More Food from Fertile Grounds

Integrating Approaches to Improve Soil Fertelity

Christy van Beek, Gert-Jan Noij, Niek van Duivenbooden, Hanneke Heesmans,
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ALTERRA
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Abstract NL
Gewassen nemen voedingsstoffen (nutriënten) op uit de bodem. Door de gewassen elders te consumeren worden nutriënten verplaatst. Door urbanisatie en globalisering wordt deze disbalans in nutriënten versterkt. Als de nutriënten onttrekking niet gecompenseerd wordt leidt dit tot bodemuitputting en uiteindelijk tot degradatie van eens productieve gronden. Onttrekking van nutriënten kan gecompenseerd worden met organische en minerale (kunst)mest. Vooral in gebieden ten zuiden van de Sahara wordt dit vaak niet of onvoldoende gedaan, omdat kunstmest duur en risicovol is en er vaak onvoldoende organisch materiaal beschikbaar is.

Keywords: Fertile Grounds Initiative, Sub-Sahara Africa, soil degradation, fertiliser.

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Summary

Every year more than 10 million ha worldwide are prone to soil degradation, resulting in a loss of fertile topsoil that is worth about 40 billion US$. This is a serious threat to social stability in general and to food security in particular for large parts of Sub-Saharan Africa (SSA), South-America and South-East Asia. To halt and reverse this trend, dozens of projects and initiatives, ranging from national fertiliser subsidy programmes to local fertiliser demonstration trials have been implemented over the past decades, but none lived up to the needs to restore or retain soil fertility in a satisfying way. Instead, the accumulation of nutrients in developed countries and the depletion of nutrients in developing countries is increasing and thereby soil fertility loss, and its consequences for food security, has become a global concern. Consequently, new approaches to maintain and improve the productive capacity of soil are required.

In this report such a new approach is presented based on the following findings from literature review and key expert interviews:

- A large number of interventions to improve soil fertility was developed that differ in time perspectives (long term vs short term effects) and input levels (low input vs high input);
- There are no silver bullet solutions to maintain and improve the soils productive capacity. Local conditions (farmer skills, resources availability, socio-economic conditions, and climate) determine the best sets of interventions;
- The way forward should be on the basis of Integrated Soil Fertility Management (ISFM), that includes the application of both mineral fertiliser and organic fertilisers to improve the soils' productive capacity;
- Nutrient management is closely linked to energy use and climate change, both locally and globally. Locally, there is competition for organic matter between fuel for cooking, animal feed and soil amendment. Globally, soil organic matter represents one of the largest carbon stocks that can be depleted or restored, while N fertilisers claim energy for their production and their use causes greenhouse gas (GHG) emissions;
- The limited productive capacity of nutrient depleted soils in one part of the world and the environmental degradation caused by excessive nutrient use in other parts of the world, are two sides of the same coin. Both are struggling to reverse the consequences of these processes. Linking nutrient flows across scales is an opportunity for urban and intensive agriculture regions to reduce environmental problems, turn waste and its associated costs for society into valuable resources and a source of economic activity;
- Nutrients have an intrinsic value and consequently can be (and in a few circumstances: are already) traded. Business cases are designed that stimulate improved nutrient use efficiency and improved distribution of nutrients.

Based on these conclusions the Fertile Grounds Initiative (FGI) was designed to close the nutrient cycle and restore nutrient balances at various spatial levels to maintain or improve the productive quality (soil health) of the land in the long run. It is a coordinated strategy of collaboration between actors in nutrient management (e.g. farmer, fertiliser industry) and other stakeholders (e.g. legislation) to begin with within a country. In the FGI nutrients are traded in a concerted way between suppliers and users, ensuring the best possible combination to ensure sustainability. The initiative requires brokerage, optimizing the match between supply and demand, and minimizing transport of organic and inorganic fertilisers.

The Fertile Grounds Initiative consists of the following eight components:

- Inventory of demand: farmers define their nutrient demand based on soil and crop specific fertilizer recommendations.
- Inventory of potential supply: pools of organic matter within the sphere of activity are identified in terms of quality and quantity.

- Product formulation and processing: sources of organic nutrients are converted into compost and supplemented with single or multiple compound mineral fertilizers to produce optimal compositions of nutrients as integrated fertilizer products.
- Brokerage: supply and demand of nutrients are brought together and arrangements for trade are developed.
- Trade and logistics: business case design, nutrient trade and transport.
- Capacity building: farmers, extension workers, brokers and salesmen receive training in best practices for optimal nutrient management.
- Institutional arrangements: cooperating with existing farmers' organizations and/or setting up farmers' cooperatives, defining the role of a nutrient bank, legal and institutional embedding, as well as government and policy support.
- Creating an enabling environment for economic growth: mobilising support for market access, micro-credits, insurances, etc. for smallholders.

The Fertile Grounds Initiative is expected to make a significant practical contribution to sustainable development in areas with limited soil fertility and nutrient availability, while at the same time resolving problems arising from nutrient excess in certain parts of the world and from (urban) waste streams, turning these into economic assets.

1 Introduction

1.1 Rationale

In 2013 the Dutch Ministries of Economic Affairs and Foreign Affairs faced the ongoing degradation of agricultural soils (including nutrient mining, soil erosion, etc.) in many parts of the world (mainly developing countries) in the light of increasing demand for food and called for action. Notably, the topic is of urgent and of paramount importance considering that:

1. Global trends like population growth, economic growth with changing diets, urbanization and globalization put more and more pressure on the available land. As long as agricultural production is not sufficiently intensified this leads to over-exploitation of land and to land grabbing, which has become an issue on the political agenda, partly because of the high risk of affecting smallholder farmers and partly because of the possible disturbance of global power relations.
2. Agriculture is facing serious threats caused by climate change. According to the latest comprehensive UNCTAD trade and environmental review (UNCTAD, 2013) a systemic change in agriculture is urgently needed to withstand these threats. The good news is that carbon sequestration in agricultural land is not only a good mitigation and adaptation strategy to climate change, but also for restoring and maintaining the soils productive capacity.
3. Policy makers are increasingly aware of the paradox in combating nutrient emissions to the environment in developed parts of the world while at the same time nutrient depletion is jeopardizing food security in developing parts of the world. Nearly two-fifths of global average N inputs are lost from agro-ecosystems to the environment (Liu *et al.*, 2010). This is both a valuable loss and an environmental concern.
4. The areas where the problem of low soil fertility levels is most prominent, particularly Sub-Saharan Africa (SSA), are rapidly changing in terms of urbanization, demography, socio-cultural patterns and land use. Also from a market perspective SSA is gaining interest with associated increased pressure on the land to fulfil the needs of the markets with more nutrient mining without external inputs.
5. The international cooperation policy of the Dutch government has recently changed, focusing on a limited number of so-called concentration countries, many of which belong to SSA. The Dutch government now strongly promotes private sector involvement in development projects. At the same time it wishes development to be sustainable. So further overexploitation of land is not acceptable, on the contrary, land management (including soil fertility and water) should be reinforced to safeguard land for the future on which farmers can make a living.
6. Time seems also right for action at the international level. During the 2^{nd} Global Soil Week 2013: ‘Losing ground?’ an agenda for action was presented for scaling up and integrating international initiatives to safeguard soil, referring to the United Nations Convention to Combat Desertification (UNCCD), the Rio+20 sustainable development goal to achieve a land degradation neutral world (LDNW), the Economics of Land Degradation Initiative (ELD), and FAO’s Global Soil Partnership, Intergovernmental Technical Panel on Soils (ITPS), and voluntary guidelines on the responsible governance of tenure of land endorsed by the Committee on World Food Security.

The above trends all point in the direction of urgent action to save our soils and land, because:

a. Doing nothing will inevitably lead to soil fertility decline and subsequent degradation of large areas of land that are needed for feeding the growing world population (i.e. food security) and for supporting rural livelihood (sustainable economy). Throughout history, when soils became depleted, land was abandoned in search for more fertile areas. Nowadays, there is hardly anywhere left to go, and if new land is taken for agriculture it is at the expense of ecosystems that render services that we need for coping with future hazards.
b. The ongoing nutrient and carbon depletion of soil in large (particularly remote) areas of the world cannot be simply neutralized by resupplying large amounts of nutrients and organic matter. If overexploitation surpasses a certain thresholds or trajectories, the soil ecosystem deteriorates to a level where it will fall prey to erosion or desertification, and can only be rebuilt at high efforts that

cannot be compensated for with the very low yields from these soils. In practice this means these soils are abandoned or left bare without further contribution to food production nor mitigating climate change.

c. Soil fertility is not just another growth factor for closing the yield gap. It is the very fundament of agriculture. Soil fertility should be regarded an investment that needs maintenance, rather than a production factor that can be provided or depleted. Soil fertility represents an economic opportunity value that is reflected in the price of land. Degraded land is worth nothing. But unlike chemical pollution, oil spillage, landfill sites, cutting down tropical forests, landslides and other visible threats to the ecosystem on which humanity depends, soil fertility decline is hidden and therefore often underestimated as an obstacle for sustainable food production. It also gets little attention because restoration takes a long time and, with low returns on investment, few companies wish to get involved. Yet is maybe worthwhile to investigate how to define mechanisms that enable farmers with records of maintaining their soils fertile to get a micro-credit/insurance more easily than farmers who are mining their soils.
d. Nutrient supply is one of the growth factors determining agricultural production that can best be influenced with interventions. Areas with low soil fertility have an enormous agricultural growth potential, which may contribute to global food security and improved livelihoods for (marginal) farmer households across the globe.
e. Nutrient and water use efficiencies together with labour use efficiency must increase in order to cope with increased pressures both on the land and the farmer's family to produce enough food for themselves and the market.
f. Business-as-usual is not effective. There is a huge gap between large scale governmental driven fertiliser programmes and small scale field demonstrations, both in terms of distance or access, and in terms of approach. Although many actors are involved, limited coordination results in patch-work far away from any 'real change' with coherent activities aimed at a clear goal.

