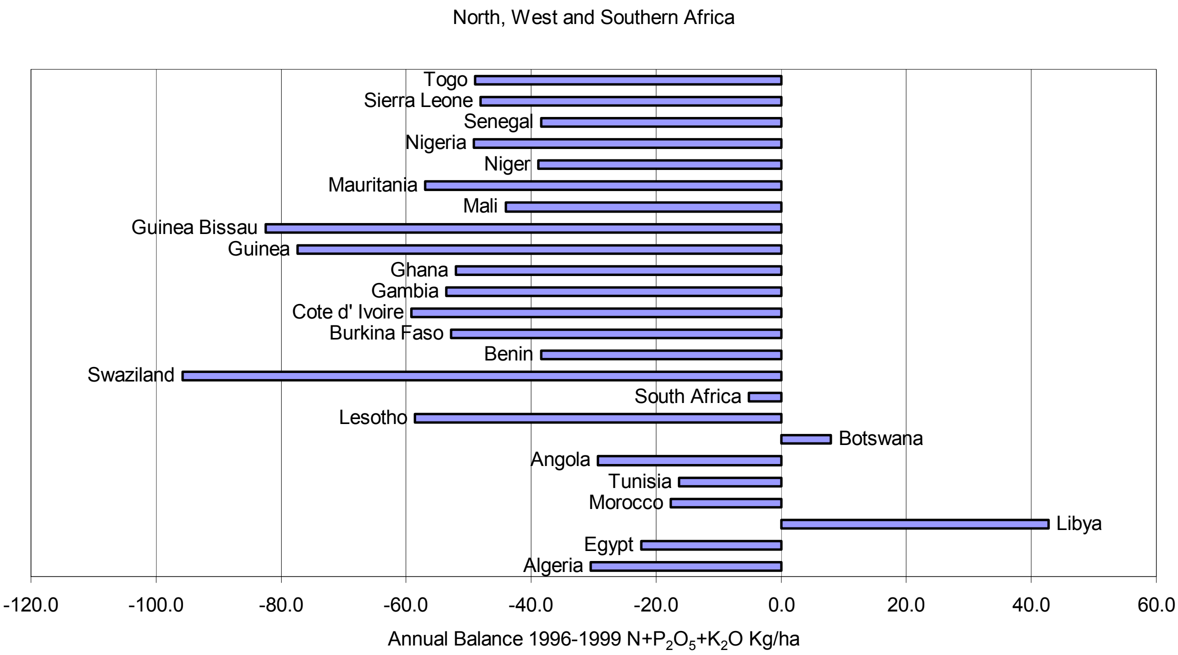


Figure 5b: Annual NPK Balance of Arable Land for North, West and Southern African Countries (1996-99)



Assessment of nutrient depletion at the macro scale for countries in agricultural regions in Africa from the present study (see Figure 5a and 5b) is as follows. In 1996-1999, all African countries except Mauritius, Botswana, and Libya show negative annual nutrient balances. In the semiarid, arid, and Sudano-Sahelian areas that are more densely populated, average nutrient loss ranges from 60-to-100 kg/ha of nitrogen, phosphorus (P_2O_5), and potassium (K_2O) each year. The soils of these areas are shallow, have low water retention capacity, are highly weathered, and are subject to intensive cultivation but with low levels of fertilizer applications. These areas have restricted crop diversification and short growing seasons contributing to additional pressure on the land.

In other important agricultural areas, such as those located in the sub-humid and humid regions and in the savannas and forest areas, nutrient losses vary greatly. Rates of nutrient depletion range from moderate (30 to 60 kg NPK /ha per year), in the humid forest and wetlands in southern and Central Africa, to high (more than 60 kg) in the East-African Highlands.

Most West African countries, particularly those located in the sub-humid wooded savanna, fall into the high nutrient depletion range. The nutrient imbalances are highest where fertilizer use is particularly low, and nutrient losses, largely from soil erosion, are high. The inherently low mineral stocks in these soils and the harsh climate of the interior plains and plateaus aggravate the negative impact of nutrient depletion.

Some specific examples of data on the balance of nutrient inputs and outputs for agricultural areas in West African countries are: -52 kg/ha for Ghana, -38 kg/ha for Benin, and -49 kg/ha for Togo. An analysis of contributing factors to the nutrient depletion in these three countries, indicates that the two main factors are soil erosion as well as plant uptake and grain plus residue removal.

Continuous cropping of cereals, few rotation systems, inappropriate soil conservation practices, and inadequate fertilizer use are the main underlying causes of nutrient losses from African farms. Nutrient loss due to erosion ranges from 33% to -64% of the total NPK loss for N, 18% to -77% for P, and 33% to -50% for K. Leaching appears to be a relatively minor cause of nutrient depletion. Leaching losses of N and K increase with the amount fertilizer and (green) manure applied and can be significant for other nutrients (Poss and Saragoni, 1992).

The replacement cost of nutrient depletion in Africa is a total of US$1.5 billion (based on 1996 fertilizer prices) per year. Yields of crops in many areas of Africa did not change substantially between 1981 and 1995. To redress these losses nutrient gains are needed through increased mineral fertilizer application, nutrient deposition, and nitrogen fixation. A total application of 8 million t of NPK is needed each year if farmers in Sub-Saharan African countries are to maintain current average levels of crop production without depleting soil nutrients. In the worst affected countries, such as Burkina Faso, this would involve an 11-fold increase in fertilizer consumption. Fertilizer currently tends to be used mostly on cash and plantation crops because of the high profitability of fertilizers in the production of export crops. Food crops get less fertilizer because unfavorable crop/fertilizer price ratios and financial constraints faced by farmers. Relay or intercropping of cash crops and food crops may provide a means for soil fertility replenishment.

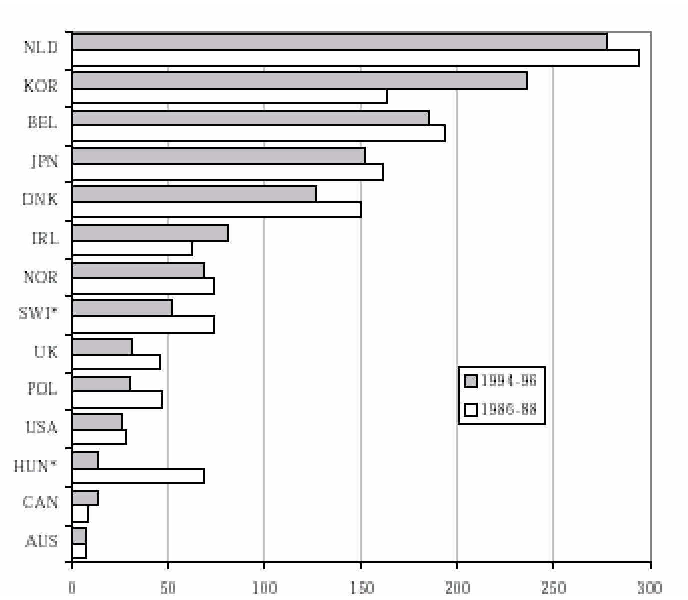
As with Latin American countries, African countries and regions need to integrate agricultural land management with economic and sector policies. More economic and environmental impact analyses at the country level are needed to help set priorities for agricultural land issues, to assess the cost and benefits of policy decisions and the type of agricultural land management and investments that will be required to increase production and prevent land degradation and nutrient depletion. Prevention of nutrient mining through sound economic policies, research, and information dissemination should be actively promoted in most countries in Africa and Latin America.

2.3 Nutrient Balances in Surplus Countries

In many developed countries, in transition countries of Eastern Europe and in some of the fast growing economies of East Asia, intensive use of fertilizer and feed has led to nutrient loading, habitat destruction and water pollution. The results of OECD calculations of surface soil nitrogen balances indicate that many industrialized countries have large nutrient surpluses. These results contrast dramatically with the nutrient balances of countries in Sub-Saharan Africa. However, the OECD methodology produces a nitrogen balance that includes nitrogen remaining in soil, or lost to the atmosphere and/or the surface- and ground-water. Figure 6 shows the OECD results for 1986 to 88 and 1994 to 1996. The striking feature of the nitrogen balances is that all are positive; however, values range from less than 10 kg N/ha in Australia to nearly 300 kg N/ha in the Netherlands. Several European countries show a decline in N balance between 1986 to 88 and 1995 to 96, in line with the Convention for the Protection of the Marine Environment of the North-East Atlantic for the North Sea (OSPAR, 1998). Nevertheless, countries such as Korea and Ireland show an increasing trend with time. Note that since the balance values shown include nitrogen released into the atmosphere and water plus what remains in the soil, it is not correct to assume that all of the nitrogen surpluses contribute directly to environmental pollution.

Figure 6: The Nitrogen Balance of the Surface Soil of Agricultural Land in OECD Countries

Agricultural nitrogen balance: (kg nitrogen/ha) 1986-88: ☐ 1994-96: ■



Notes:
Nitrogen (N) balance in kg per hectare of total agricultural land = N Inputs (fertilizer manure etc.) minus N plant uptake, which if > 0 = N Surplus: if < 0 = N deficit.
*1986-88 to 1993-95
Source: OECD Agri-envirionmental Indicator Database.

(see http://www.oecd.org/oecd/pages/home/displaygeneral/0,3380,EN-statistics-150-4-no-no-no-150,00.html ; accessed July 2002)

The OECD database and the deficit country data discussed in Section 2.2 do not provide for sufficiently detailed analysis to draw conclusions about the pollution potential of surpluses or the inefficiencies and losses of valuable nutrients in deficit countries. Detailed country-level nutrient balances for agricultural lands are needed, and several such studies have been published. Examples include reports on Australia (Reuter, 2001), China (Xing and Zhu, 2002), the Netherlands (Oenema and Pietrzak, 2002) and the United States of America (Howarth et al., 2002). The study in China focuses on the Changjiang River, Huanghe River and Zhujiang River which are the three major rivers in that country that are flowing into the Pacific Ocean. In 1996, the total population of these river basins was 582 million, of which nearly 80% live in rural areas. The main nitrogen inputs were: fertilizer 22.2 Tg; NO_x deposition from combusting fossil fuel 4.2 Tg; N fixation by leguminous crops 2.16 Tg; non-symbiotic N fixation in farmlands 2.17 Tg; and 0.52 Tg from food/feed import. The main outputs annually were estimated as: 14 Tg in harvested crops; 11.1-16.1 Tg as gaseous losses; 12 Tg in soil storage and 11 Tg transported in water bodies. Only 0.11 Tg was exported in food and feed. The sheer scale of these flows of nitrogen must be weighed against the high population, and the high population density in the large cities such as Shanghai and Guangzhou. Xing and Zhu (2002) estimate that the amounts of nitrogen in human wastes alone total 4.2 Tg, 27% of which comes from the urban population. Clearly most of China cannot be classified as nutrient deficit. As discussed in Chapter 3, the increased demand for livestock products due to income growth will exacerbate the environmental problems.

In areas of high animal concentrations, excess nitrogen and phosphorus leaches or runs-off into groundwater, damaging aquatic and wetland ecosystems. The spreading of manure on land can lead to nitrogen leaching into water. Nitrates contaminate surface water, leading to high algae growth, eutrophication and damage to the aquatic and wetland ecosystems. Phosphates, although less mobile than nitrates, can cause similar problems. Tests in Pennsylvania have shown that about 40 percent of the tested soil samples from dairy-crop farms exhibited excessive phosphorus and potassium levels. Soils are saturated, and surplus nutrients are leached into surface water and pollute the environment (Bacon et al., 1990; Narrod et al., 1994). A similar scene is set in Brittany, France, where in the 1980s, one in eight counties had soils with nitrate levels of more than 40 mg/l. Now all eight counties report similar nitrate levels (Brandies et al., 1995), which can cause extensive damage to the region's aquatic systems. In addition, such nutrient surpluses may affect valuable ecosystems which are adapted to poor soil conditions by allowing encroachment by flora and fauna which are adapted to fertile soils. Therefore, overall biodiversity might be reduced.

The Netherlands present another case of a country with surplus nutrients and associated environmental problems. According to Oenema and Pietrzek (2002), nitrogen fertilizer inputs to agricultural land in 2000 total 340 Gg whereas inputs from animal feed were 354 Gg. The outputs in crop and animal products were 209 Gg, creating a surplus of 485 Gg. These data reflect the poor efficiency with which animals convert the nutrients in feed into protein. Van der Hoek (1998) estimates that the overall efficiency of nitrogen use in animal production is only 10%, leading to an annual excretion of 102 Tg of nitrogen by domesticated animals worldwide. In a small country like the Netherlands, crop and pasture fields are relatively close to livestock production areas, so provided manure applications rates are not exceeded, surplus nitrogen can be recycled to some extent (Oenema and Pietrzek, 2002). In countries such as Germany and the United States, many livestock production areas are far from feed grain producing areas, making the disposal of nutrients in livestock wastes a major environmental problem, since spreading of manure on nearby cropland is not practicable. According to Howarth et al. (2002), the Northeastern USA imports 1000 kg N km^{-1} in food and feed and exports 1070 kg N km^{-1} in wastewater and non-point source river pollution. The Mississippi River basin, on the other hand, exports 1300 kg N km^{-1} in food and feed and exports 566 kg N km^{-1} in the river system.