Numerous reports and papers have indicated the severe threats related to the current disconnected global nutrient cycles that cause both environmental pollution in the developed parts of the world through nutrient accumulation and loss of productive land in the developing parts of the world through nutrient depletion (e.g. Sutton, 2013). Although the interest for soil fertility issues has recently increased in the realm of policy making, followed by several (political) declarations to emphasize the importance of soil quality for sustainable development, soil nutrient depletion is still ongoing and sometimes even worsening in developing countries (Mateete *et al.*, 2010; Bekunda *et al.*, 1997). Recent CGIAR, FAO, RIO+20 and UNEP documents seem to have a blind spot for soil fertility management and focus on 'hot topics' like climate change, food security, water availability and biodiversity loss (Bouma, 2013; WWF, 2013), and most of them treat soil fertility as a single issue, rather than integrating the issues.

1.2 Goal

In this report an analysis of declining soil fertility is made for the following objectives:

1. To make recommendations for national and international cooperation policies, projects and programmes related to soil fertility and food security.
2. To develop an integrated approach for improving soil fertility and sustainable nutrient management in agricultural development cooperation.
3. To build a stakeholder network to undertake and support initiatives related to these goals. Such an integrated approach should comprise innovative concepts, a defined role for actors in several sectors and a coherent activity plan for several spatial levels and time scales.

1.3 Guidelines for reading

This report does not have the ambition to provide a complete review of the role of (reduced) soil fertility on food security. Rather, it aims to provide a balanced insight in the current state of affairs of (decreasing) soil fertility levels in relation to food security. The report provides the motivation to develop new pathways of change. To do so, the report starts with an introduction in soil fertility (Chapter 2) and **Overview of actors.** The **diagnosis** of the situation in Chapter 3. This chapter addresses the content of the problem, including its spatial appearance and the people who are affected. Chapter 4 reviews the current **trends** that affect soil fertility management in order to identify options for intervention. In chapter 5 different **spatial scales** and options for linking scales are assessed. Chapter 6 gives an overview of actors that affect or are affected by changes in soil fertility. Chapter 7 elaborates the relation between **food security** and soil fertility and Chapter 8 reviews different intervention strategies to identify **conditions for success.** In Chapter 9 a new approach to improve soil fertility is presented based on the prior results. The **conclusions and recommendations** are found in Chapter 10. The findings presented in this report are based on literature research and interviews with respondents who are listed in Annex 1.

2 A brief introduction to soil fertility

Crops need light, CO_2, water, nutrients and a certain temperature range to grow. Of this list, light and temperature are the least manageable and nutrients the most manageable direct production factors. This is why – since the very first settlements – mankind has devoted so much energy to mobilising nutrients for crop growth. Whether through slash and burn, collecting manure and turf, composting, soil conservation, or high-tech fertiliser applications, all over the world nutrient management has been vital for farmers through history. This is also why we take soil fertility and nutrient management as the starting point for sustainable agricultural development.

Soil fertility is commonly defined as the capacity of the soil to sustain biomass production. Other definitions emphasize the chemical (nutrients, pH), physical (soil structure, air and water) and/or biological aspects of soil fertility (a well-functioning soil food web, symbiotic micro-organisms, macro fauna for soil structure). In fact these aspects are closely correlated (Figure 1). For instance, a good soil structure (physical) allows the crop to exploit a larger volume of soil, thus providing better access to nutrients (chemical). Applying fertilisers improves yield, while organic matter inputs through crop residues, compost, or manure improve biological and physical soil fertility. In order to stimulate crop growth a fertile soil must fulfil all chemical, physical and biological conditions for plant growth.

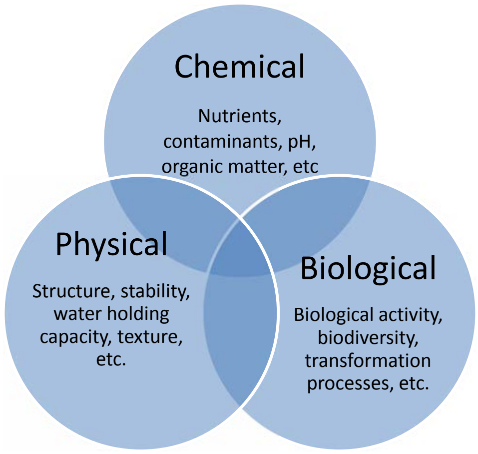


Figure 1 *The three components of soil fertility.*

Of the three components of soil fertility, the chemical component is most easily managed. i.e. soil nutrient availability can be manipulated with mineral and organic fertilisers. While physical aspects like soil structure and aeration are conditional soil factors for plant growth, nutrient availability is typically a growth factor that determines the magnitude of the yield (especially under non-water limited conditions, but also under water limited conditions). Hence, nutrient management is commonly taken as an entry point to affect (the interactions between) chemical, biological and physical soil fertility. To reach a sustainable optimum productive capacity of the soil and optimum resource use efficiencies, all aspects of soil fertility, and indeed all growth factors together with land and water management need to be addressed.

The macronutrients nitrogen (N), phosphorus (P) and potassium (K) are taken up by the crops in largest quantities. Micronutrients such as zinc (Zn, Fe), cobalt (Co), manganese (Mn), etc., are taken up in much smaller quantities but can be essential for specific physiological functions of the crop. Therefore severe micronutrient deficiencies can also reduce crop growth. Specific soil nutrient deficiencies (e.g. Zn and Se) are related to human or animal nutrient health problems.

Nutrient demand is different for different crops and varieties. Each specific crop performs within a range of minimum and maximum soil nutrient content. Below the minimum contents there is hardly any growth and above the maximum growth is limited by other factors and/or other nutrients. So, nutrient uptake by a crop depends on crop type (demand), nutrient availability (supply by the soil) and yield level (i.e. other growth factors). A good fertiliser recommendation takes all these aspects into account, and clearly there is no one size fits all nutrient requirement.

Some nutrients, particularly P, K, Mg and Ca are supplied by the soil through dissolution or weathering of soil minerals, or desorption from its cation exchange complex (CEC). Soils can supply other nutrients such as N, P and S through decomposition (mineralization) of soil organic matter. When nutrient uptake by crops is not compensated for with mineral fertilisers and organic matter, the soil will be mined; nutrient supply declines and ultimately the soil may become prone to degradation and erosion.

Soil nutrient contents can be determined typically through extraction of the soil with chemical agents. Fertiliser recommendations are typically based on the correlation between soil nutrient content and crop response. Table 1 provides some general guidelines for chemical soil fertility levels in the form of nutrient content ranges in soil, frequently used by NGOs and policy makers. However, nutrient availability for the crop also depends on various other soil conditions, e.g. texture, structure, rooting depth, moisture content, aeration, cation exchange capacity (CEC), and pH. Therefore it is not possible to simply define chemical soil fertility in terms of nutrient content of the soil. In the Netherlands, for instance, fertiliser recommendations do not only distinguish between crops and sometimes expected yield levels (maize, grassland), but also between soil types (sand, clay, loess loam, peat). Sometimes these recommendations also take into account the N mineralization potential or the measured mineral N content of the soil in spring.

Table 1
General guidelines for interpretation of soil chemical data (CLNS 2013).

	pH (-)	P (ppm)	K (ppm)	S (ppm)	Zn (ppm)	Organic matter (%)
Very Low	< 5.2	< 10	< 60	< 10	< 1	<2.0
Low	5.2 – 5.8	10 – 20	60-120	10 to 20	1 to 2	2.0-3.0
Optimum	5.8 – 6.8	20 – 80	120 - 600	20 - 80	2 to 10	3.0 - 7.0
High	6.8 -7.5	80 – 150	600 - 900	80 - 100	10 to 20	7.0 - 8.0
Very High	> 7.5	> 150	> 900	> 100	> 20	>8.0

A soil type is determined by soil formation, which is primarily governed by climate and geology. Soils that have developed on volcanic, marine or riverine sediments are generally more fertile and less susceptible to decline. Soils that have developed in other sediments and under high rainfall and temperature regimes, are highly weathered, contain less organic matter and are less fertile and more susceptible to decline, especially if these soils were formed a long time ago, like in large areas of Africa and South America. Sanchez and Cochrane (1980) analysed the relation between soil types and the occurrence of soil fertility problems in Latin-America (Table 2) and demonstrated that different soil types are susceptible to different soil fertility problems. The old, highly weathered oxisols and ultisols, commonly found in SSA are highly susceptible to nutrient depletion.

Crop residues, animal manure, compost and organic mulches are the resources for sustaining a complex food web inside the soil that transforms fresh materials into more stable organic compounds. This is a living system that uses oxygen (or nitrate) for the decomposition of organic matter and produces CO_2. Although this causes CO_2 emission, which aggravates climate change, building up soil organic matter sequesters CO_2 and thus contributes to climate change mitigation.

Table 2

Frequency of soil related productivity problems (%; modified after Sanchez and Cochrane, 1980).

Soil fertility problems		FAO soil classification										
		Alfisols	Incep-tisols	Molli-sols	Entisols	Verti-sols	Ando-sols	Oxisols	Ultisols	Incep-tisols	Entisols	Histo-sols
Physical problems	Erosion	62	39	16	64	100	67	3	50	39	91	0
	Water logging	21	7	9	0	0	20	0	23	39	0	100
Chemical problems	Salinity	0	0	1	0	0	30	0	0	0	0	0
	Alkalinity	1	0	1	0	0	23	0	0	0	0	0
Toxicity	AL	0	0	0	0	0	0	80	80	15	83	0
Deficiency symptoms	N	97	84	0	94	100	100	98	96	60	100	0
	P	58	45	16	61	83	0	100	100	70	94	100
	P fixation[1]	46	27	0	0	0	0	100	50	0	0	0
	Fe	16	13	29	6	13	70	0	0	0	0	0
	Zn	16	13	29	6	13	70	91	31	0	88	0
	S	0	45	0	0	0	0	100	50	0	83	0
	low CEC	0	18	0	61	0	0	98	0	0	83	0

[1] i.e. added P fertiliser is fixed by the soil and unavailable for plant uptake

3 Diagnosis

3.1 What is the problem?

Land is a resource at risk, but dire needed to feed the growing world population and for economic development of the rural poor. It is estimated that 24 billion tons of fertile soil are lost to erosion by wind and water every year (GSW, 2013). According to UNCCD, each year 12 million hectares are lost by degradation. In Africa about 80% of all arable land (95 million hectares) is already seriously degraded (Henao and Baanante, 2006). During the 20th century cultivated soils have lost 30-75%, and soils under pasture or prairie 50%, of their organic matter (GRAIN, 2013), thus contributing to soil fertility decline, food insecurity, climate change and soil erosion.

In many tropical countries soil fertility levels used to be maintained by fallowing, like in Europe during the early middle ages. Fallowing restores the natural fertility by weathering and organic matter turnover. Due to land scarcity the exploitation of 'natural' fertility had to be intensified. In the tropics this was done mainly by shortening the fallow period, which initiated soil fertility decline. Europe followed another strategy: with shorter fallowing periods nutrients were imported from nearby unproductive areas like forests and heath and concentrated on the best arable soils. Since the previous century low 'natural' soil fertility has been compensated for with mineral fertilisers and manure, partly produced with feed stock and nutrients imported from other parts of the world.

In many developing countries this strategy cannot be simply copied, and there are various reasons why replenishing the soil with (mineral and organic) fertilisers is not an easy way out:

- Because there is not enough manure or other sources of organic matter at a reasonable distance, if available at all;
- Organic fertilisers derived at or in the vicinity of the farm are typically poor regarding the nutrients most needed;
- Smallholder farmers often apply suboptimal quantities and qualities of fertilisers because of the high fertiliser prices due to ill performing supply chains with large distances, high transportation costs and rent seeking by various brokers. Fertiliser subsidy systems are not always successful (see section 8.1.1);
- Degraded soils in nutrient poor areas show little response to mineral fertilisers, which makes them less cost-effective. Poor soils may not be able to store the mineral nutrients for later uptake by the crop. The first rains then flush away large parts of the nutrients causing loss of (expensive) fertilisers. Hence one should 'repair' soil quality of these degraded soils first with large amounts of organic amendments (compost, farm yard manure, etc.);
- Mineral fertilisers do not contain organic matter and therefore do not contribute to restoring the physical soil quality. Mineral fertilisers work best in combination with organic amendments;
- Even if crop response is cost-effective in average years, farmers often avoid taking credit for fertilisers because of the risk of crop failure in extreme years (drought, pests and other perils), which would leave them with a debt they cannot repay;
- In some countries farmers are unfamiliar with mineral fertilisers or lack the knowledge to use them effectively.

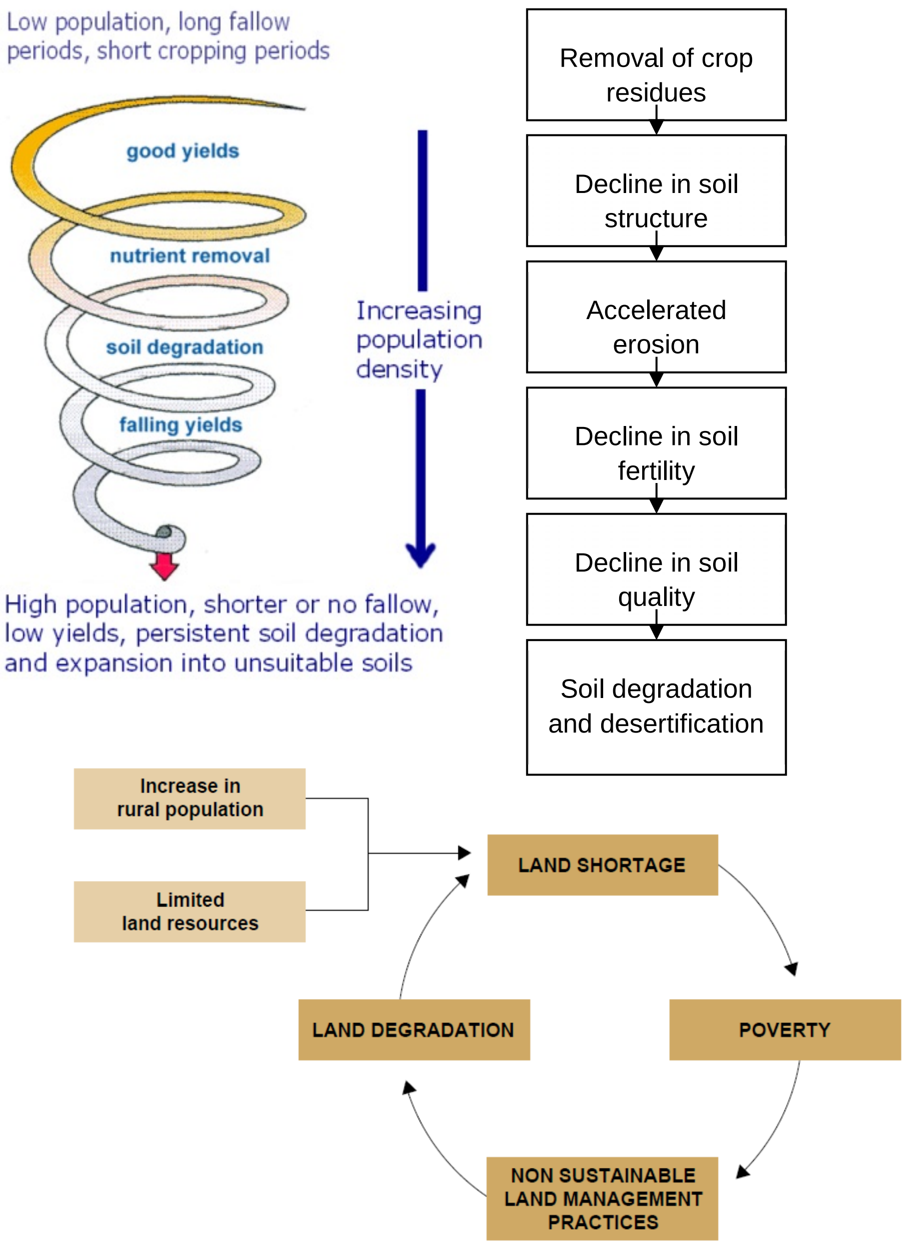


Figure 2 *The poverty trap (above left), the classic collapse (above right) and the causal nexus of poverty and land degradation (below). All three concepts highlight the importance of soil fertility decline on downwards livelihood spirals (After FAO, 2007 and Diamond, 2002).*

Finally and typically, degradation of cultivated soil starts with the removal of crop residues for fodder or fuel, without compensating nutrient and organic matter amendments. In grassland systems the cause is overgrazing without proper manure management for the return of lost nutrients and organic matter. This results in lower soil organic matter content and thus reduces the nutrient and water holding capacity, and the biological activity of the soil. As the soil is mined for nutrients, soil fertility declines, crop yields drop and the farmer enters the poverty trap (Figure 2). After prolonged depletion, soils fall prey to erosion and desertification or become so unproductive that they are abandoned for agricultural production, and can no longer render the ecosystem service of carbon sequestration.

As a consequence soils are being depleted in many developing countries. Together with the low natural soil fertility this puts current and future food security under major threat.

3.2 Where is the problem?

Soil fertility decline is scattered around the globe (Figure 3), but is certainly typical for many areas of Sub Saharan Africa (SSA). Starting with Stoorvogel and Smaling (1990) and Van Duivenbooden and Gosseye (1990) numerous studies have contributed to the awareness of the problem of massive nutrient depletion, especially in SSA. However, despite all efforts made, the situation has hardly changed, and in some areas even worsened (André de Jager; IFDC; pers. comm. 2013).