Of the examples of detailed country studies mentioned above, only the Australian study considers nutrients in addition to nitrogen. Reuter (2001) analyzed trends in N, P, K, S, Ca and

Mg in regional farming systems in Australia, as part of a comprehensive National Land and Water Resources audit. The cropping systems studied range from tropical sugar to temperate wheat. The study pinpointed soil nutrient depletion in some cereal production systems, imbalanced fertilization and K deficiency in Western Australian wheat systems, and soil fertility buildup in many farming systems based on phosphorus-fertilized legume pasture leys. Reuter estimates that 60% of the nitrogen in Australian agriculture comes from biological nitrogen fixation, a proportion higher than most countries in the world, with the exception perhaps of New Zealand.

In an industrialized country like the United Kingdom, the costs of modern intensive agriculture resulting from externalities which range from soil degradation to the contamination of water with nutrients and pesticides, biodiversity loss and damage to human health have been estimated to amount up to US$300/ha/year. That is the equivalent amount to some 90% of average net farm income (Bunyard, 2001). Annual external costs arising from agriculture have been estimated by Pretty et al. (2001): in Germany US$ 2 bn, in the UK US$3.8 bn, and in the United States US$34.7 bn. These costs are equivalent to US$81-343 /ha of arable and grassland.

Agriculture is -- through runoff and leaching -- the largest single source of nitrate pollution at the EU level. It has been calculated for example that European agriculture is responsible for 60% of the total riverine flux of nitrogen to the North Sea, and 25 % of the total phosphorus loading (Ongley, 1996). Excessive nutrient loading is often the single largest cause of water quality impairment. There are a number of hot spots to be found in the world, which have been caused by surplus nitrogen and nutrient loads like the Gulf of Mexico or the Aral Sea. Agriculture also makes a substantial contribution to the total atmospheric nitrogen loading to the North and the Baltic Seas. In the last ten years, outbreaks of harmful micro-organisms in coastal waters have become more frequent. Excess nutrients – phosphorus and nitrogen – from agricultural and other activities are thought to contribute to such outbreaks (UNEP 1999). The costs of such environmental externalities are massive. The cost of eutrophication over the period of 1987 – 93 is estimated at more than US$100 million a year for the United States alone (GPA 2002).

This consideration of nutrient surplus countries highlights the high degree of variability in the levels of nutrient flows and balances both between and within-countries. A recent review of nitrogen balances and flows in Europe (van Egmond et al., 2002) highlights the importance of trade in the nitrogen balance sheet. According to these authors, 7.6 Tg nitrogen per annum is imported in Europe, compared with fertilizer production of 14 Tg nitrogen. The annual loss of nitrogen in exported products is estimated as 6.3 Tg, whereas the riverine transport to the sea is 4.0 Tg per annum. The next section considers the riverine transport in more detail.

2.4 Pollution of Surface Waters

Van Drecht et al. (2001) have published estimates of the fate of nitrogen from point and nonpoint sources of nitrogen. Their estimates of nitrogen inputs and export in major rivers systems of the world are shown in Table 1. The results illustrate the low contributions from agriculture and sewage in African and South American rivers flowing through nutrient-depleted countries with low population density. The higher proportions of human-induced nitrogen export in the Mississippi, the Rhine, the Po and the Chinese rivers reflect the discussion on nutrient-rich countries in Chapter 2.3 above.

Table 1: Characteristics of Ten Selected Rivers

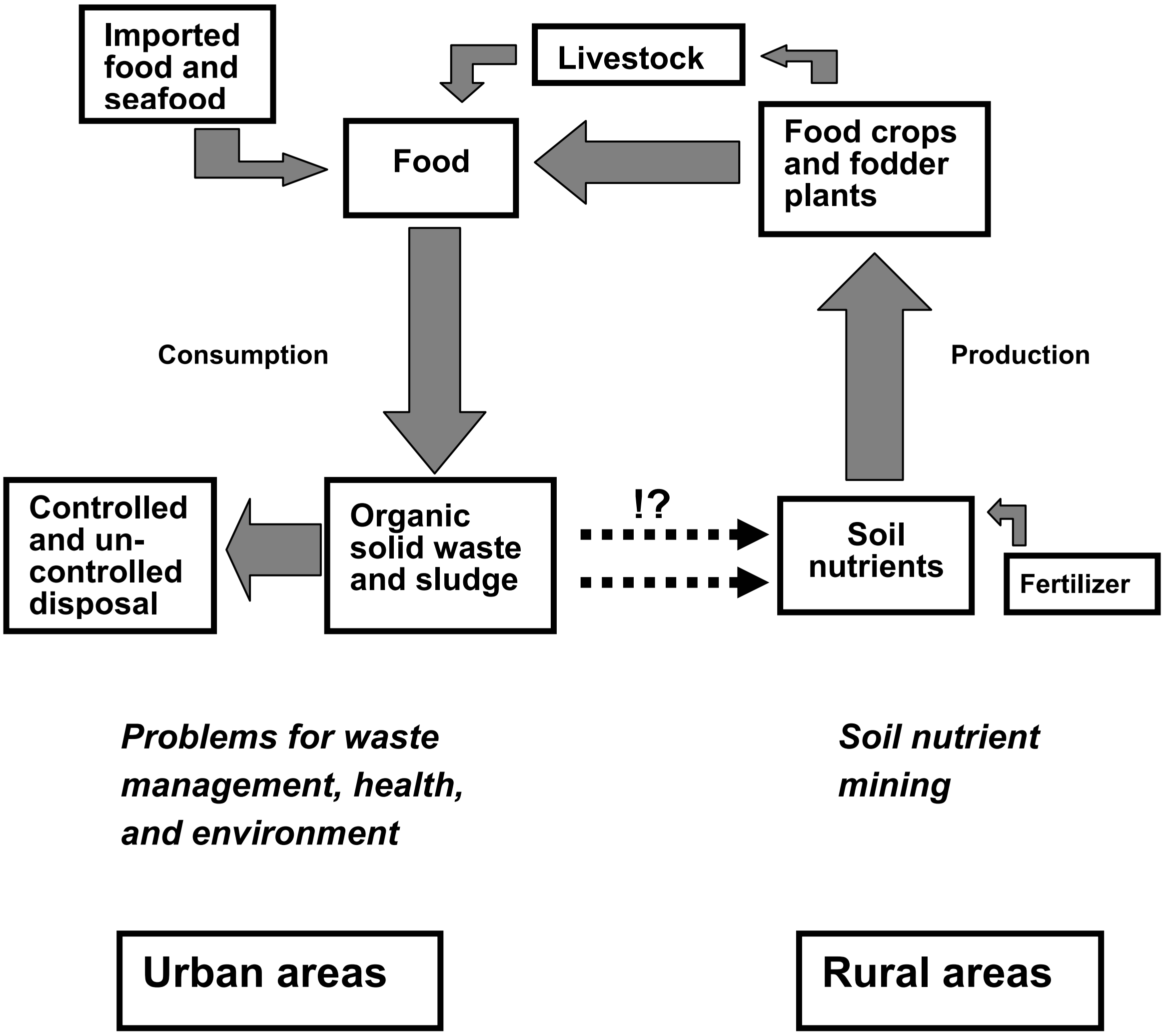
					Inputs				Export[a]				
River	Drained land area (10^6 km^2)	Runoff (1000 km^3 year^{-1})	Population (Inh./km^2)	Rural Pop. (%)	Total (kg N km^{-2} year^{-1})	Natural (%)	Agriculture (%)	Sewage (%)	Total (Gg year^{-1})	Total (kg N km^{-2} year^{-1})	Natural (%)	Agriculture (%)	Sewage (%)
Mississippi	3.2	0.6	21	44	7489	9	89	1	1910	597	27	63	10
Amazon	5.8	6.4	4	68	3034	83	17	0	4001	692	93	6	1
Nile	3.7	0.3	38	71	3601	31	67	2	998	268	43	37	20
Zaire	3.6	1.2	16	76	3427	81	18	0	2290	632	90	9	1
Zambezi	1.9	0.4	14	74	3175	52	47	1	641	330	68	25	6
Rhine	0.2	0.1	292	10	13941	15	77	9	459	2795	21	49	30
Po	0.1	0.1	196	29	9060	11	81	8	185	1841	17	56	27
Ganges	1.6	1.2	286	78	9366	16	81	3	2051	1269	30	55	15
Chang Jiang	1.8	0.9	237	73	11823	6	92	2	3959	2237	9	83	8
Huang He	0.9	0.1	153	66	5159	9	88	3	190	214	17	24	59

Source: van Drecht et al. (2001)

2.5 The Urban-Rural Divide

The foregoing discussion of nutrient balances in both nutrient-rich and nutrient-poor areas primarily considered agricultural land or averages at the country scale. This focus, which is common in much of the published literature, disguises the important influence of urban concentrations of population on nutrient flows. The pace of urbanisation in the developing world is accelerating the transfer of nutrients from rural to urban areas (see Drechsel and Kunze, 2001). In West Africa, where the data presented in Chapter 2.2 above show extensive nutrient depletion in rural areas, two-thirds of the population will be living in urban centers by the year 2020.

Figure 7: Pathways of Nutrient Flow between Rural and Urban Areas



Source: Drechsel et al. (1999)

Nutrients flow into urban areas in food commodities from rural areas and from imports (Figure 7). The flow is largely uni-directional and, after consumption of the foodstuffs, the resultant accumulation of solid and liquid wastes in urban areas creates massive nutrient disposal problems for city governments. Keeping the nutrients out of surface water and drinking water is a major concern, because of ecological problems as well as health hazards such as methaemoglobinaemia caused by nitrate in drinking water. These threats may be partly resolved if wastes can be used in peri-urban and urban agriculture, which in the process may become more productive (Cofie et al., 2001). Cofie et al. analyzed the potential for such a win-win situation in West African cities, collecting data on nutrient flows that show the abundance of nutrients that could be re-cycled in peri-urban and urban agriculture. However, they also identified the need for a comprehensive approach to a decision support system that assists urban authorities on realistic options for re-cycling.

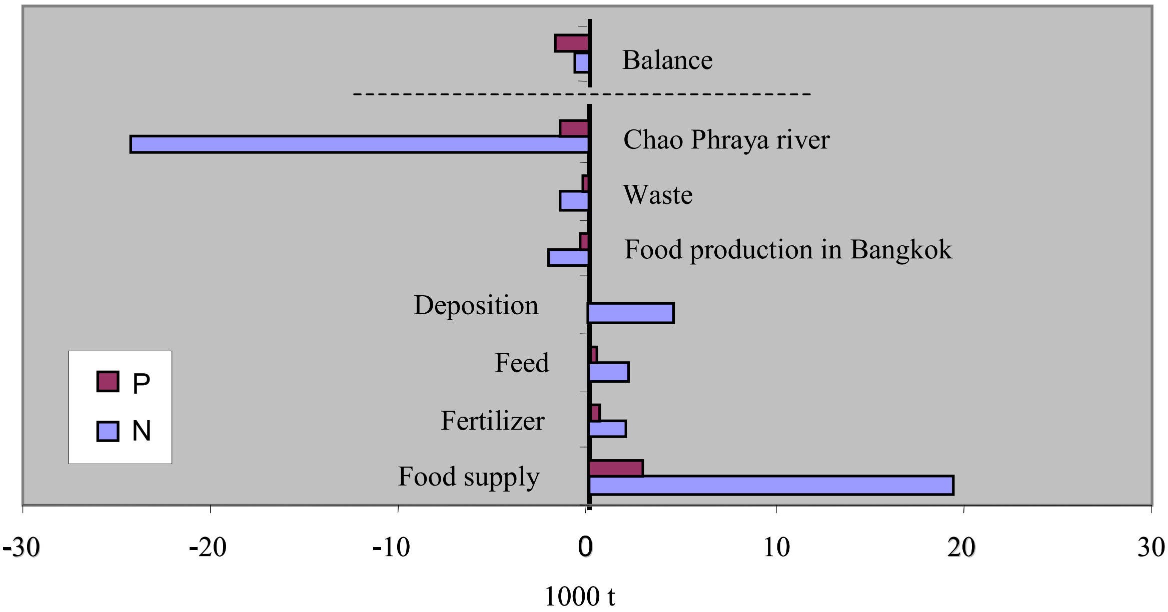
In most developing countries, in particular for pig and poultry production in Asia, lack of regulations and weak infrastructures allowed a surge of peri-urban production. Industrial livestock production emerges where the demand for animal products increases too rapidly for land-based systems to respond. This creates a vacuum which draws livestock into land-detached industrial systems. Because of weak infrastructure and therefore, high transport costs, these systems are usually found close to urban centers. Industrial production which is based exclusively on external inputs, bears enormous pollution problems and associated human health risks. Animal concentrations are out of balance with the waste absorptive and feed supply capacity of the land and, because of pollution and health hazards, most industrial-type livestock production is to be moved out of city boundaries as soon as infrastructure permits.

Industrial and specialized livestock production systems emit large quantities of waste, resulting in excessive loading of manure on the limited land areas within reasonable distances of the producers. Globally, pig and poultry industries produce 6.9 million tons of nitrogen per year, which is equivalent to 7 percent of the total inorganic nitrogen fertilizer production in the world. According to Bos and de Wit (1996), 44, 50 and 20 percent of the nitrogen excreted by pigs, broilers and laying hens respectively is lost before being applied to the land.

Like waste from animal production, the processing of animal products results in environmental damage when it is concentrated and unregulated. This is the case in urban and peri-urban environments, particularly in developing countries. Slaughtering requires large amounts of hot water and steam for sterilization and cleaning. Therefore, the main polluting component is waste water (Verheijen et al., 1996). Also the quality of drinking water is affected. Huge variations have been found, due to large differences in scale, in housekeeping and management practices of each factory or plant. The quantity of water used during processing is of major importance with high water use related to high emission values. In principle, the production of waste water does not necessarily lead to environmental problems if livestock processing is small scale and not concentrated in a given area (Verheijen et al., 1996).

In large cities in developing countries where disposable incomes are rising significantly, the level of nutrients accumulated annually in food brought into urban areas is increasing dramatically because of the increase in demand for animal proteins. Faerge and Penning de Fries (2001) recently published a nutrient balance for Bangkok (Figure 8). The results show that of the nutrients brought into the city in food, only 7% of the N and 10% of the P is recovered and re-cycled. Of the losses of N, 97% could be accounted for by elevated levels of N in the Chao Phraya river, compared with 41% in the case of P. The environmental impacts of the 25,000 t of N flowing into the river and the sea must be a cause for concern. Bangkok is a model that could be applied to many cities in the Asian region; there is a clear parallel in the large cities of the major river valleys in China, where nutrient transport into water bodies is estimated by Xing and Zu (2002) to be 11 Tg. Xing et al. indicate that the high nutrient loads are leading to marine environmental problems such as red tides in addition to eutrophication in inland water bodies. Rising incomes and greater demand for animal protein, and the increased imports of nutrients in food and feed will exacerbate the problems.

Figure 8: The N and P Balance of Bangkok



Source: Faerge and Penning de Vries (2001)

3 Nutrient Flows in Agricultural Trade

3.1 Background

Our analysis has highlighted the general trend to negative nutrient balances in developing countries and the excess of nutrients in many developed countries. Within both developed and developing countries, our analysis of the rural-urban divide shows that the movement of food results in a net transport of nutrients from rural areas to cities are creating major nutrient disposal problems. On a global scale, the material flow of agricultural commodities in international trade results in major nutrient movements between countries. Japanese scientists recognized the importance of this problem in their own country which, as a major food and feed grain importer, faces serious nutrient disposal problems due to pollution and eutrophication (Miwa, 1992). Miwa emphasized that each country should consider the effects on its ecosystems of nutrient imports. He pointed to the period 1980 to 2000 during which demand for livestock products in developing countries was projected to grow 2.4-fold, and feed grain use to grow from 48 million t to 190 million t. Livestock production lies at the heart of environmental concerns because, as indicated by data for nitrogen, the efficiency of nutrient conversion from feed to animal production is only 10% (van der Hoek, 1998).

3.2 Methods

The study of Miwa (1992) utilized FAO data on food production and trade in the period 1979-81, calculating nutrient flows using average nutrient contents of the commodities. In the IFPRI IMPACT study “Global Food Projections to 2020” by Rosegrant et al. (2001), future nutrient flows in traded agricultural commodities, using FAO data from 1997 as a baseline, have been projected. The IMPACT projections of supply and demand for major agricultural commodities are integrated with price and subsidy information to derive net trade by commodity for each country. The data include neither non-food commodities such as wool and cotton, nor industrial commodities such as rubber. IFPRI provided data for the commodities listed in Appendix 2. This Appendix also shows the nitrogen, phosphorus and potassium contents of the commodities; we used data were taken from a variety of sources, as also listed, and these can be considered as average values. Appropriate corrections were made for the moisture content where analytical data were on a dry weight basis. Note that nutrient data are expressed in elemental rather than oxide forms; the use of P and K oxide data is normally restricted to use with fertilizer statistics. In order to make the data equivalent, fertilizer data used in this section for comparisons with nutrient flows in net trade were converted from oxide to elemental contents. The countries and regional groupings in the IFPRI data used in the present study are listed in Appendix 3.

The presentation of the nutrient data and manipulations of the data also requires some comment. In trade data, an export is normally expressed as a positive and imports as negative. However in the case of nutrient balances, the export becomes a negative and an import a gain to the country. The signs on the IFPRI data converted to nutrient flows were therefore changed to reflect the ecological implications. Additionally, the IFPRI data on net trade are presented as individual or groups of like commodities (e.g. roots and tubers) because quantities of commodities such as eggs and wheat are not additive. In the case of nutrients, the weights of N, P and K in different commodities are additive, and amounts of the different nutrients can also be summed. We were therefore able to aggregate the nutrient data and summarize them as shown in Appendix 4, which also shows fertilizer consumption data on NPK expressed as the elemental forms so that comparisons can be made with the nutrient trade data.

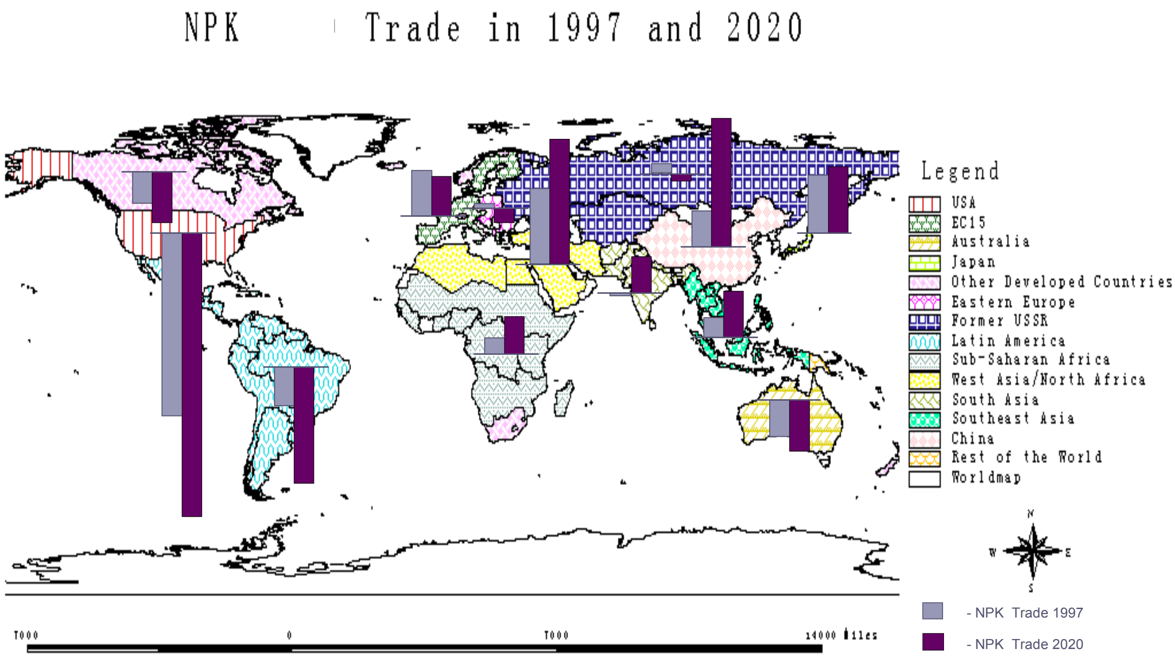
3.3 Results on Nutrient Flows in Agricultural Trade

The 2020 study by Rosegrant et al. (2001) provides a wealth of insights into major changes between 1997 and 2020 in the supply and demand for major food commodities in countries from developed and developing regions. Under their baseline scenario, economic growth, rising incomes and rapid urbanization in developing countries are driving fundamental changes in the global structure of food demand. As incomes rise, direct consumption of maize and coarse grain will shift to wheat and rice, while the higher demand for meat will increase the demand for feed grain. Agricultural trade will increase, with wheat leading the cereals and poultry the livestock commodities. West Asia/North Africa (WANA), China and Sub-Saharan Africa will increase imports, whereas the United States, Latin America and Southeast Asia will increase the value of their net exports. For a detailed analysis of the IMPACT data, readers are referred to the IFPRI publication (Rosegrant et al., 2001).

Aggregated data on net flows of NPK in trade vary widely across regions and countries (Figure 9). The countries and regions showing major gains of NPK through imports of traded commodities are WANA and China. Both show major increases between 1997 and 2020, and this is especially true in China, which will increase NPK imported in food from 0.6 Tg to 2.2 Tg. These imports will probably go to the cities where, as noted above, major nutrient excesses are causing serious water pollution. Other countries and regions with moderate levels of NPK in imports are EC15, Japan, Southeast Asia and Sub-Saharan Africa. From a balance in 1997, South Asia is predicted to become a net importer of NPK in food (0.6 Tg). The NPK imported in food into Sub-Saharan Africa is predicted to increase significantly between 1997 and 2020, as is the case with other developing regions such as Southeast Asia.

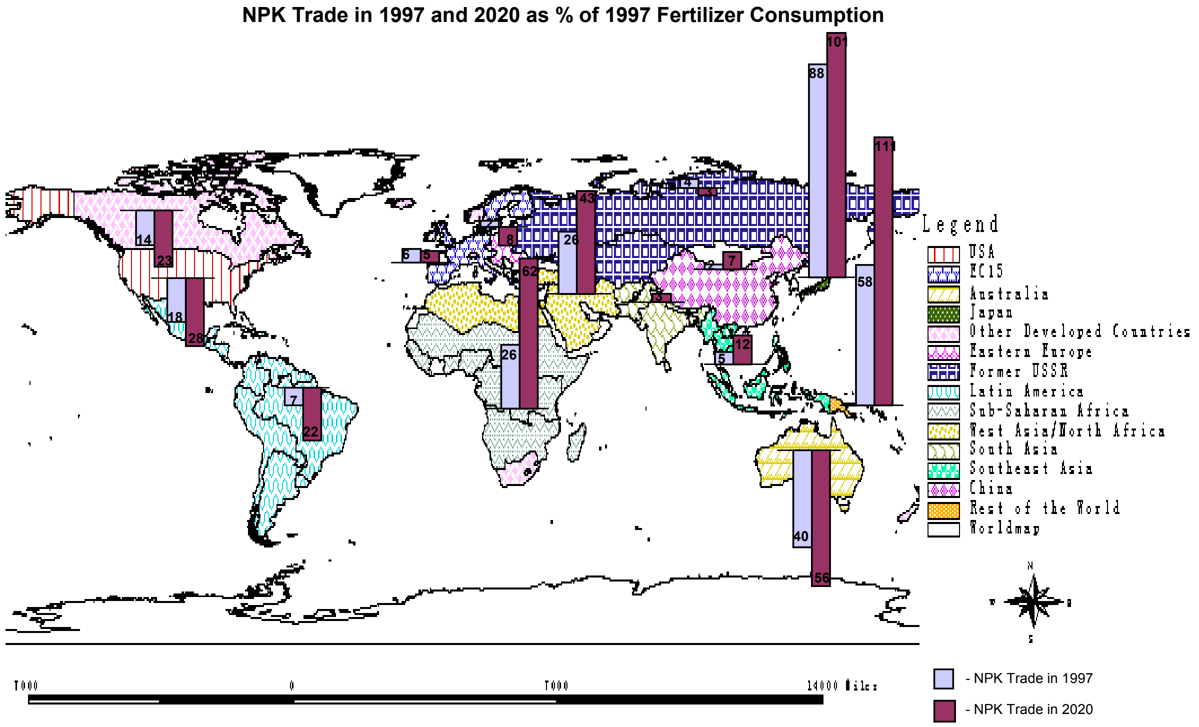
Figure 9 also shows that the United States, Australia, Latin America, and 'other developed regions' (includes Canada), which represent the major food exporting countries, also show the largest net loss of NPK in agricultural commodity trade. In the case of the United States, the exports of NPK will increase from 3.1 Tg in 1997 to 4.8 Tg in 2020. This represents a major flow of nutrients in terms of the potential perturbation of nutrient cycles in natural ecosystems. The most significant increase in NPK outflows is Latin America which loses 0.65 Tg in 1997 increasing to 1.95 Tg in 2020. Eastern Europe is predicted to increase exports of nutrients to 0.2 Tg, from a low level of import (0.15 Tg) in 1997. The net trade in NPK in the former Soviet Union is generally close to zero in both years.

Figure 9: Relative Flows of NPK in Net Agricultural Trade 1997 and 2020 (IMPACT Model)



Putting the data on nutrient flows in traded agricultural commodities into perspective requires a basis for comparison. Some workers such as Miwa (1992) have expressed country data as Kg/ha of agricultural land. This comparison indicates the potential to recycle nutrients by spreading livestock and urban wastes. However, this approach may be misleading since the practicality of spreading nutrients imported into cities across distant arable areas is questionable. Furthermore, areas importing feed for livestock may be distant from the bulk of arable land, making the spreading of nutrients across all cropping land impractical. An alternative basis for comparison is the fertilizer consumption in the importing or exporting country concerned. This comparison does not take account of the fact that traded commodities contain non-fertilizer derived nutrients such as nitrogen from biological fixation; fixed N is especially important in traded legumes such as soybean. Nevertheless, as shown in Appendix 4 and Figure 10, the data on NPK in net trade in 1997 and 2020 were calculated as a percentage of fertilizer consumption in the corresponding country or region. Since data on projected fertilizer consumption in 2020 were not available, IFDC fertilizer data from 1997 were used.