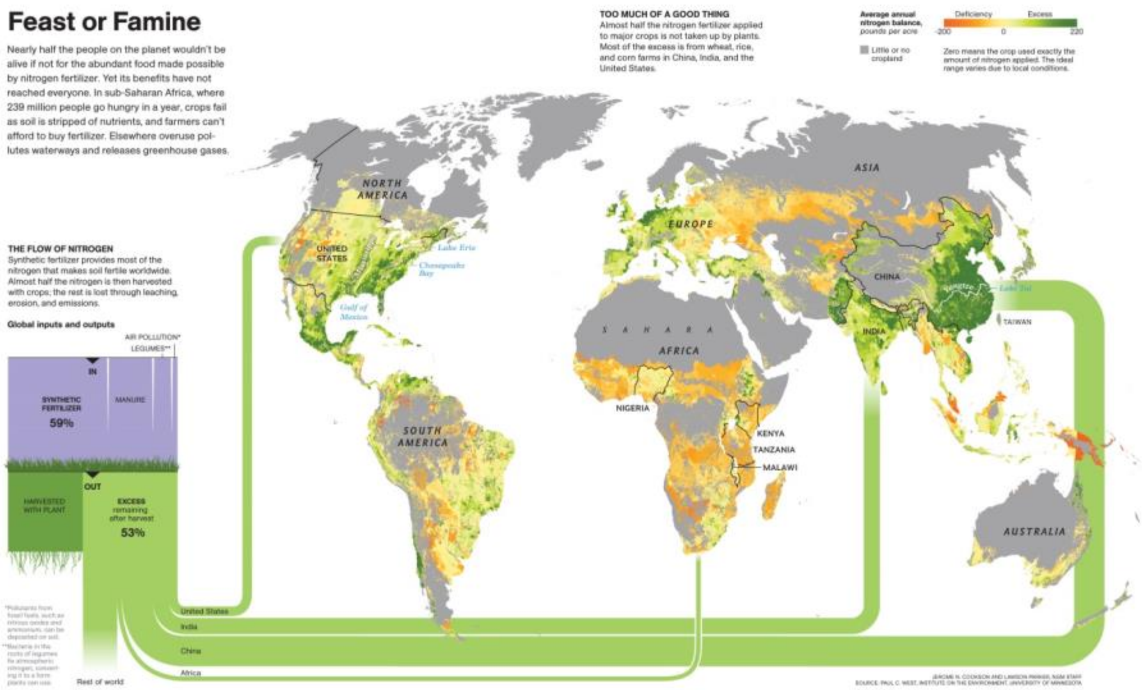


Figure 3 *Global nitrogen deficiency and excess (national geographic 05/2013, with courtesy).*

Figure 3 shows the global nitrogen balance and shows the hotspots of nutrient depletion in large parts of SSA, South-America and South-East Asia. Hotspots for nutrient accumulation occur in Europe, North America, China and India. Nutrient balances are useful signalling tools and, therefore, are frequently applied. However, they do not explain the different responses to nutrient depletion in different situations. For instance, Figure 3 indicates severe nutrient depletion in Central Asia, but as these soils are generally considered very fertile (mainly consisting of chernozems) nutrient depletion is not the main threat to agricultural production (in contrast to moisture and erosion; Karabayev, 2008).

The soil fertility problem can, in its essence, be seen as a distribution problem at various spatial scales. At global level, nutrients are transported from one area to the other with no or little return flows. For example, Dutch livestock feeds on concentrates from imported feed stock, which causes a manure surplus with negative impact on the environment. At regional and national level, nutrients are depleted from rural areas and accumulate in urban areas. At field level nutrients are taken up from the soil and accumulated in biomass. The continuous (disconnected) cycle of concentration and dispersion of nutrients crosses the different spatial scales.

At the farm scale Tittonell and Giller (2013) showed that fields near the homestead responded more to fertilisers compared to the fields further away from the homestead. They argued this was caused by preferred application of compost to the nearest fields. Also Fofana *et al.* (2008) reported higher nutrient use efficiencies and millet yields in the Sahel region on the more fertile home fields, even with low precipitation. However, for P, natural gradients across fields may mask this effect (Vanlauwe *et al.*, 2006). The disconnectedness of nutrients at all scales demands for spatially implicit approaches to nutrient management.

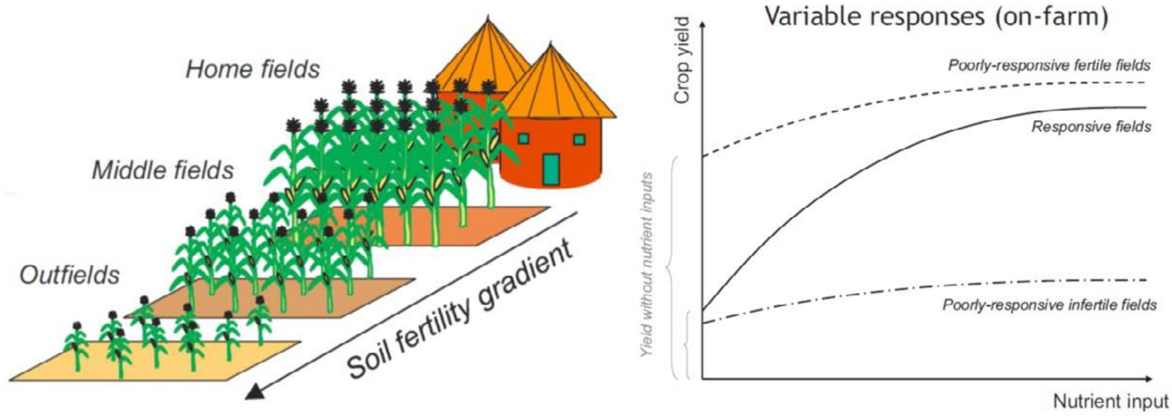


Figure 4 *Within-farm variability of soil fertility (right) causes different response to fertilisers (left, Tittonell and Giller, 2013).*

3.3 Who is affected?

Low soil fertility levels are foremost a concern of the farmer, who sees his/her production decline. At present about 85% of the farmers can be considered smallholders, with landholdings smaller than 2 ha, low yields and only occasional selling to (local) markets. Half of the global food production comes from smallholder farms. Smallholder farms in developing countries produce more cereals, coarse grains, roots and tubers, pulses and oil crops (about 2.8 billion tonnes per year), than farms in the developed countries (1.8 billion tonnes per year; FAO, 2011 in Tittonell (2013)). Hence, the problems of smallholder farmers affect global food security and are a global concern. Although still under debate, this situation is not likely to change in the near future. While some authors claim smallholder farmers will leave agriculture (Koning, 2013), medium-term forecasts indicate that agricultural production will largely remain in the hands of smallholders for decades to come, even though farm holdings will become less than one hectare (Rabobank Group, 2012). Also Vorley *et al.* (2012) expect that the majority of the world food production will remain in the hands of smallholders. Nevertheless, most initiatives to improve food security focus on bigger farms and better-off farmers acting on one or just a few value chains. The future farmers who are expected to feed the growing world population are todays' rural youth. In SSA rural youth is expected to peak between 2030 and 2040 (Protoc and Luchesi, 2012).

Smallholder farmers' first concern is to feed their families and only then to produce for the market. Two-thirds of small maize farmers do not sell maize at all, and often suffer food shortage (World Bank, 2013), while only 2% of the farmers produce half of the global marketable maize production. For the vast majority of smallholders agricultural trade is still within the farmer's vicinity (Arias *et al.*, 2013).

Whether smallholder farmers actually regard themselves as problem owner largely depends on the land tenure system. In systems with insecure land tenure farmers are less motivated to invest in their land and to maintain soil fertility; they tend to regard soil fertility decline a problem of the society (or government), rather than an individual problem. De Jager (1998) and Opaza (2013) estimated that about 10% of the income of smallholder farmers in Kenya and Ethiopia was achieved through nutrient mining, which is like taking credit without repaying the debt.

On the other hand smallholder farmers spend increasing parts of their income on fertilisers. This should not be a problem as long as it contributes to increasing yields (the soil responses to fertiliser) and is accompanied by organic fertilizers. Therefore a strategy is required that reduces the farmers risk when buying inputs like fertilisers, such as micro crop insurances integrated with micro credits.

Hence, although soil fertility decline is directly affecting the farmers' proceeds from the land, the maintenance of healthy soils is a common, global concern, making it already a public good. The Dutch minister for Foreign Trade and Development Cooperation recently stated that, in spite of the current trend towards private investments, common goods cannot be regulated through supply and demand mechanisms. Consequently international legislation and cooperation is needed to safeguard international public goods, including healthy soils (Ploumen, 2013). Also State Secretary Sharon Dijksma and Ambassador at the FAO Gerda Verburg recently stressed the importance of maintaining sound soil fertility levels at various spatial scales.

In a situation with a growing population, declining soil fertility and other increasing production constraints (mainly water and seed quality) may jeopardize the social stability of a region. The violent eruptions in Rwanda, Sudan and Burundi have initiated a debate on the effect of natural resource scarcity (viz. water and nutrients) in armed conflicts. According to Theisen (2008) soil degradation is a significant risk increasing factor in armed conflicts and Dinissen and van Schaik (2013) called for more attention for land degradation as threat amplifier in armed conflicts, although it is never one only driver that causes armed conflicts (Figure 5).