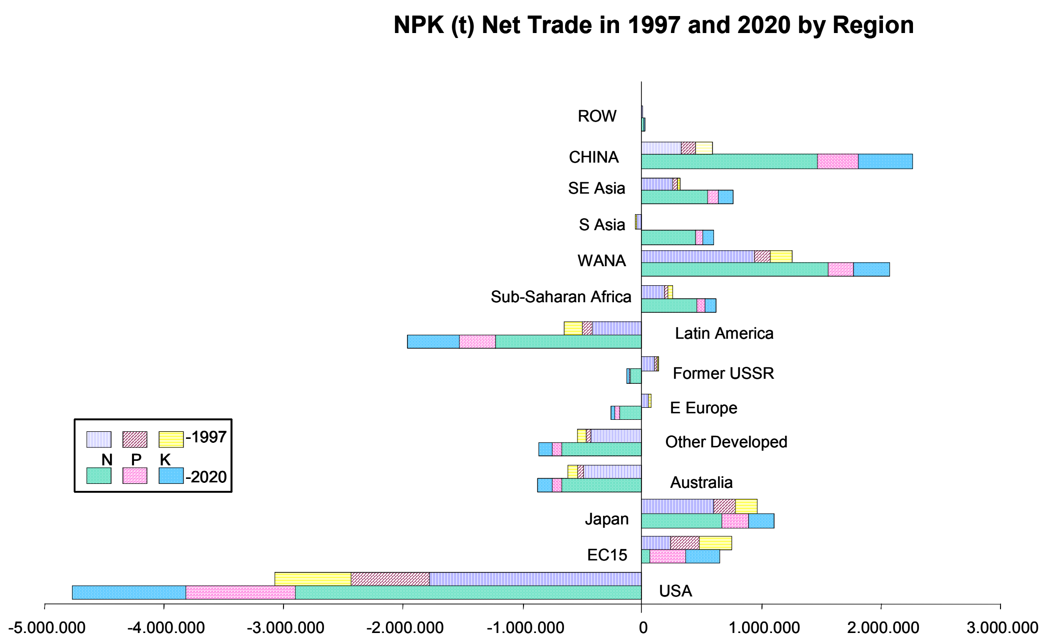
Figure 10: Net Flows of NPK in Trade in 1997 and 2020 Expressed as a Percentage of 1997 Fertilizer Consumption



The comparisons with fertilizer consumption in Figure 10 provide useful insights into the relative importance of the nutrient trade flows. The largest exporter of nutrients, the United States, exported in 1997 only the equivalent of 18% of its fertilizer consumption. This rises to 28% in 2020, but fertilizer use will doubtless increase to compensate. Nevertheless, the large amounts of nutrient involved do present challenges to US policymakers in the areas of subsidies, trade and environmental protection. The largest importer of nutrients in absolute terms is China, but the amounts of NPK in relation to fertilizer consumption represent only 2% in 1997 and 7% in 2020. Clearly domestic NPK consumption in China dwarfs the NPK imports in food. On the other hand, the concentration of imported nutrients in the cities may still be a cause of concern since environmental problems are already serious, as noted in the discussion above. Japanese imports of the equivalent of 88 to 101% of fertilizer consumption points to the familiar problem of nutrient overload, discussed above. Although the aggregated data presented for the EC15 do not reveal it, the Netherlands, Belgium and other small countries that import large amounts of animal feeds have the same environmental problems.

In 1997 Sub-Saharan Africa imported the equivalent of 26% of fertilizer consumption and this increases to 62% in 2020. At first sight this result may appear counter-intuitive, since the major problem in Sub-Saharan Africa is nutrient depletion in rural areas due to low rates of fertilizer use. However, the data presented are averages across and within countries. If the nutrients imported in food end up as wastes in the major cities, the rural lands will not benefit. The result does highlight the potential for nutrient re-cycling in peri-urban and urban agriculture. Another key issue is that while the fertilizer data include nutrients applied to plantation crops, the trade data exclude plantation and industrial crops. Vlek (1993) estimated that in 1987 the export of N, P_2O_5 and K_2O in agricultural commodities, mainly cotton, tobacco, sugar, coffee cocoa and tea, was 296 t; a not insignificant amount in this nutrient deficit region. In WANA the import of NPK in food is equivalent to 26 to 43% of fertilizer consumption. On the debit side, exports of nutrients from Latin America will increase from 7% in 1997 to 22% in 2020. Interpretation of these data indicate an exaggerated effect when on the one hand large exports of soybean contain biologically fixed rather than fertilizer N, and on the other the 2020 data are expressed as a proportion of 1997 fertilizer data. Latin American countries will need to increase fertilizer use to avert soil fertility decline. Similar comments apply to Australia which is exporting large amounts of NPK in relation to fertilizer consumption. In Australia's case the biologically fixed nitrogen comes from pasture legumes grown in rotation with cereal crops. Nevertheless, the significant increases in exports to 2020 also point to the need to maintain soil fertility by replacing exported nutrients.

Figure 11: Net Flows of N, P and K in Traded Agricultural Commodities in 1997 and 2020 (IMPACT Model)



The separation of the nutrients N, P and K in the net trade data is shown in Figure 11. The results show the proportional dominance of N in the nutrient movements. Potassium transfers are nevertheless significant and may contribute opportunities for eventual re-cycling of this important nutrient, given its high cost of mining and transportation. Nitrogen is the most dynamic nutrient and after transformation can move in the atmosphere as well as aquatic systems. Nitrogen has been the most studied nutrient and is the subject of regular international conferences (See Galloway and Cowling, 2002). The amounts of N involved in transfers through trade are significant ecologically, especially when our 2020 projections are considered. Most importantly, as has been stressed before, the concentration of NPK imported in food into cities presents the greatest challenge. The total net global flows of N, P and K estimated in the present study are 4.8 Tg in 1997 and 8.8 Tg in 2020. As Miwa (1992) points out, each country must consider the consequences of nutrient flows in food trade to its own ecosystem. For example, since livestock industries based on imported feeds create such massive nutrient disposal problems, the possibility of importing livestock products directly presents a solution. Government policies will determine such outcomes; the next section of this paper considers policy questions in detail.

Further trends in international nutrient trade result from livestock production. Demand for livestock products is growing fast, especially in many developing countries. In Europe, about 60% of the total cereals available are used as animal feed, while worldwide this is 30%. Massive trade in feedstuffs involves transport from other continents to Europe, then conversion to meat and animal wastes in highly concentrated areas, where there is easy access by ship, train or roads with high emission rates to air and groundwater and export of meat and milk to other countries (van Egmond, Bresser, and Bouman, 2002).

The return of nutrients to land-based systems via manure frequently causes problems due to high water content and high transport cost. While it is difficult to generalize, transport beyond 15 kilometers is often uneconomical. In addition, mineral fertilizers, frequently a cheaper and more readily available source of nutrients, reduce demand for nutrients from manure even further, turning the latter into "waste". Surveys in Brittany have shown that, while the manure nitrogen would suffice, farmers bought an additional 80-100 kg of nitrogen /ha per year in inorganic fertilizer. At the farm level, the type of management defines the environmental burden of this waste. At the regional level, the nutrient surpluses result from feed imports. With low levels of feed imports, such as prevailing in Denmark, almost all manure can be used on the farm. With large feed imports, such as in the Netherlands, regional imbalances emerge and transport costs become a critical issue.

4 Policy Recommendations

4.1 Agricultural Trade Liberalization and Nutrient Allocation

As has been highlighted in Section 3, there are major nutrient movements between nutrient deficit and surplus countries. These movements have been caused in part by agricultural policy distortions influencing agricultural trade patterns. In many developed countries, which count nowadays mostly as nutrient surplus countries, agricultural subsidies have boosted agricultural production to a large extent, while taxation has imposed constraints on agricultural production in many nutrient deficient developing countries. Overproduction of food and other agricultural products has led to environmental degradation based on nutrient surpluses in most developed countries as well as artificially high exports. The United States, Europe and Japan spend a total of US$350 billion each year in agricultural subsidies. It is estimated that these farm subsidies cost poor countries about US$50 billion a year in lost agricultural exports. This is equal to the total aid provided by developed countries to developing countries (Kristof, July 6, 2002). In contrast, developing countries have been unable to increase their investments in agriculture, including nutrient inputs. Due to their limited access to developed country markets, their returns have been further decreased and due to the cheap imports from developed countries, their internal markets have also been further distorted.

In November 2001, the Ministerial Conference in Doha, Qatar, set new framework conditions with major implications for development policies. Members of the World Trade Organization (WTO) acknowledged the need to further correct the prevailing restrictions and distortions in agricultural world markets. The negotiations and their results as stated in the Ministerial Declaration constitute the mandate for further negotiations of the Agreement on Agriculture (AoA) in the context of WTO. The commitment of creating a fair agricultural trading system that will recognize the special needs of developing countries and foster their full integration and participation in agricultural world trade has been reaffirmed. Thus, agricultural trade is being liberalized by reducing current restrictions and distortions of the agricultural world markets. This will have major impact on production patterns and thus nutrient allocation world-wide.

In an ideal world, liberalization of agricultural trade is expected to lead to regional shifts in world agricultural production guided increasingly by existing comparative advantages. On the one hand, reducing the financial support in agriculture in developed countries is expected to have a positive effect on the nutrient balance by reducing the intensity of production and thus the use of fertilizers. Improving the opportunities for developing countries to export to developed countries will, on the other hand, increase their returns from agriculture, thus allowing them to invest more into their land by increasing their fertilizer input. A more efficient allocation of natural resources and nutrients and more equity worldwide as a whole is expected to result.

Taking analytical evidence from several studies into account one can conclude that global liberalization would: (a) generate substantial benefits for developing countries in the order of US$50-100 billion annually; (b) increase world prices for agricultural products by around 10%; and (c) create sizeable export opportunities for developing countries through both trade diversion and trade creation. However, the gains will be distributed diversely across countries and also across different population groups within countries.[4]

The liberalization of trade in the agricultural sector under WTO is based on three pillars: the reduction of export subsidies, increasing market access and cutting domestic support. In the following, major emphasis will be put on the latter, cutting domestic support.

4.1.1 Cutting Domestic Support in Developed Countries

In Western Europe, a decrease and decoupling of agricultural subsidies is expected to avoid further massive surplus production and financial burdens in the context of the Common Agricultural Policy (CAP) in the future. Consequently the growth in fertilizer use is expected to lag behind other regions of the world; and this trend will be augmented by the increasing emphasis on organic agriculture (FAO, 2000). In the United States, however, subsidies will rise further under the newly launched US$180 billion farm bill.

The effects of subsidy removal can be shown in the example of New Zealand. In 1984, nearly 40% of the average sheep and beef farmer's gross income came from government subsidies. In 1985, almost all subsidies were removed. About 15 years later, the agricultural sector in New Zealand has grown and is more dynamic than ever. The removal of farm subsidies has proven to be a catalyst for productivity gains. The diversification of land use has been beneficial for the farmers, and the farming of marginal land has declined. Overall, it has been found that the subsidies restricted innovation, diversification and productivity by corrupting market signals and new ideas. Instead, they lead to the wasteful use of resources negatively impacting on the environment (Frontier Centre for Public Policy, 2002). Since many of these environmental problems are associated with nutrient surplus, a major improvement in the management of nutrients is expected to result from liberalizing agricultural trade by cutting subsidies and reducing other kinds of policy distortions.

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[4] For a review of major studies on the impact of agricultural trade liberalization see von Braun, Wobst, Grote (2002).

4.1.2 Domestic Support in Developing Countries

In a survey of 38 developing countries, FAO found that 68% of them used fertilizer subsidies (FAO and IFA,1999). In India for example, the Government introduced subsidies for inputs like fertilizer, power, irrigation and credit to farmers in the late 60s to foster agricultural growth. While these subsidies have been critical in getting the 'Green Revolution' started, the subsidies are now imposing high costs not only on the environment, but also on the fiscal budget. It has been found that the fertilizer subsidy which keeps the price of nitrogen low leads to (i) nutrient imbalances lowering the yield; (ii) declining quality of ground water; and (iii) the inefficient use and waste of fiscal resources (World Bank, 2001). In Bangladesh, fertilizer subsidies were phased out as part of the overall market liberalization. In China, subsidies were removed by simultaneously increasing producer prices in compensation (FAO and IFA, 1999).

Many other developing countries, however, like especially landlocked and food-deficit countries in Africa, are characterized by all-pervasive poverty, inadequate infrastructure, low fertilizer use and high fertilizer prices. In these cases, introducing a subsidy can help creating positive environmental externalities by giving incentives to the farmers to increase their fertilizer use to avoid soil fertility mining. In the medium- to long-term, however, the subsidies should be abolished due to their financial and environmental implications. In addition to the market distortions and the environmental problems associated with fertilizer subsidies, black markets and the misallocation of resources can arise (Tiessen, 1995).

Stability in the exchange rate is especially essential for promoting growth in fertilizer use and supply. Rapid devaluation of domestic currency reduces both fertilizer use and supply by increasing costs and reducing the confidence of investors. Since many developing countries are not self-sufficient in fertilizer supplies, adequate and timely allocation of foreign exchange for fertilizer imports should receive high priority (Bumb and Baanante, 1996).

4.2 Integrating Different Production Systems

In the following we illustrate with the example of livestock and crop production, how the integration of different production systems can promote sustainable development resulting in more balanced nutrient management.

Animal production may benefit society because it uses both agro-industrial by-products and areas only suitable for grassland. For a sustainable world, however, it is necessary to study the desired balance between human food and animal feed production in agricultural cropping systems. Environmental degradation can impose large costs on the economy and the society. These costs come in several forms, including adverse impacts on health or loss of productivity. Estimates of the economic costs of productivity losses caused by soil erosion, deforestation, and land degradation, water shortage and destruction of wetlands in China was estimated to amount to US$13.9-26.6 billion per year which is equal to 3.8 to 7.3 % of the GNP (Smil, 1996).