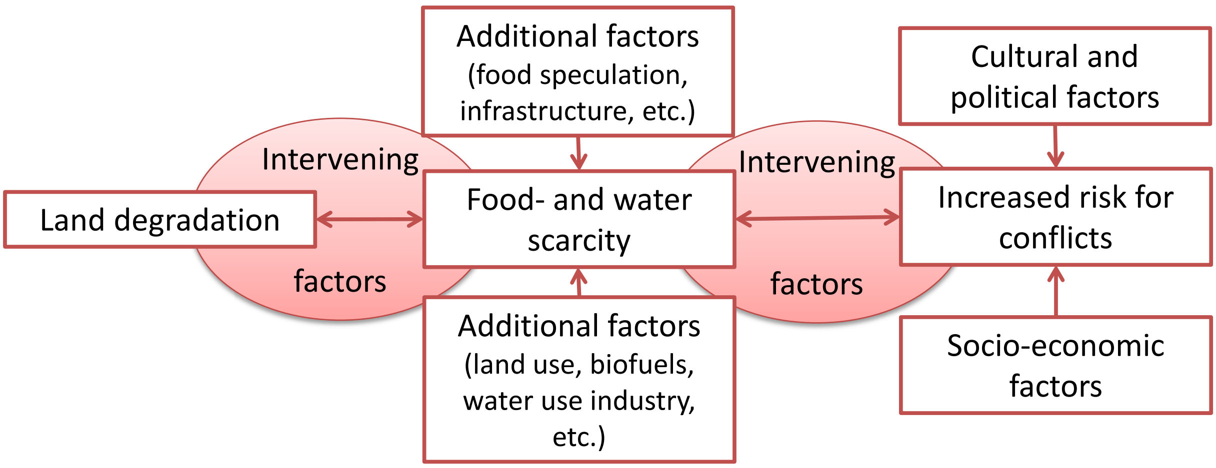


Figure 5 *The relation between land degradation and conflicts (adapted from Dinnissen and van Schaik, 2013).*

4 Current trends that affect soil fertility

In this chapter the urgency for a new step in soil fertility management is emphasized on the basis of some main actual trends that affect soil fertility, viz: i) globalization of food production, ii) population growth and shifting diets, iii) increased costs of inputs and iv) climate change and increasing demands for energy.

4.1 Globalization: accumulation and depletion of nutrients

Globalization is the process of international integration arising from the interchange of products and aspects of culture (Wikipedia). The advances in transportation and telecommunication have increased global economic and cultural interdependence. Particularly the economic globalization also applies to food production. The economic value of food and feed products allows trade and transportation around the world. However, the nutrients these products contain do not automatically return to their original source, the agricultural land. It is not feasible to simply return human sewage sludge and animal manures from accumulation areas (mainly developed countries) to depletion areas (mainly developing countries). The global soil fertility problem is caused by consequent accumulation of nutrients in more developed or urbanized areas and depletion of nutrients from less developed rural extraction areas. The larger the distance between source and sink areas, the more difficult it is to close the nutrient cycle. As the trend of globalization depends on the world's political and economic balances of power this will only change very slowly. While developing countries suffer nutrient deficits, highly developed countries have a nutrient surplus, leading to environmental problems. These countries therefore developed legislation to control their nutrient surpluses and reduce environmental impacts.

Looking back, history shows an increasing nutrient use with development stage. Figure 6 and Table 3 conceptually show different stages of societal development and associated nutrient management strategies. The third stage of development (high input, little regulation) typically lasts for some 50 years, but globalization might speed up the transitions. The present over-fertilisation of sometimes more than 1000 kg N/ha/y in China (a stage III country, pers. comm. Oenema, Bonten, 2013) shows learning lessons from the past is not obvious. Stage II countries are mainly found in SSA where almost 80% of countries are confronted with N scarcity and N stress problems, contributing to food insecurity and malnutrition.

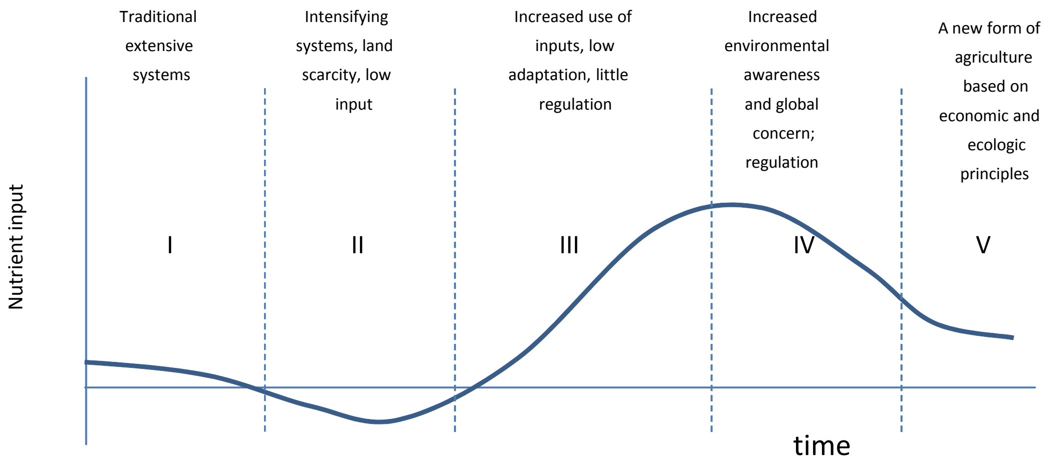


Figure 6 *Historical development of nutrient surpluses, based on personal communication with O. Oenema (2013) and Van Noordwijk (2013).*

Table 3

General transition stages in nutrient management.

Stage	Description	Examples
I	Traditional extensive systems	Traditional systems in remote areas of Africa and Southern America; Europe before the Middle Ages
II	Intensifying systems	Most smallholder systems in Africa and Asia; Europe during the Middle Ages
III	Input based systems	Commercial farms in Asia, Africa and South America; Europe and USA
IV	Regulating systems	Europe and USA since 1980's
V	Balanced systems	Niche areas of pioneer farms, organic farming, agro-ecological approaches

4.2 Population growth, urbanization and changing diets

The world's urban population is expected to grow by more than a billion people between 2010 and 2025, while the rural population will hardly grow (UN 2008). So the proportion of the global population not producing food will continue to grow (Satterthwaite *et al.*, 2010). Population growth, urbanization and changing diets all have distinct effects on soil fertility as explained in this chapter.

4.2.1 Population growth, expansion and intensification of agricultural land

Due to population growth and fragmentation, farm size decreased over the past 30 year in many developing countries with 10-80%. For instance, in Ethiopia average farm size decreased from 1.4 ha in 1977 to 0.8 ha in 1990 and is now estimated to be less than 0.5 ha (Zhou *et al.*, 2008). Consequently, the same amount of food needs to be produced on a smaller area of land. So-far growth in agricultural production in SSA was mainly achieved through expansion. While in Asia the green revolution has resulted in nearly a three-fold production increase between 1961 and 2001, in SSA this was less than 50% (Figure 7). But there is little land left to go to, or this land is fragile, so SSA still faces the turning point of intensifying the production on current lands.

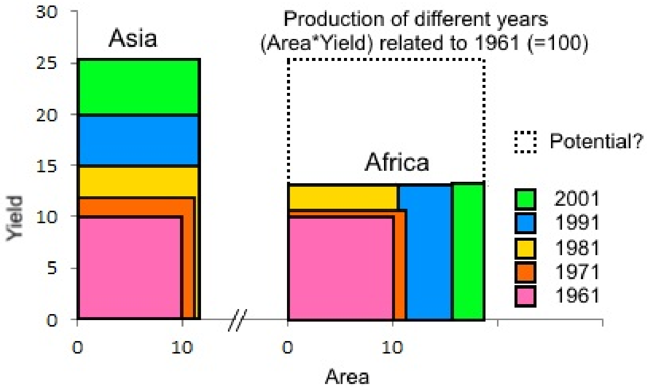


Figure 7 *Intensification and expansion of agricultural land in Asia and Africa (FAO, modified after De Jager 2013).*

4.2.2 Changing diets

Due to global economic growth over the past decades, particularly in the BRIC countries (Brazil, Russia, India and China), incomes have grown and people can afford more expensive food including animal products. The consequent increasing demand of animal protein caused a *'livestock revolution'* (Sutton *et al.*, 2013) which started in the developed countries in the 1960s, and is still rapidly progressing on the global scale. The livestock revolution is characterized by a shift from traditional land-based pastoral systems to more intensive animal husbandry with fertilised grass and fodder production to feed large numbers of livestock in a confined area or a stable. This has allowed a very rapid increase in livestock numbers and in the human consumption of animal products, both in total as per capita.

The presence of livestock on a farm may have a positive effect on nutrient management, because of the availability of manure. However, compared with the alternatives, livestock is considered an inefficient producer of organic fertiliser (Giller *et al.*, 2011). Although manure is a high quality soil amendment, its use as a fertiliser sometimes suffers competition from its alternative use for fuel and construction material. Improved strategies include growing leguminous crops for fodder to increase the N input and use the manure for soil amendment. Similar interventions proved successful in Thailand (pers. comm. Bram Wouters, 2013), but it remains an inefficient way of producing organic fertilisers. The livestock dialogue (www.livestockdialogue.org) seeks global solutions to better match supply and demand for manure.

4.2.3 Urbanization

According to Dietz *et al.* (2012) urbanization goes hand in hand with globalization and population growth. Although current urbanization level in Africa are only 36%, this number is rapidly increasing because of population growth and because of rural-urban migration (Figure 8). Many Africans combine a rural and an urban existence, others move from rural areas to small towns and then to Africa's booming cities. However, parts of the reported urbanization figures may in fact be caused by shifting administrative boundaries i.e. (endogenous growth, pers. comm. Giller 2014).

Urbanization has considerable consequences for soil fertility management. Although it is difficult to determine exact figures, it is easy to imagine that food wastes produced in rural areas are more likely to be returned to the soil compared to food wastes produced in urban centres.

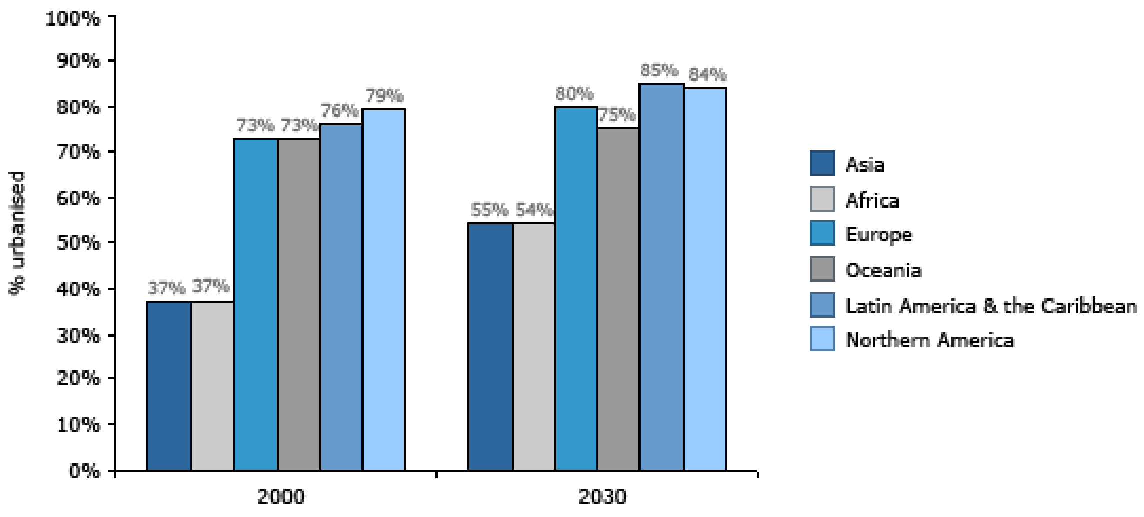


Figure 8 *Global urban population growth (% of total) in 2000 and as estimated for 2030 (http://coolgeography.co.uk).*

4.3 Nutrient resource scarcity

Recently, some alarming reports have been published with regard to expected shortages of exploitable nutrient stocks (Figure 9). Especially P and K may reach their peak within decades. Analogous to 'peak oil', 'peak P' represents the point in time where the maximum global phosphorus production rate is reached. Beyond the peak moment production rates decline. According to some researchers (Cordell *et al.*, 2009) peak P is expected in approximately 2030 and the earth's P reserves are expected to be completely depleted within 50–100 years, others (e.g. IFDC, 2010) estimate that global P rock resources will last for several hundreds of years (Figure 9). Fertiliser companies seem less concerned about P stocks, and more concerned about K stocks (pers. comm. Schröder, 2012).

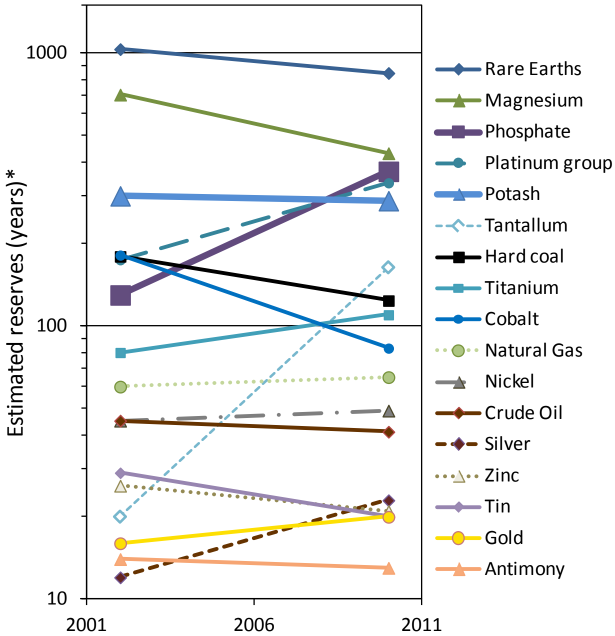


Figure 9 *Changes in estimated reserves of different commodities between 2002/2003 and 2010 (Based on Scholz & Wellmer, 2013; U.S. Geological Survey, 2012).*

The debate about nutrient scarcity continues, but all agree it will become increasingly difficult (i.e. expensive) to exploit P and K mines, partly because stocks remain in less accessible geological strata, partly because access to mines is complicated in remote areas and/or in fragile states, and partly because of the lower quality of the remaining stocks (e.g. contamination with cadmium). Therefore, Tittonell (2013) argues that it is not the stock itself, but the energy required to exploit the stock and to apply the fertilisers to the fields that will eventually hamper current rates of exploitation.

4.4 Climate change

Agriculture has a dualistic role when it comes to climate change, because it can be a culprit as well as a victim of climate change. Soil organic matter represents one of the largest carbon stocks in the world. The soil may be a GHG source in case of organic matter decline, or a sink in case of restoration of organic matter and soil fertility. According to the IPCC agriculture contributes for 11-15% to the global GHG emissions. These emissions, however, are mainly generated by larger commercial farms that rely on nitrogen fertiliser, heavy machinery and highly concentrated livestock systems. Only about 10% of the farmers contribute substantially to global GHG emissions. However, all farmers, including the smallholders, suffer the adverse impacts of climate change, viz. the occurrence of more erratic and extreme weather (e.g. droughts, storms, flooding, heat).

Agriculture contributes to the emissions of N_2O, CH_4 and CO_2, which all have different sources and respond differently to changes in agricultural management. Briefly:

- N_2O emissions are mainly associated with the application of nitrogen fertilisers and manure applied to soils. For some this is a reason to reject mineral N fertilisers (Kotschi, 2013). The global warming potential (GWP) of N_2O equals 310 times the GWP of CO_2;
- CH_4 emissions primarily originate from fermentative digestion by ruminant livestock and from wet rice cultivation. The global warming potential (GWP) of CH_4 equals 21 times the GWP of CO_2;
- CO_2 emissions mainly stem from land use changes with deforestation and soil degradation (soil organic matter decline), energy use for nitrogen fertiliser production, mechanisation and tillage and burning of crop residues.

The IPCC recently stated that for Africa the highest potential for climate mitigation is in carbon sequestration in the soil (IPCC4, WG3), because at present CH_4 and N_2O emissions are still limited. Carbon sequestration also contributes to climate adaptation because it increases the buffer capacity of the soil for water and nutrients. Yet, it remains unclear where, how and under which conditions this sequestration can be realized. CO_2 emission from above and below ground carbon stocks are more difficult to manage and are therefore considered to have a non-permanent character (Cerri *et al.*, 2007).

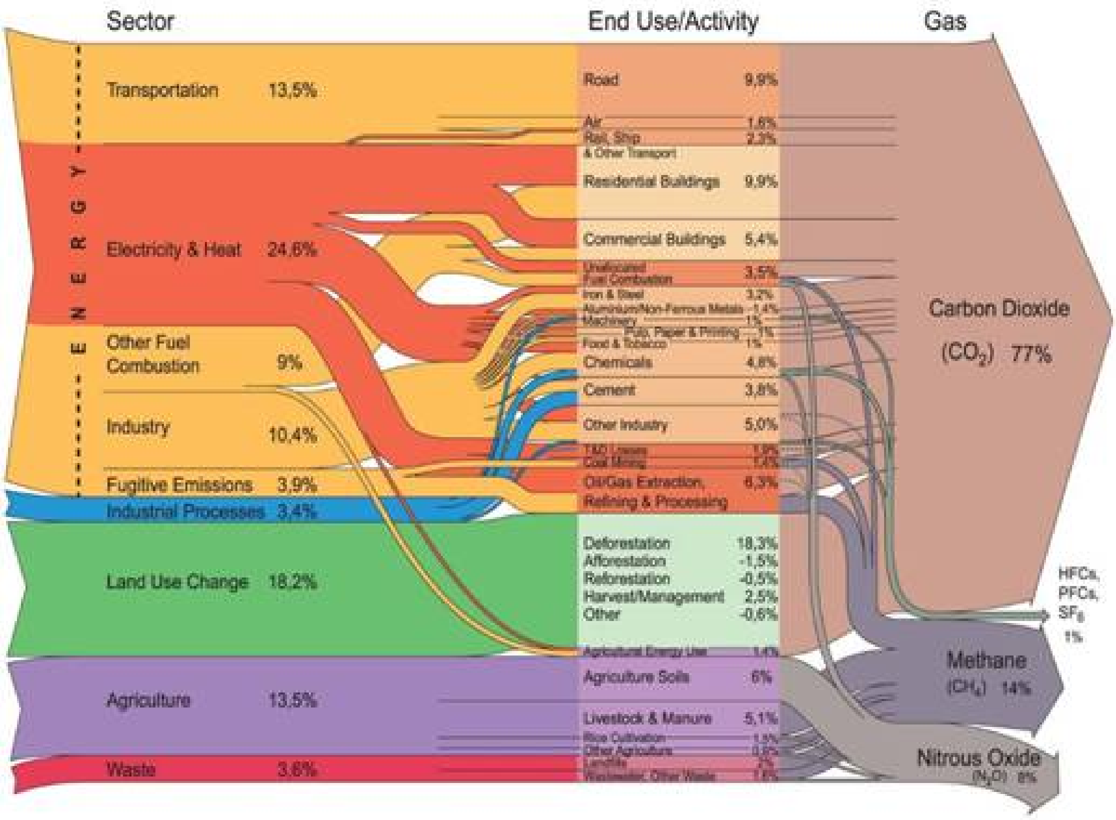


Figure 10 *Worldwide emission of GHG per sector for the year 2000 (source: World Resources Institute, http://www.wri.org/).*