Past trade policies in developing countries have often limited the synergistic effect of crops and livestock in nutrient deficient situations. Imposing high import duties to protect domestic cereal production have pushed cropping into marginal areas and upset the equilibrium between crops and livestock.

In the past, industrial systems have also benefited greatly from policy distortions which, in many cases, have given these systems a competitive edge over land-based systems. In the former centrally planned economies, beef feedlot enterprises were based on heavily subsidized feed grain and on subsidized fuel and transport. In many developing countries, however, there are often no direct subsidies on feed and on energy. Since energy is a major direct and indirect cost item in industrial production systems, economy-wide policies such as subsidies tend to favor them over their land-based counterparts.

For agriculture, there are good possibilities to optimize nitrogen efficiency by integrating livestock and crop production. The integration still represents a major avenue for intensification of food production. Mixed farming provides farmers with an opportunity to diversify risk from single crop or livestock production, to use labor more efficiently, to have a source of cash and to add value to low value or surplus feed. To varying extents, mixed farming systems allow the use of waste products of one enterprise (crop by-products, manure) as inputs to the other enterprise (as feed or fertilizer). Mixed farming is, in principle, beneficial for land quality in terms of maintaining soil fertility. In addition, the use of rotations including various crops and forage legumes replenishes soil nutrients, and reduces soil erosion as well as reducing the risk of pests and diseases common in cereal monoculture (Thomas and Barton, 1995).

Many mixed farming systems have a negative nutrient balance, but deficits are partially covered by a flow of nutrients from (often communal) grazing areas to cropland. As population pressure changes the crop/grazing land ratio, and if other sources are not available, soil fertility gaps widen. In input-intensive urban farming in nutrient deficit countries, the high load of nutrients can be washed into rivers or ground water and thus contributing to water eutrophication (Kyei-Baffour and Mensah, 1993). Nevertheless, some of these nutrients might reenter the system by contributing to the nutrient requirements of irrigated crops. This is consistent with interviews held with some farmers who believe that water provides a detectable fertilizer benefit to their crops (Cornish et al., 1999). Thus to some extent the off-site costs of water eutrophication might be balanced by the fertilizer value of the water.

Adding manure to the soil increases the nutrient retention capacity, improves the physical condition by increasing the water-holding capacity and improves soil structure stability. This is a crucial contribution because, in many systems, it is the only avenue available to farmers for improving soil organic matter. It is also substantial in economic terms. Approximately 20 million tons or 22 percent of the total nitrogen fertilization of 94 million tons (FAO, 1997) and 11 million tons or 38 percent of phosphate is of animal origin, representing about US$ 1.5 billion worth of commercial fertilizer. Not only does animal manure replenish soil fertility but it helps to maintain or create a better climate for soil micro-flora and fauna. It is also the best way of using crop residues.

Since the nitrogen-use efficiency in animal production systems is much lower than in crop production, higher efficiency of the food production system as a whole can be achieved by reducing export-oriented livestock production in intensive systems far from feed crop production areas. Such a change could be accompanied by a shift from the use of imported animal feed to on-farm production or animal feed purchased from local producers so as to close the N cycle on the farm or regional scale.

4.3 Control and Command Measures

In OECD countries, nutrient excess situations are increasingly regulated, alleviating some of the environmental hazard. There are a number of measures which set certain regulations for the use of chemical fertilizers, such as

- requirement for fertilizer nutrient plans,
- maximum application amounts,
- regulation of times of application in order to reduce leaching and volatilization, and
- severely limited use of fertilizers in e.g. water extraction areas and nature protection areas.

With respect to organic fertilizers, additional measures include:

- maximum numbers of animals /ha based on amount of manure that can be safely applied per ha of land,
- holdings wishing to keep more than a given number of animals must obtain a license, and
- minimum capacity for manure storage facilities.

In cases of non-compliance with these regulations, fines and other legal enforcement measures are applied to combat environmental degradation. However, it must be mentioned that there is ample evidence of lack of enforcement of environmental regulations and laws in developing countries.

As an example of a control and command measure, the European Union (EU) has introduced in 1991 the Nitrates Directive to combat water pollution from agriculture. The directive includes the obligation of member states to designate so-called Nitrate Vulnerable

Zones (NVZs). Nitrate concentrations in water in these zones are to be reduced to values below 50 mg/l. In addition to the Codes of Good Agricultural Practice, valid on a country-wide basis and often consisting of voluntary-based measures, specific Action Programs with mandatory measures have to be developed for the NVZs. These Action Programs include measures like: a proscribed period for fertilizer application; restrictions to applications on sloped soils and on soaked, frozen or snow-covered soils; limitations to applications near watercourses; and mandatory minimum capacity limits for manure storage and fertilization plans. Besides compulsory measures, also voluntary-based measures like frequent sampling and analysis of manure are promoted.

An assessment of the directive has shown that the farmers' awareness on the protection of the waters has increased. Action programs are valuable tools to enforce measures that lead to a reduction of the water pollution by agricultural activities. Regional projects show that significant improvements can be achieved e.g. in terms of reduced fertilizer inputs while maintaining the economic potential of agriculture (Monteny, 2002).

Another example for command and control measures can be found in Flanders, Belgium. There, the agricultural sector accounts for two thirds of nitrogen losses to the environment. The nitrogen surplus amounted to 187 million kg N or 294 kg/ha which equaled almost half of the inputs. Comparing OECD statistics, it can be seen that Flanders nitrogen balance is even higher than the Netherlands. To reduce the nitrogen surplus, a number of different measures have been applied: Initially, the manure policy was aimed at distributing the manure surplus equally across Flanders and at stopping the growth of livestock by a strict licensing policy. Soilless livestock farms usually need to have contracts with feed producers. Later on, the policy switched to the use of individual target commitments by farmers.

Command and control policies alone are often inefficient, and require supplementary market-oriented policies to enhance the effectiveness of environmental protection. Implementation of control measures at the farm level will only be successful and sustainable if the farmer can determine his or her economic interest to undertake such measures. Therefore, the economic benefits from such factors as implementation of erosion control measures to maintain soil fertility, capital costs associated with improved manure handling and distribution, etc. must be clearly seen to be offset by reduced energy consumption in minimum till situations, improvement in soil fertility by improved manure handling and erosion control, reduced fertilizer costs etc.

In addition, it should be mentioned that the establishment of nutrient accounting systems combined with financial accounting systems has been suggested as an important audit system and as a policy instrument. Bookkeeping of inputs and outputs at the level of individual farms has been selected as a new solution to control nutrient use and to tax nutrient surpluses in agriculture. At the same time, nutrient accounting presents important management information (Breembroek, Koole, Poppe, Wossink, 1996).

4.4 Voluntary Measures

The adoption of diverse voluntary measures, practices and technologies has the ability of minimizing adverse environmental effects. In order to improve nitrogen efficiency, 'Best Agricultural Practice' has been promoted. Decreasing or optimizing the production and use of chemical fertilizer is an effective means of changing the amount of nitrogen in the system. However, a reduction of chemical fertilizer is only possible in an agricultural operation where organic manure can serve as an alternative. Next to codes of best practice, also the promotion of the „polluter pays principle" (PPP) aims at internalizing environmental costs resulting from nutrient overflow at the farm level.

Also eco-labeling might be a useful measure to show that no or less fertilizer and pesticides have been used, thus benefiting the environment. Eco-labeling is defined as a practice of providing information to consumers about a product which is characterized by improved environmental performance and efficiency compared with similar products, and it has gained increasing popularity in recent years.

Eco-labeling is considered as an attractive policy measure because of its voluntary nature and market-driven approach to achieve environmental goals. The idea is that growing concern of consumers for the environment encourages them to pay relatively higher prices for agricultural products which have been produced in an environmentally friendly way. Producers have the incentive to pay more attention to the environmental effects of their production processes and the quality of their final products, by labeling and then receiving price premiums for their products. Most of the agricultural products which are certified are produced in systems based on organic farming or integrated pest management. However, eco-labeling also offers challenges and has raised concerns, especially in developing countries but also among many consumers in developed countries[5].

4.5 New Economic Approaches

New economic approaches involve full resource valuation and full cost pricing of resources. Often, a judicious mix of market-based instruments and standard setting is the most appropriate approach. It must be also considered that each country situation is different, and while the choice of instruments may be similar, their designs are very different (UNEP, 1999). In the following, economic analysis and nutrient trading permits are presented as new economic approaches towards a more efficient nutrient management.

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[5] For a literature review on the role of eco-labeling in agriculture, see Grote (2002).

4.5.1 Economic Analysis

An important issue in the preparation and choice of environmental policies is the evaluation of their costs imposed on all farm sizes. Some policy options are more beneficial to certain size operations than others. A comparison between the environmental or social benefits with the economic costs for different policy measures provides a basis for selecting the most appropriate and lowest cost policy options at the national level (Kjaer and Narrod, 2000).

Economic analysis can provide a guide to the level of actions required to reduce nitrogen losses and environmental risks in a cost-effective manner, while also allowing consideration of relative costs of controls to various groups.

Research on alternative policies for reducing nutrient loads to the Gulf of Mexico has been conducted (Doering et al., 2002). Comparisons were based on the evaluation of the social and economic costs and benefits of methods for reducing nutrient loads. Two basic approaches were taken: First, the amount of N reaching the surface waters in the Mississippi Basin was to be reduced, and second, the N concentration already in the waters within the basin flowing to the Gulf was to be reduced. The analysis indicates that N losses from agriculture can be reduced in the 20% range through either nutrient restrictions or programs aimed at reducing N losses. A modest area of wetlands (1-2 million acres) can be restored in a cost-effective manner. The strategies combined would not greatly affect farm prices or consumer food costs. However, some farmers would have higher costs of following a program than others. For example, farmers on marginal soils or in drier areas may have limited flexibility in trying to meet N-reduction goals (Doering et al., 2002). It is not possible to know the full costs of the specific program be they wetlands restorations, N restrictions, or N loss reductions requiring incentives.

Further it has been shown that as N was restricted or N losses were controlled, production declined and agricultural prices increased. For example a 20% fertilizer restriction resulted in a 6% increase in corn prices and a 2% increase in wheat prices. A 40% restriction resulted in a 28% increase in corn prices and a 13% increase in wheat prices.

Management of agricultural N requires estimates of integrated budgets which may be considered in relation to national agricultural soil surface areas. For effective management of N, reliable data and budgets are required for identifying relevant emission sources, and for helping policy makers to select possible options for control. Ideally agricultural budgets should be considered on a farm-by-farm basis, which provides detailed datasets to help increase the awareness of the farming community and identify inefficiencies. For international agreements, there is a strong need for comparable, reliable, up-to-date data provided on a continuous basis. Balance sheets are an important tool. When looking at regional or national solutions special relocation of functions (nature, agriculture) might provide the means to solve some local problems.

4.5.2 Nutrient Trading Permits

Low-cost, innovative approaches are needed to effectively reduce pollution from non-point sources like agriculture and urban runoff. Faeth (2000) compared different policy approaches to reduce phosphorus loads in specific watersheds in the US. He estimated that one variation utilizing trading costs about US$2.90 per pound of phosphorus removed, compared to almost US$24 per pound for conventional point-source requirements. He therefore recommends trading among industrial and municipal point sources whenever new nutrient reduction requirements are put in place.

Emission trading is a new instrument in environmental policy. It has been used to create markets in air or water pollution. In addition, trading is the leading option proposed to address the build-up of greenhouse gas emissions that could cause climate change. For trading, an overall level of permissible pollution is set. The permissible aggregate level of pollution is lower than the current level, so that an artificial scarcity is created and the permits acquire market value. The permits divide this level between producers based on norms agreed by policymakers. Producers who wish to expand, for example, need to reduce the pollution from their own production sites or buy permits from others. Thus, trading increases flexibility and reduces costs by allowing producers with new obligations the option of adapting their own facilities or financing comparable reductions by others. Sources with low treatment costs on the other hand may reduce their own effluents beyond legal requirements, generate a credit, and sell these credits to dischargers with higher treatment costs. This flexibility produces a less expensive outcome overall while achieving - and even going beyond - the mandated environmental target. The desired reduction in pollution occurs at least cost. However, there have been also cases where administrative and transaction costs increased, making trading difficult.

EPA estimates that if background pollution from agriculture were reduced, the need for tertiary water treatment could be avoided - providing a net saving of US$15 billion in capital costs for tertiary treatment (cited by Faeth, 2000).

A new scientific approach – a concept of optimum nitrogen management for society – has been suggested as an alternative or complement to the critical load/critical level approach now widely used in Europe. This concept is based on the idea of an optimum but extends this concept to include all types of land use within society. With an optimum curve in place for each type of land use and each curve translated into emission ceilings, which do not exceed critical limits, various economic and regional sectors of society could negotiate and then adjust emissions accordingly in a cost-effective way for a more sustainable and equitable society.

Dekkers (2002) notes that the implementation of an emissions or pollutant trading scheme requires a number of difficult changes in people's perceptions and attitudes.

4.6 Institutional Strengthening and Developing Infrastructure

Institutional failures often prevail, hindering an adequate policy response in favor of a more efficient fertilizer management system. Therefore, institutional strengthening is expected to lead to better environmental results. In this context, the issues of access to inputs like fertilizer and credit, extension, education and new technologies as well as the increase of cooperation at the national and international level will be discussed in the following.

4.6.1 Access to Fertilizer

Institutional constraints that may prevent the adoption of fertilizers in developing countries are generally related to a lack of access to markets leading to high transaction costs. An improvement in the marketing of fertilizer is expected to increase their use in developing countries, thus avoiding further soil mining. Efficient and appropriate organizations should be created to ensure that fertilizer reaches the farm on time, in adequate amounts, and at minimal cost. One strategy to promote fertilizer use is to apply the "mini-pack" method in which small packets of 100g and 200g of fertilizers are sold outside shops, in market places or outside churches (FAO and IFA, 1999). In general, the private sector should have the primary responsibility for marketing and distribution of fertilizer, while the government should develop and implement appropriate regulatory and quality control measures for efficient functioning of the fertilizer markets. In those areas where markets are underdeveloped, the government may take the lead in developing markets and supporting infrastructure.

Poor land tenure security, especially in the rainfed mixed farming systems of the developing world, has provided a disincentive for investment in long-term soil fertility improvements, such as the use of inorganic fertilizers and the use of green manure and leguminous fodder crops in the crop rotation (Bumb and Baanante, 1996). It has been found that in the State of Paraná, Brazil, inappropriate land parceling and a poor marketing system led to short-term unsustainable agricultural systems. The resulting loss of NPK fertilizers from an average erosion of 20t/ha/year represents an annual economic loss in fertilizer equivalent of US$242 million in nutrients (Ongley, 1996).

Policies that promote markets for sustainably produced and certified agricultural products can also help to internalize the environmental costs of production and consumption.

4.6.2 Access to Credit

Limited availability of funds for farmers to purchase fertilizers is a major constraint to fertilizer use. The growing participation of the private sector in fertilizer marketing and distribution mandates that fertilizer dealers also have access to financial resources. Every effort should be made to ensure adequate funds at reasonable interest rates for both farmers and fertilizer dealers.

4.6.3 Extension, Education and New Technologies

Adequate extension and educational support should be provided to farmers. In countries with low education levels, farmers are sometimes not aware of the environmental impacts of the use of fertilizers. Education and extension would then provide a better basis for sustainable development. The development of better application methods and of new, environmentally sound fertilizers as well as soil testing should be promoted. New technologies suitable for targeted application of fertilizer should be encouraged. The proper use of suitable forms of fertilizer leads to less emission of ammonia and nitrous oxide making the same crop yields are feasible with less fertilizer. In addition, the formulation and composition of feed should be changed to reduce amount of nutrients, as well as adding enzymes to improve the utilization rate of plant phosphorus. Research should also put more emphasis on how to reduce ammonia loss.

Additional reductions may be achieved by shifting to a human diet with less animal protein. However, human diets are generally not the subject of policy formulation but can be influenced through strategies such as marketing and public awareness raising (van Egmond, Bresser, and Bouman, 2002).

4.6.4 Cooperation at National and International Levels

Environmental, fiscal and agricultural objectives often conflict with each other. To facilitate policy making, a number of organizations like the Ministries of Agriculture, Finance and the Environment need to cooperate at a national level. Similarly, also agricultural, environmental and consumer lobby groups which follow different goals influencing the establishment of environmental standards for example, need to cooperate.

Policies aimed at solving environmental problems associated with nutrient surplus (mostly nitrogen and phosphorus) must often be multinational in scale. To foster coordination at a higher level, very often information exchange needs to be increased. For example, the N input to the North Sea is subject to the North Sea Action Plan and the OSPAR convention. Reductions of up to 50% have been agreed on by Rhine and North Sea countries.

4.7 Conclusions

Environmental costs are often not factored into the debate on nutrient management. Such costs include moving and disposing of waste from millions of tons of nutrients in feed grains used for feedlots and other systems of intensive livestock production. As has been shown, it costs governments billions of dollars to establish and control elaborate environmental regulations to avert water and atmospheric pollution, and it costs society even more when these regulations fail. Food and feed traded internationally in agricultural commodities, alone contains an estimated 4.8 million tons of nitrogen, phosphorus and potassium. This is predicted to grow to 8 million tons in 2020, much of the increase being in feed rather than food grain trade because of the increased demand for meat as incomes rise in developing countries. To the extent that meat-exporting industrialized countries such as the Netherlands, Belgium and the US increase production to meet the demand, so will the hot spots of nutrient pollution in those countries grow, and the costs will be passed on to their taxpayers. Knowledge of the scope and the long-term costs of these problems should prompt societies and politicians in these countries to support reductions in agricultural subsidies and opening up their markets. On the other hand, given a level playing field and a helping hand, developing countries could expand their livestock production in environmentally benign and profitable ways. The resulting economic development would reduce the need for handouts and probably help stem the out migration from developing countries.

There are a number of different initiatives at different levels available to improve the world-wide allocation of nutrients and thus contribute to sustainable development. At the global level, trade liberalization is supposed to bring major benefits to the allocation of nutrients. In addition, the role of agriculture is considered as a transboundary issue within the larger framework of water quality management. At the national level, governments use macro-economic policy, trade regulations, agricultural and environmental policies to impact on nutrient allocation. At the farm level, input subsidies, or education and extension are examples of often-used policy measures. Fertilizer use will remain an essential component of future strategies for ensuring food security and protecting the natural resource base. In fulfilling that role, however, fertilizer use should be approached differently in the future. Emphasis should be put on growth with management rather than on growth per se, so that the broader goals of food security, agricultural growth, and environmental protection are not sacrificed.

Very often, a mixed and interdisciplinary policy approach is needed to tackle problems associated with inefficient nutrient management. Not only the environmental impact of different measures, but also the costs of different approaches need to be taken into account. While hydrologists, soil scientists or engineers determine what is technologically feasible and set maximum allowances, economists identify the relatively cost-effective options and their impacts on equity, meaning on the per capita income of farmers. In addition, public perceptions and values play a major role in the final choice of the policy measures.

5 Summary

The expansion and intensification of agricultural production to meet the needs of a burgeoning population has transformed vast areas of the land surface. These changes have perturbed nutrient cycles in the soil-water-plant-atmosphere continuum at a range of scales, from farm to global levels. The contrasts between the nutrient balance of agricultural soils in nutrient deficit and in nutrient surplus countries reflect the large disparities in wealth, farmer use of purchased nutrient inputs, and agricultural policies between less developed and industrialized countries respectively. The consequential environmental and ecological impacts of nutrient flows within and between countries require more study. One particularly neglected area is the impact of the international movement of nutrients in traded agricultural commodities. This paper addresses some of these knowledge gaps by reviewing and presenting data on nutrient balances and global nutrient movements, and by considering a wide range of government policies that impinge on nutrient availability and flows.

New data were derived in the form of time series (from 1980-2001) on the nutrient balance of agricultural lands in countries in Africa, Latin America and the Caribbean as part of a research program of IFDC. The nutrient balance of agricultural lands was calculated from estimates of the available soil nutrients and the added organic and inorganic fertilizer added, minus the nutrient loss by removal at harvest and by various loss mechanisms. The results for 1996-1999 show that the annual balance of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) in the vast majority of countries in the study regions is negative. Of the 24 countries in Latin America, five show positive nutrient balances in their agricultural land ranging from 28 kg/ha in Venezuela to 188 kg/ha in Chile. Of the 21 countries where the soil fertility is depleting, the annual NPK balance ranges from -5 kg/ha in Panama to -170 kg/ha in Guyana. In Africa only Botswana, Mauritius and Libya show positive nutrient balances, while the other 42 countries studied showed extensive annual nutrient depletion, that ranged from >110 kg/ha in Rwanda to <5 Kg/ha in South Africa. In the majority of countries in Africa the nutrient balance of agricultural land was in the range of -40 kg/ha to -80 kg/ha. The high rates of nutrient depletion in soils in majority of the countries in Africa and Latin America and the Caribbean are not sustainable. The most obvious way to redress the depletion in soil fertility is to add more nutrients as chemical or organic fertilizers, and/or to enhance biological nitrogen fixation so that nutrients removed by crop harvests are replaced. Additionally, greater efforts are needed to combat soil erosion which is a major cause of nutrient depletion, particularly in steepland areas.

Nutrient surplus in some agricultural areas of industrialized countries causes serious environmental problems such as emissions of greenhouse and pollutant gases, as well as pollution of surface and ground waters. The water pollution affects human health and disturbs aquatic ecosystems. Published data show that in 1994-1996 the annual N balance (N inputs minus N plant uptake) of total agricultural land in all OECD countries is positive and ranges from 10 kg/ha in Australia to nearly 300 kg/ha in the Netherlands. Most encouraging is the reduction in N surplus in several countries between 1986-1988 and 1994-1996, as governments have recognized the need to address the environmental problems. Detailed nutrient balance studies in a number of countries show that nutrient surpluses tend to be localized, particularly in areas with intense livestock production systems. Nutrient loads derived from agriculture in major rivers are most serious in industrialized countries of Europe and the USA, but also occur in densely populated areas of countries such as India and China. Recent research highlights the problems and opportunities associated with urban concentrations of nutrients around big cities. Nutrients mined from the soils of rural areas, or imported as food or feed to the cities, create mammoth waste disposal problems that might be resolved through safe re-cycling of solid wastes and waste waters in urban and peri-urban agriculture.

Nutrient movements in traded agricultural commodities provide a unique international dimension to nutrient flows. We obtained net trade data for major food commodities for 1997 from FAO and for 2020 used projections from the International Food Policy Research Institute IMPACT model. Commodity trade data for different regions and countries were converted to weights of N, P, and K using average nutrient contents from the literature. The results show that international net flows of NPK vary widely across regions, but amount to 4.8 Tg in 1997 and are projected to increase to 8.8 Tg in 2020, representing a major human-induced perturbation of global nutrient cycles. Major net importers of NPK in traded agricultural commodities are West Asia/North Africa and China. Despite a widely recognized problem of soil nutrient depletion, Sub-Saharan Africa is a net importer of NPK in agricultural commodities (0.3 Tg in 1997 and 0.6 Tg in 2020). However, nutrients imported in food and feed commodities to Sub-Saharan countries are commonly concentrated in the cities creating waste disposal problems rather than alleviating deficiencies in rural soils. Countries with a net loss of NPK in agricultural commodities are the major food exporting countries – the United States, Australia, and some countries of Latin America. In the case of the United States, exports of NPK will increase from 3.1 Tg in 1997 to 4.8 Tg in 2020. When these data were expressed as a percentage of fertilizer consumption in the United States, net exports in 1997 were the equivalent of only 18% of its fertilizer consumption and will export only 28% in 2020 (based on 1997 fertilizer data). Equivalent data for China, the largest importer, show only 2% in 1997 and 7 % in 2020. On the other hand, because of its small land area, Japan will import in commodities the equivalent of 90-100% of its fertilizer consumption; and because of the low current rates of fertilizer use, Sub-Saharan Africa will import as much as 26% and 62% in 1997 and 2020 respectively.

A wide range of policy measures influence agricultural trade, nutrient flows and balances. Agricultural trade liberalization and the reduction of production subsidies is expected to reduce excessive nutrient use in nutrient surplus countries and make inputs more affordable to farmers in nutrient deficient countries. In an ideal world, this should result in a more efficient global allocation of natural resources and nutrients and reduced environmental costs, although some level of subsidy to developing country farmers may be justified to introduce them to fertilizer technologies. Policies that encourage diversified production systems should have similar effects by ensuring that animal wastes are not concentrated in areas with no opportunities to recycle nutrients on arable crops. Other measures include more direct environmental policies to regulate nutrient disposal, as exemplified by the recent nutrient accounting scheme in the Netherlands. Alternative voluntary approaches include the promotion of best agricultural practice or eco-labeling. For nutrient surplus countries, innovative policy options such as nutrient trading are being examined. For nutrient deficient countries, institutional strengthening and infrastructure development are valid approaches that entail credit schemes, extension, training, etc.

Our study highlights the need for environmental costs to be factored into the debate on nutrient management. Such costs include moving and disposing of waste from millions of tons of nutrients in feed grains used for intensive livestock production. It costs governments billions of dollars to establish and control elaborate environmental regulations to avert water and atmospheric pollution, and it costs society even more when these regulations fail. Because of the increased demand for meat as incomes rise in developing countries, meat-exporting industrialized countries will increase production to meet the demand, increasing the hot spots of nutrient pollution in those countries, and the costs will be passed on to their taxpayers. Knowledge of the scope and the long-term costs of these problems should prompt societies and politicians in these countries to support reductions in agricultural subsidies and opening up their markets. On the other hand, given a level playing field and a helping hand, developing countries could expand their livestock production in environmentally benign and profitable ways. The resulting economic development would reduce the need for handouts and probably help stem the out migration from developing countries. We advocate more inter-disciplinary research on these important problems, and solutions such as that proposed above. The results of the research should better inform the public whose perceptions and values play a major role in the final choice of the policy measures.

References

Asian Livestock (2000): Buffalo meat: The most economical source of protein. Asian Livestock, FAO Regional Office, Bangkok Thailand, 24 (2), pp. 11-13.

Bacon, S.C., Lanyon, L.E. and Schlauder, R.M. Jr. (1990): Plant Nutrient Flow in the Managed Pathways of an Intensive Dairy Farm. *Agronomy Journal* 82(4), pp. 755-761. Pennsylvania State University, University Park, PA.