By 2050 N_2O and CH_4 emissions are expected to have increased with 150% unless farm type specific measures are taken (van Beek *et al.*, 2010). The Netherlands is an international advocate of climate smart agriculture (Ploumen, 2013). Robust or resilient farming systems need to be designed that maximize the potentials of climate mitigation (reduce emissions and increase sequestration) and climate adaptation by revitalizing the soils natural buffering capacity. Proper soil management is paramount to this.

5 Linking scales - activities and stakeholders

Through transport and conversion processes, nutrient cycles cross several spatial scales: from the adsorption-desorption processes at molecular level to global atmospheric interactions. Hence several authors emphasize that closing the nutrient cycles requires a multi-scale approach (e.g. Sutton et al., 2013). However, at each distinct spatial scale different barriers to change are apparent that need to be overcome, as demonstrated in Box 1. In this chapter nutrient management at different spatial scales is assessed.

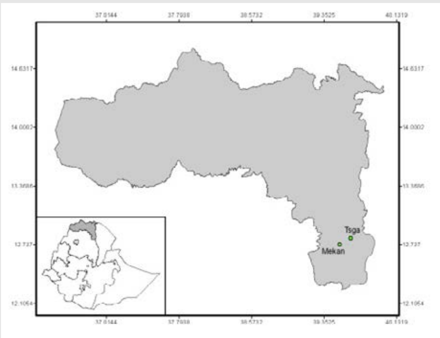
Box 1. An example for the farm of Aberehech Desta in Ethiopia.

Aberech is a widow of 49 years. She has 4 children and lives on a farm in Mekan, Tigray, Ethiopia. The farm has an area of 1.8 ha distributed over 8 plots: 5 wheat plots, 1 teff plot, 1 beans plot and 1 maize plot. Nitrogen (N) was used as a proxy for nutrient balances at different spatial scales.

Table
N balances at plot, farm, regional and national scale (kg ha^{-1}).

Field: wheat	Farm: Aberehech	Region: Tigray	Nation: Ethiopia
-17	31	11	10

The table above demonstrates that at different spatial scales nutrients concentrate and diffuse. 'Real' losses only occur at the field scale where nutrient diffusion is maximum.



5.1 Micro scale

Several scientists who were interviewed as part of this study envisage the evolution of a new form of agriculture based on ecological principles (agro-ecology, see Annex 1 for list of interviewed persons). They thereby mainly refer to the positive interactions between biodiversity and the productive capacities of soils in which micro-fauna and micro-flora play an important role.

Examples of such interactions are:
- Mycorrhiza: symbiotic association between a fungus and the roots of a vascular plant. The fungus colonizes the host plant's roots as in arbuscular mycorrhizal fungi (another form is ectomycorrhizal fungi, but this form is less relevant to crops). Mycorrhiza are an important component of soil life and soil chemistry and increase the availability of P;

- Biological nitrogen fixation: several bacteria are capable of fixing atmospheric N into plant available N-Rhizobium bacteria have symbiotic associations with leguminous crops (e.g. most beans, clover) and acacia trees;
- Biodiversity: there are many interactions between (soil) biodiversity and soil functioning. Some of these interactions are known (e.g. termites), but many are still unknown. It therefore remains necessary to include biodiversity hotspots as a pool for diversity for applications to come.

5.2 Field scale

At field scale the soil productive capacity is most apparent. Yet, as described in section 3.2. even fields within a single farm can have very different soil fertility levels. This can be due to differences in geographical settings, but also as a consequence of differences in management. Tittonell and Giller (2013) plead to include responsiveness of fields to fertilisers in intervention strategies. They concluded that 'yields gaps in Africa remain wide and likely to increase further if soil degradation is not reverted, keeping poor farmers confined within recurrent poverty traps'. To account for variability between fields detailed determinations of the soil fertility levels are needed in order to generate relevant and adequate nutrient management recommendations. Typically, the classic laboratory analyses are too expensive and have a too long turnaround time for smallholder farmers. Recently, some private initiatives provide alternatives, with different levels of success. These alternatives include mobile labs with infra-red soil analysis and portable soil test kits amongst others (see also Chapter 6.5). At field level nutrient balances are typically mostly negative because soil mining and loss processes (erosion, leaching and volatilization) occur at the field level (see also the example in Box 1).

5.3 Farm scale

The farm scale is the decisive scale. It is here where farmers decide about inputs, labour division, crop selection, etc. Although soil fertility is typically ranked high as 'problem area' by farmers in depletion areas, it is definitely not the only concern of farmers. At farm level all aspects of farming come together, including positive and negative trade-offs and relations between different farm compartments. The farm scale is also the scale of finance for the farmer. At this scale it becomes apparent which practice paid off and which did not and consequently the farm scale is an important scale for adoption of (improved) practices. Performance indicators at farm level (e.g. net farm income, gross margins, market share, etc.) often refer to the past season, whereas investment in soil fertility require a long term perspective. In this regard the issue of land tenure-ship is key. Several authors (e.g. Brasselle *et al.*, 2002) highlighted that insecure land tenures adversely affects the willingness of farmers to invest in their land quality.

5.4 District scale

At the district scale[2] mismatches between nutrient flows and land management become apparent. Examples are erosion and siltation of reservoirs and eutrophication of open waters. The district scale however also offers opportunities to re-use nutrients.

[2] We avoid the word 'region' as this can be both a sub-national scale as supra-national scale. What we mean here is the (administrative) division of a nation, referred to as province or district.

Notably, the majority of the urbanization (see Chapter 4.2.3) is within the district, and so-far un-exploited resources of nutrients may be available at district level, e.g.:

- Bio-wastes from the bio-energy industry;
- Organic wastes from food processing industry;
- Sewage water and sludge;
- Composted organic residues (city wastes);
- Rock fertiliser: including rock dust and stone meals.[3]

With regard to this last option, stone-meals recently received renewed attention, not only as a source of lime, but also as a source of micro-nutrient and basis for soil fertility. E.g. Bergsma (2013) argues that rock (in the form of rock dust) is the basis of soil fertility and is vital for stabilizing organic C. Well-known sources of rock fertilisers are saltpetre (nitrate), phosphate rocks; guano (P- and N-compounds), potash (sylvite and K- salts), K-silicates, pyrite (sulphides), gypsum (sulphates), calcium and magnesium carbonates and various materials to conserve nutrients (e.g. zeolite) and/or soil moisture (e.g. scoria and pumice) (van Straaten, 2002). These rocks may be found within the district and/or are sometimes available as by-product of industrial mining. Yet, different levels of success are reported. The main problems are that rock fertilisers are hardly known, possibly because of disincentives from the fertiliser industry and long transport distances. Although stone-meal may be a cheaper source of (especially) K compared to currently used K, the option is far from operational (Rietra, pers. comm. 2013).

5.5 National scale

At the national scales policies are developed that may facilitate the use of nutrients (most often mineral fertilisers) to increase agricultural production levels. By 2020 Africa is projected to import more than 60 million metric tons of cereal each year to meet the demand (Henao and Baanante, 2006). The bulk of this import is to keep pace with population growth (on average about 3% per year) and only a small part can be attributed to changes in diets and consequently increased livestock feed demands. One may question whether it would be more efficient to import nutrients in stead of cereals to have a more sustainable growth.

African policymakers came together in 2006 at the African Fertiliser Summit in Abuja and resolved that member states should grant ‘targeted subsidies in favour of the fertiliser sector’. During this summit increased use of fertiliser was taken as a starting point to reach the Millennium Development Goals and a fertiliser subsidy fund was raised. Also the New Partnership for Africa’s Development (NEPAD) has declared that Africa's economic development vision must be based on raising and sustaining higher rates of economic growth (7% per year). To implement this vision, African heads of state and government adopted the Comprehensive Africa Agricultural Development Programme (CAADP) which calls for a 6% annual growth in agricultural production as a framework for the restoration of agricultural growth, food security and rural development in Africa. By now (2014), the Abuja declaration did not live up to its expectations with fertilisers usage in SSA still far below the worlds average (about 8 and 50 kg N/ha/year respectively; Morris *et al.*, 2007).