Bindraban P. S., Stoorvogel, J. J., Jansen, D. M., Vlaming, J., and Groot, J. J. R. (2000): Land quality indicators for sustainable land management: proposed method for yield gap and soil nutrient balance. In: *Agriculture, Ecosystems & Environment,* 81, pp. 103-112.

Bos, J.F.F.P. and de Wit, J. (1996): Environmental impact assessment of landless monogastric livestock production systems. Working Document Livestock and the Environment: Finding a Balance. FAO/World Bank/USAID. Rome.

Bouma, J. and van Lanen, H.A.J. (1987): Transfer Functions and Threshold Values: From Soil Characteristics to Land Qualities, In: Beek, K.J, Burrough, P.A. and. McCormack, D.E (Eds), *Quantified Land Evaluation Procedures,* ITC pub. 6, pp. 106-110.

Brandies, P.J., de Wit, J., van der Meer, H.C. and van Keulen, H. (1995): Environmental Impact of Animal Manure Management. Working Document Livestock and the Environment: Finding a Balance. FAO/World Bank/USAID. Rome.

Breembroek, J.A., Koole, B., Poppe, K.J. and Wossink, G.A.A. (1996): Environmental Farm Accounting: The Case of the Dutch Nutrients Accounting System. In: *Elsevier Science Ltd.*, Agricultural Systems 51 (1996) pp. 29-40.

Breman (1994): Modélisation dans l'élaboration de systèmes de production animale durables. In: Powell, J.M., Fernandez-Rivera, S., Williams, T.O., and Renard, C. (Eds), *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa,* Proceedings of an International Conference, ILCA, Addis Ababa, Ethiopia, Nov. 1983. pp 473-492.

Breman H. and Kessler (1995): Woody plants in agro-ecosystems of semi-arid regions. With an emphasis on the Sahelian countries. Advanced Series in Agricultural Sciences 23, Springer-Verlag, Berlin.

Broekhuyse, Th. (1983): Economie rural des mossi: Tomes I-II, Technical report, Royal Tropical Institute, Amsterdam, The Netherlands.

Bumb, B.L. and Baanante, C.A. (1996): Policies to Promote Environmentally Sustainable Fertilizer Use and Supply to 2020, IFPRI, Washington D.C., 2020 Vision Brief 40, October 1996.

Bunyard, Peter (2001): Should we pay farmers to sequester carbon in their soils? In: *The Ecologist*, published on 22/10/2001. (http://www.theecologist.org/archive_article.html?article=280&category=72; accessed 30 June 2002).

Charreau, C. (1972): Problemes poses par l'utilisation agricole des sols tropicaux par des cultures annuelles. In: *Agron. Trop.* No. 9.

Cofie, O.O., Drechsel, P., Amoah, P., Danso, G., and Gyiele, L. (2001): Improving rural-urban nutrient flows through urban and peri-urban agriculture. In: *Rural-Urban Encounters: Managing the Environment of the Peri-urban Interface*. Development Planning Unit International Conference, University College, London.

Cornish, G.A., Mensah, E. and Ghesquire, P. (1999): An Assessment of Surface Water Quality for Irrigation and its Implications for Human Health in the Peri-Urban Zone of Kumasi, Ghana. Report OD/TN 95 September 1999, HR Wallingford, U.K.

Craswell, E. T. (2001): Sustainable Land Management for Crop Production In Yajima, M and Tsurumi, K. (eds) *Agricultural Technology Research for Sustainable Development in Developing Regions* JIRCAS International Symposium Series No. 9. pp. 39-48. Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

de Jager, A., Nandwa, S. M., and Okoth, P. F., (1998): Monitoring nutrient flows and economic performance in African farming systems (NUTMON) I. Concepts and methodologies: *Agriculture, Ecosystems & Environment*, 71, pp. 37-48.

Dekkers, Chris P.A. (2002): NOx Emission Trading in a European Context: Discussion of the Economic, Legal, and Cultural Aspects. In: *Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection*. Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The Scientific World (2001), pp. 958-967.

Doering, O.C., Ribaudo, M., Diaz-Hermelo, F., Heimlich, R., Hitzhusen, F., Howard, C., Kazmiericzak, R., Lee, J., Libby, L., Milon, W., Peters, M., and Prato, A. (2002): Economic Analysis as a Basis for Large-Scale Nitrogen Control Decisions: Reducing Nitrogen Loads to the Gulf of Mexico. In: *Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection*. Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The Scientific World (2001), pp. 968-975.

Drechsel, P. and Gyiele, L.A (1999): The Economic Assessment of Soil Nutrient Depletion. Analytical Issues for Framework Development. International Board for Soil Research and Management. Issues in Sustainable Land Management No. 7. Bangkok.

Drechsel, P. and Kunze, D. (2001): *Waste composting for urban and peri-urban agriculture - Closing the rural-urban nutrient cycle in Sub-Saharan Africa*. IWMI/FAO/CABI: Wallingford.

Faeth, Paul (2000): Fertile Ground – Nutrient Trading's Potential to Cost-Effectively Improve Water Quality. World Resources Institute, Washington, D.C.

FAO (1981): FAO/UNESCO Soil Map of the World, Vols. 1-10, UNESCO, Paris

FAO (1981): Reports of the Agro-Ecological Zones Project, World Soil Resources Report 48, Vols. 1-4, Rome, Italy.

FAO (1982): Land Resources for Populations of the Future. FAO. Rome, Italy

FAO (1986): World-wide Estimates and projections of the Agricultural and the non-Agricultural Population Segments, 1950-2025, Documents ESS/MISC/82-2. Rome, Italy.

FAO (1993a): Integrated Plant Nutrient Systems and Sustainable Agriculture. 17th Consultation of the FAO Fertilizer Programme, Islamabad, Pakistan.

FAO, AGROSTAT (1994): Information system: Computerized data bank on external assistance to agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (1995): Fertilizer Yearbook 1994-1995, Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (1996): Production Yearbook 1995, Vol. 49, Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (1996): The Sixth World Food Survey. Food and Agriculture Organization of the United Nations. Rome. Italy.

FAO (1997) Current World Fertilizer Situation and Outlook 1994/95-2000/2001. FAO/UNIDO/World Bank Working Group on Fertilizers. Rome.

FAO and IFA (1999): Fertilizer Strategies. Food and Agriculture Organization of the United Nations and International Fertilizer Industry Organization, revised version, Rome.

FAO/IFA/IFDC (1999): Fertilizer Use by Crop. Document ESS/Misc/1999, Rome, Italy.

FAOSTAT (2000): Food and Agricultural Organization of the United Nations. Statistical Databases. (http://apps.fao.org; accessed 08 January 2004)

FAO (2000): Fertilizer Requirements in 2015 and 2030. (ftp://ftp.fao.org/agl/agll/docs/barfinal.pdf; accessed on 08 January 2004)

FAO (2002): Animal Feed Resources Information System. (http://www.fao.org/DOCREP/003/W6928E/w6928e1k.htm; accessed 8 March 2000)

Faerge, J., Magid, J. and Penning de Vries, F.W. T. (2001): Urban nutrient balance for Bangkok. In *Ecological Modeling,* 139, pp. 63-74.

Frontier Centre for Public Policy (2002): Life after Subsidies. The New Zealand Farming Experience – 16 Years later. In: *Frontier Backgrounder*, Frontier Centre for Public Policy, Feb. 2002.

Galloway, James N., Cowling, Ellis B. (2002): Reactive nitrogen and the world: 200 years of change. In: *Ambio,* 31, pp. 64-72.

Gigou, J., F. Ganry, and Pichot, J. (1985): Nitrogen Balance in some Tropical Agrosystems, In: *Nitrogen Management in Farming Systems in Humid and Sub-Humid Tropics*, Proceedings of IITA Symposium, Ibadan, Nigeria, Oct.23-26, 1984

GPA (2002): Did you know? GPA Coordination Office of the United Nations Environment Programme, The Hague. (http://www.gpa.fao.org.; accessed in August 2002)

GROTE, U. (2002), Eco-labelling in the agricultural sector: an international perspective. In: *European Council, Proceedings of the High-Level Pan European Conference on Agriculture and Biodiversity: towards sustainable agriculture in Europe integrating biological and landscape diversity*. Strasbourg. (http://www.nature.coe.int/ CONF_AGRI_2002/; accessed on 08 January 2004)

Henao, J. and Baanante, C.A (1999): Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa. International Fertilizer Developing Center. Muscle Shoals, Alabama

Howarth, R.W., Boyer, E.W., Pabich, W. J., and Galloway, J.N. (2002): Nitrogen use in the United States from 1961-2000 and potential future use trends. In: *Ambio,* 31, pp. 88-96.

Hoekstra, D., and Corbett, J.D. (1995): *Sustainable Agricultural Growth for the Highlands of East and Central Africa: Prospects to 2020,* International Food Policy Research Institute, Washington, D.C., U.S.A.

IFDC (1992): Soil fertility restoration project. Final Project Report. International Fertilizer development Center, Muscle Shoals, AL., USA.

Kang B.T., Reynolds, L., and Atta-Krah, A.N. (1990): Alley farming. In: *Advances in Agronomy*, 37, pp. 183-248.

Kjaer, S. and Narrod C (2000): Economics and Policy Options. (http://lead.virtualcentre.org/en/ele/awi_2000/6session/6paper.htm; accessed 12 August 2002)

Kristof, N.D. (July 6, 2002): Agricultural absurdity. In: *International Herald Tribune* (IHT).

Kyei-Baffour, N. and Mensah, E. (1993): Water Pollution potential by agrochemicals. A case study at Akumadan. In: *Proceedings of 19th WEDC Conference*, Sept. 93, Accra, Ghana, pp. 301-302.

Lal, R., Sanchez, P.A., Cummings, R.W. (1986): *Land Clearing and Development in the Tropics.* A.A. Balkema, Rotterdam, The Netherlands.

Larson, W.E. and Pierce, F.J. (1991): Conservation and Enhancement of Soil Quality, In *Evaluation of Sustainable Land Management in the Developing World,* IBSRAM Proceedings No. 12, Vol.2, pp. 175-201, Chiang Rai, Thailand.

Lefroy, R. D. B. and Konboon, Y. (1998):. Studying nutrient flows to assess sustainability and identify areas of nutrient depletion and imbalance: an example for rainfed rice systems in Northeast Thailand. In: Ladha, J.K., Wade, L.J., Dobermann, A., Reichardt, W. Kirk, G.J.D. and Piggin C. (Eds.) *Rainfed lowland rice: Advances in Nutrient Management Research*. Proceedings of the International Workshop on Nutrient Research in Rainfed Lowlands, 12-15 Oct. 1998, Ubon Ratchathani, Thailand. IRRI, Philippines. pp. 77-93.

Milliman, J.D. and Meade, R.H. (1983): Worldwide delivery of river sediment to the oceans. In: *Journal of Geology*, 91, pp. 751-762.

Miwa (1992): Global nutrient flow and degradation of soils and environment: Transactions 14th International Congress of Soil Science , Kyoto, Japan, August 1990, V, pp. 271-276.

Monteny, G. J. (2002): The EU Nitrates Directive: A European Approach to Combat Water pollution from Agriculture. In: Optimizing *Nitrogen Management in Food and Energy Production and Environmental Protection*. Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The Scientific World (2001), pp. 927-935.

Mosier A. and Kroeze C. (2000): Potential impact on the global atmospheric N_2O budget of the increased nitrogen input required to meet future global food demands. In: Chemosphere – Global Change Science 2, pp. 465-473.

Nandwa, S. M. and Bekunda, M. A., (1998): 1998, Research on nutrient flows and balances in East and Southern Africa: state-of-the-art. In: *Agriculture Ecosystems & Environment* 71, pp. 5-18.

Narrod, C., Reynnells, R. and Wells, H. (1994): Potential Options for Poultry Waste Utilization: A Focus on the Delmarva Peninsula. Washington D.C.: United States Department of Agriculture and the Environmental Protection Agency.

National Land and Water Resources Audit Project (2001): – Nutrient Balance in Regional Farming Systems and Soil Nutrients Status. Australian National Heritage Trust (CD-ROM).

Oenema, O. and Pietrzek, S. (2002): Nutrient management in food production: Achieving agronomic and environmental targets. In: *Ambio*, 31, pp. 159-168.

Ongley, E. D. (1996): Control of water pollution from agriculture. FAO Irrigation and Drainage Paper 55, Rome.

OSPAR (1998): Ministerial Meeting of the OSPAR Commission: Sintra, 22-23 July 1998 - Programmes and Measures. Convention for the Protection of the Marine Environment of the North-East Atlantic, London.

Parris, K. (1998): Agricultural nutrient balances as agri-environmental indicators: an OECD perspective. In: *Environ. Pollution,* 102, pp. 219-225.

Pieri, C. (1983): Nutrient Balances in Rainfed Farming Systems in Arid and Semi-Arid Regions. In: *Nutrient Balances and the Need for Fertilizers in Semi-Arid and Arid Regions,* Proceedings of the 17th Colloquium of the International Potash Institute, Rabat Morocco, pp. 181-209.

Poss, R. and Saragoni H. (1992): Leaching of nitrate, calcium and magnesium under maize cultivation on an Oxisol in Togo. In: Fertilizer Research, 33, pp. 123-133.

Pretty, J., Brett, C., Gee, D., Hine, R., Mason, C., Mori, J., Rayment, M., van der Bijl, G. and Dobbs. T. (2001): Policy challenges and priorities for internalising the externalities of agriculture. In: *Journal of Environmental Planning and Management* 44(2), pp. 263-283.

Reuter (2001): Nutrient balance in regional farming systems and soil nutrient status. In: *Fertilizers in Focus.* Fertilizer Industry Federation of Australia, Inc., Conference 28-29 May 2001.

Rhodes, E., Batiano, A., Smaling, E.M.A., and Visker, C. (1995): Nutrient stocks and flows in West African soils. In: Mokwunye, A.U., de Jager, A., and Smaling, E.M.A. (Eds), *Restoring and Maintaining the Fertility of West African Soils: Key to Sustainable Development.* International Fertilizer Development Center – Africa, Lome, Togo, pp.17-26.

Rosegrant , M. W., Paisner, M.S., Meijer, S., Witcover, J. (2001): 2020 Global Food Outlook: Trends, alternatives and choices. International Food Policy Research Institute, Washington, D.C.

Scherr, S.J and Yadav, S. (1996): Land degradation in Developing World: Implications for Food, Agriculture, and the Environment to 2020. Food, Agriculture, and Environment Discussion Paper No 14. International Food Policy Research Institute, Washington, D.C.

Seitzinger, S.P. and Kroeze, C. (1998); Global distribution of nitrous oxide productions and N inputs in freshwater and coastal marine ecosystems. In: *Global Biogeochemical Cycles,*11, pp. 93-113.

Sheldrick, W. F., Syers, J. K., and Lingard J., (2002): A conceptual model for conducting nutrient audits at national, regional, and global scales: *Nutrient cycling in Agroecosystems*, 62, pp. 61-72.

Smaling, E.M.A., and Fresco, L.O. (1993): A Decision-Support Model for Monitoring Nutrient Balances under Agricultural Land Use. (NUTMON). In: *Geoderma,* 60, pp. 235-256.

Smaling M.A., Oenema, O. and Fresco, L.O. (1999): Nutrient disequilibria in agroecosystems: Concepts and case studies. CABI, Wallingford, UK.

Smil, V. (1996): Environmental Problems in China: Estimates of Economic Cost. East-West Center Special Reports No.5, East-West Center, Honolulu, Hawaii.

Smil, V. (2001): Enriching the Earth: Fritz Haber, Carl Bosch and the trsnformation of World agriculture**.** The MIT Press, Cambridge MA.

Smith (1994): The role of technology in agricultural intensification: The evolution of maize production in the Northern Guinea Savanna in Nigeria. University of Chicago Press, Chicago, IL., U.S.A.

Souci S.W., Fachman, W., Kraut, H. (1969): Die Zusammensetzung der Lebensmittel: Naehrwert-Tabellen. Wissenschaftliche Verlagsgesellschaft, Stuttgart.

Stanton T.L. (1999): Feed composition for cattle and sheep. Colorado State University Cooperative Extension Livestock Series No. 1.615.

Stoorvogel, J.J., Smaling, E.M.A. (1990): Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Report 28, The Winand Staring Center, Wageningen, The Netherlands.

Stoorvogel, J.J., Smaling, E.M.A and. Jansen, B.H. (1993): Calculating Soil Nutrient Balances at Different Scales: I. Supra-national scale. In: *Fert. Res*., 35, pp. 227-235.

Swift, M.J., Seward, P.D., Frost, P.G.H., Quershi, J.N., and Muchena, F.N. (1994): Long-term experiments in Africa: Developing a database for sustainable land use under global change. In: R.A Leigh and A.E. Johnson (Eds.), *Long-term Experiments in Agricultural and Ecological Sciences.* CAB International, Wallingford, England. pp. 229-251.

Thomas, D. and Barton, D. (1995): Interactions between Livestock Production Systems and the Environment Impact Domain: Crop-Livestock Interactions. Working Document Livestock and the Environment: Finding a Balance. FAO/World Bank/USAID. Rome.

Tiessen, H. (1995): Scope 54 – Phosphorus in the Global Environment – Transfers, Cycles and Management. (http://www.icsu-scope.org/execsum/scope54.htm; accessed 30 July 2002)

UNEP (1999): Global Environment Outlook GEO-2000. UNEP, Nairobi.

USDA (1993a): Long-term Agricultural Baseline Projections. Staff Report WAOB-93-1. Washington, DC, USA.

USDA (2002): National Agricultural Laboratory (http://www.nal.usda.gov/fnic/cgi-bin/list_nut.pl; accessed 2 April 2002)

van der Hoek, K.W. (1998): Nitrogen efficiency in global animal production. *Environmental Pollution,* 102, pp. 127-132.

van der Pol, F. (1992): Soil Mining: An Unseen Contributor to Farm Income in Southern Mali. Bulletin 35, The Royal Tropical Institute, Amsterdam, The Netherlands.

van Diepen, C.A., van Keulen, H., Wolf, J. and Berkhout J.A.A. (1991): Land Evaluation: From Intuition to Quantification, *Adv. Soil Sci.,* 15, pp. 141-204.

van Drecht, G., Bouwman, A.F., Knoop, J.M., Meinardi, C., and Beusen, A. (2001): Global pollution of surface waters from point and nonpoint sources of nitrogen. Proceedings of the 2nd International Nitrogen Conference on Science and Policy. *The Scientific World 2001*. pp. 632-641.

van Duivenbooden, N. (1990): Sustainability of West African Cropping Systems in terms of nutrient elements: A Study for the 5th Region of Mali. CABO, Wageningen, The Netherlands.

van Egmond, K., Bresser, T. and Bouwman, L. (2002): The European Nitrogen Case. In: Ambio Vol.31, No.2, pp. 72-78, March, Royal Swedish Academy of Sciences.

Verheijen, L.A.H.M.; Wiersema, D.; Hulshoff Pol, L.W. and de Wit, J. (1996): Management of Waste from Animal Product Processing. (http://www.fao.org/DOCREP/004/X6114E/X6114E00.htm; accessed on 22 August 2002)

Vitousek, P. M., Mooney, H.A., Lubehenco, J. and Melillo, J.M. (1997): Human domination of Earth's ecosystems. In: *Science*, 277, pp. 494-499.

Vlek, P.L.G. (1993): Strategies for sustaining agriculture in sub-Saharan Africa: The fertilizer technology issue. In: *Technologies for agriculture in the tropics*. ASA Special Publication 56. pp. 265-278, Madison, WI, USA.

Vlek, Paul L.G., Kühne, R.F. and Denich, M. (1997): Nutrient resources for crop production in the tropics. In: *Phil. Trans. R. Soc. Lond. B*, 352, pp. 975-985.

von Braun, J., Wobst, P. and Grote, U. (2002): „Development Box“ and Special and Differential Treatment for Food Security of Developing Countries: Potentials, Limitations and Implementation Issues. ZEF Discussion Papers on Development Policy, No.47, Bonn.

World Bank, Energy Sector Unit (2001): India: Power Supply to Agriculture. Volume 1, Summary Report No.22171-IN.

Xing, G. X., and Zhu, Z. L. (2002): Regional nitrogen budgets for China and its major watersheds, *Biogeochemistry*, 57/58, pp. 405 – 427, 2002

6 Appendix

Appendix 1: Basic Data and Sources of Information for Nutrient Balance Studies

Class	Table	Information Sources	Period
1	Statistics (Series)	Crop areas (FAO, IFDC, Country) Crop production (FAO, IFDC, IFPRI, CIAT) Fertilizer use (IFDC, FAO, IFA, Country) Land use (FAO, IFPRI, IFDC, CIAT) Livestock population (FAO, Country)	1981-2001
2	Soils	Soil classification systems (USDA, FAO) Soil fertility classification (USDA, IFDC) Fertilizer use by Crops (IFDC, IFA, FAO) Soil constraints (USDA, FAO) WRI, GLASOD, ISRIC, IFDC, Country)	
3	Climate	Rainfall (WMO, Country) Global Agro-ecological Zones (FAO/IIASA, USDA, CIAT)	1981-2001
4	Management	Crop nutrient uptake (IFDC, IFA, Country) Residue management (IFDC, Country) Mineral fertilizer management (IFDC) Organic fertilizer management (IFDC, Country, ATTRA)	1981-1999
5.	Socio-Economics	Fertilizer and crop prices (IFDC, TFI, IFA, FAO) Rural and urban population (FAO, IFPRI, Country)	1981-2001
6.	Experimental	Experiment results. Soil analysis (IFDC, Country)	

Appendix 2: IFPRI IMPACT Commodities and Nitrogen, Phosphorus and Potassium Contents

Products	**Units**	**Nutrient Content**		
		N	**P**	***K***
Beef	Kg/t	25	2.1	3.5
Pork - (pig meat)	Kg/t	24	5.6	2.2
Sheep/goat	Kg/t	23	1.6	2.4
Poultry	Kg/t	24	1.5	2.7
Eggs - whole egg *(USA)*	Kg/t	16.8	2.6	1.2
Milk - whole milk (cow)	Kg/kL	5.3	0.93	1.6
Wheat	Kg/t	21	2.3	3.2
Maize	Kg/t	11.7	2.1	2.4
Rice - (grain & hulls)	Kg/t	9.2	2.1	2.6
Other coarse grains		15.6	2.6	3.6
barley		*18*	*2.4*	*3.8*
millet/canary grains		*17.8*	*2.9*	*3.5*
oats		*14.2*	*2.4*	*3.6*
rye (cereal rye)		*12.5*	*3.0*	*4.1*
sorghum		*15.3*	*2.1*	*3.0*
Potatoes (tubers)	Kg/t	3	0.4	4.4
Sweet potatoes	Kg/t	2.4	0.5	3.7
Cassava and other roots & tubers cassava	Kg/t	2.6	0.4	2.9
Soybeans	Kg/t	17	20	16.4
Meals	Kg/t	32.1	0.8	6.8
Oils	Kg/t	0	0	0

Sources of nutrient concentration data in Appendix 2:

Beef
NPK: Asian Livestock (2000)

Sheep/goats
chicken
Souci et al. (1969)

Pork (pig meat)
Eggs
Milk
Wheat
Maize
Rice
Other course grains
Potatoes (tubers)
Sweet potatoes
Cassava
NPK: National Land and Water Resources Audit Project (2001)

Soybeans –
For N & P: FAO (2002) Animal Feed Resources Information System
For K: Stanton (1999)

Meals –
For N & P: Animal Feed Resources Information System
For K : Stanton (1999)

Oils –
N, P, K : USDA (2002)

Appendix 3: IFPRI IMPACT Countries and Regional Groupings

Individual Countries or Regions	**Countries**
USA	
EC15	Austria, Belgium/Lux, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, UK
Japan	
Australia	
Other Developed Countries	Canada, Iceland, Israel, Malta, New Zealand, Norway, South Africa, Switzerland
E Europe	Albania, Bosnia-Herzegow, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovakia, Slovenia, Yugoslavia Fr
Former USSR	Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russian Fed., Tajikistan, Turkmenistan, Ukraine, Uzbekistan
Latin America	Ant&Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil Chile, Costa Rica, Colombia, Cuba, Dom. Rep, Dominica, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico Neth. Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Lucia, St. Kitts & Nevis, St. Vincent & G, Suriname, Trinidad & Tob, Uruguay, Venezuela
Sub-Saharan Africa	Angola, Benin, Botswana, Burkina-Faso, Burundi, Cameroon, Central Af. Rep., Chad Comoros Is., Congo Dem.R. (Z), Congo Rep., Cote d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao-Tome Prn., Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe
West Asia/North Africa	Algeria, Cyprus, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Saudi Arabia, Syria, Tunisia, Turkey, UAE, Yemen
South Asia	Afghanistan, Bangladesh, India, Maldives, Nepal, Pakistan, Sri Lanka
South East Asia	Brunei Cambodia Indonesia, Laos Malaysia, Myanmar, Philippines, Thailand, Vietnam
China	
South Korea	
Other East Asia	Korea D. P. Rep., Macau, Mongolia,
Rest of the World	Cape Verde, Fiji, Fr Polynesia, Kiribati, New Caledonia, Papua N Guinea, Seychelles, Vanuatu

Appendix 4: NPK Flows in Net Trade in 1997 and 2020 (Tg) and Expressed as a Percentage of NPK Consumption in 1997

Countries/ Regions	**1997 Total NPK Consumption (Tg)**	**1997 Total NPK in Net Trade (Tg)**	**1997 NPK in Net Trade as a %age of 1997 NPK Consumption**	**2020 Total NPK in Net Trade (Tg)**	**2020 NPK Net Trade as a %age of 1997 NPK Cons.**
USA	17.003	-3.066	-18%	-4.757	-28%
EC15	13.570	0.760	6%	0.662	5%
Japan	1.105	0.974	88%	1.116	101%
Australia	1.530	-0.611	-40%	-0.859	-56%
Other Developed Countries	3.687	-0.527	-14%	-0.856	-23%
E Europe	3.239	0.148	2	-0.244	-8%
Former USSR	3.949	0.148	4%	-0.116	-3%
Latin America	8.950	-0.646	-7%	-1.951	-22%
Sub-Saharan Africa	1.012	0.266	26%	0.628	62%
West Asia/North Africa	4.899	1.260	26%	2.086	43%
South Asia	17.412	-0.044	0%	0.607	3%
South East Asia	6.463	0.331	5%	0.771	12%
China	29.870	0.600	2%	2.152	7%
Rest Of the World	0.029	0.017	58%	0.032	111%

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