At a national level nutrient balances in SSA over often negative, but can be positive especially when imports are high. Such a positive nutrient balance at national level however only masks nutrient depletion as food imports do not contribute (or very modestly through indirect effects on e.g. composting) to soil fertility.

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[3] Different terms refer to differing origins. Rock dust is a by-product of basalt processing industries. Stone meals refer to silicate-materials.

5.6 Global scale

As a consequence of globalization nutrients nowadays are transported all over the world. It is impossible to trace all nutrient movements, but just looking at the global fertiliser trade map demonstrates the global dragging of nutrients. Yet, these flows are mainly between America and Asia, SSA being hardly involved, except as extraction area for P in Morocco and Togo (Figure 11).

Sutton *et al.* (2013) identified the main characteristics and related problems per continent and concluded that for SSA the main nutrients threats are '*Lack of access by farmers to N and P limits food production and exacerbates land degradation. Little investment in fertiliser production, with existing facilities focused on export*'. As key need for the future policies they state that '*Commitment to improve infrastructure for adequate N & P supply to farmers, while developing existing recycling best-practices and improving NUE*' is required for SSA. With this remark, we are again back to the field scale and below.

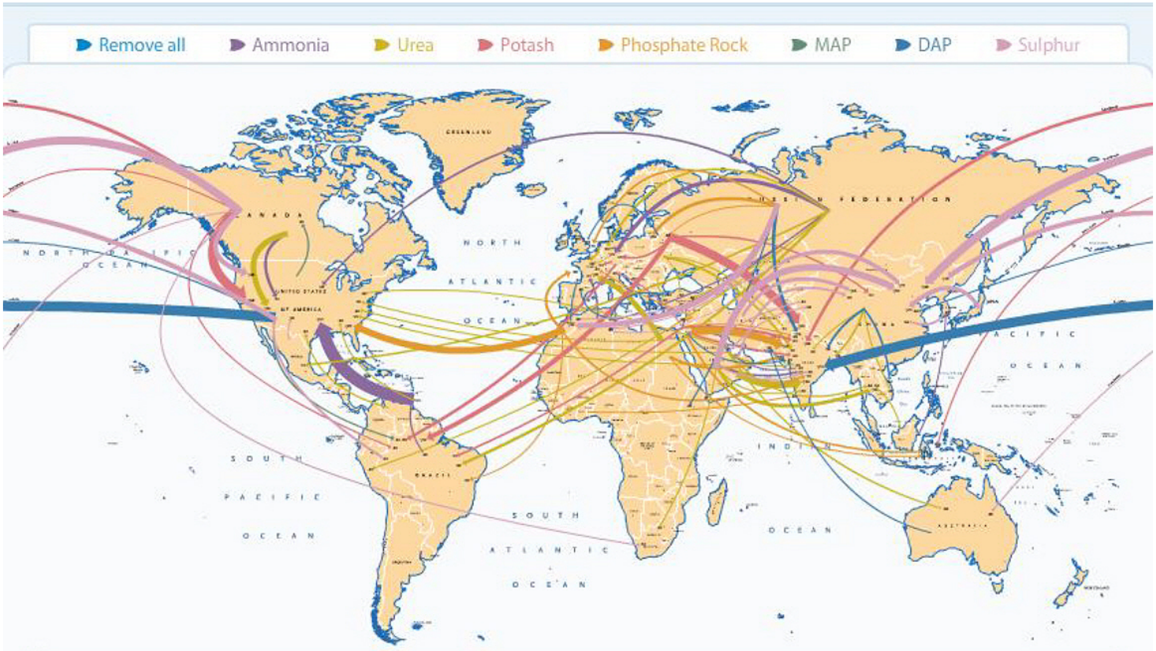

Figure 11 *Global Fertiliser Trade Flow Map. The map represents trade flows of fertiliser products between the major producing and importing countries in the world, as well. Source: ICIS (www.icis.com).*

Another phenomenon at the global scale is the issue of land acquisition (also termed land grabbing) of foreign investors in developing countries. According to the World Bank about 45 million hectares was under negotiation in 2009 of which 70% was located in Africa, but other studies report even higher figures (up to 80 million hectares; WB 2010 and ILC 2011). The investors in foreign land originate from a range of actors including multinational companies, sovereign wealth funds (from Europe and the Gulf States), private equity funds, other financial institutions and South-South deals. Land acquisition is changing regional economic powers and will affect the traditional north-south relationships. The ultimate overall affect is unclear, but will largely depend on (not yet existing) global regulation. Definitely, the deals being made now are reshaping the map of food production and food distribution in Africa and globally (Hall, 2011).

6 Actors

Talking about change is talking about people as only people can make change happen. In Chapter 3 the position of the smallholder farmer was already discussed. Although the smallholder has the final decision on land management, he or she relies on the wider environment for access to inputs, knowledge and markets. Keeping in mind the current trend of 'trade not aid' an increasing role of the private sector in international development is expected. In this chapter different private sector initiatives are discussed and how they can contribute to reducing depletion rates in depletion areas (and reducing environmental degradation in accumulation areas).

6.1 Mineral fertiliser industry

Obviously the fertiliser industry plays an important role in the global nutrient cycle. With regard to N fertilisers, the industry can be typified as a global and scattered industry. Notably, the largest companies have less than 5% of the production capacity, but a higher market share which seems to be increasing (YARA, 2003). For some civil societies this is an argument to control global nutrient trade very carefully. They refer to the seed industry, where a limited number of companies dominate the sector. Yet, there is a clear difference between N industries and P and K industries, where the first is basically a chemical industry and is driven by global energy prices and the second is a mining industry with a limited number of sites.

Currently, about 1000 companies with some 2000 – 3000 production sites produce about 360 million tonnes fertilisers per year. Different actors can be identified in the fertiliser industry (Soh, 2001):

- Primary producers or extractors: Produce basic products or intermediates such as phosphate rocks, potash, ammonia, phosphoric acid, nitric acid, NPK's, etc.;
- Formulators, blenders, mixers: Custom-made products to suit user's needs;
- Distributors: Import and/or supply the products down the distribution chain;
- End-users: Farmers/agricultural producers.

According to YARA (2003) the global fertiliser market is driven by:

- Substitutes: the risk from substitution through organic fertilisers is considered low for the global fertiliser industry. Notably, also fertiliser industries do recognize the importance of organic matter, but point at the accuracy of mineral fertilisers (in terms of time of release and content) to minimize losses of nutrients;
- Competition: the global fertiliser market is generally fragmented, with limited product differentiation. Strong regional presence and closeness to customers in the different markets are key success factors, requiring an extensive distribution and sales network;
- Entry barriers: The production technology for commodity N fertilisers is readily available, but the production process is highly capital intensive. Economies of scale are important in reducing fixed costs per tonne and achieving general cost competitiveness. Another key element is access to low cost gas, which is only available in certain regions of the world;
- Purchasing strength of the customer.

6.2 Local waste processing industry

Organic wastes may prove a valuable source of nutrients to replenish soil fertility. Yet, bio-waste is often dumped and left to rot. Especially in cities these wastes are commonly regarded as nuisances and treated likewise, i.e. they are disposed of (to official and unofficial dumpsites) or burned. This type of waste handling can lead to a number of problems:

- Pollution of groundwater and eutrophication of surface waters through emissions of nutrients (from disposal sites);
- Waste disposal sites dumps can become sources for pests and diseases;
- Anoxic conditions in waste disposal sites lead to emissions of CH_4;
- Odour problems from landfills;
- Burning is generally in open fires leading to air quality and health problems.

Bio-waste conversion technologies are already implemented in Africa; compost production from bio-waste fractions is widely accepted in Africa as a best practice (especially in agricultural areas) and the widespread adoption of manure-to-biogas technologies have paved the way for bio-waste-to-biogas technologies to become accepted and implemented in Africa. The largest challenge to recycle bio-waste in Africa is to make it cost efficient and to create sufficient capacity for environmentally sound bio-waste management, which is currently hampered by inadequate or limited awareness and appreciation of best practices for environmentally sound management, access to finance and technological know-how (UN, 2009).

In some countries, compost is imported from abroad whilst the locally available biomass is not re-integrated into the eco-system. Recently some initiatives aimed at turning locally wasted biomass into high quality compost. Compost helps to increase the water holding capacity of soils, suppress diseases, and improve the soil structure. Furthermore, it may (partly or completely) substitute mineral fertilisers and/or increases the efficiency of mineral fertilisers.

6.3 Organic fertiliser industry

Some entrepreneurs recently started to process organic wastes from accumulation areas into organic pallets for export (e.g. Culterra, Ferm-o-Feed). Due to import-export balances and associated transport costs it is currently more attractive to export these pallets to other accumulation areas (viz. China) than to source or depleted areas. Yet, with increasing demands and purchasing power of some depletion areas interest is shown to export also to e.g. Africa. Some pilots are running and this could be an important component of closing the global nutrient cycle. However, the viability of this industry highly depends on transport costs, i.e. international trade balances. Although there is a preference for local solutions, it is acknowledged that international trade is definitely an interesting option for (partly) filling the nutrient gap.

6.4 Multinationals

Multinationals increasingly understand and believe that sustainable practices can help to tackle some of the world’s biggest challenges including loss of soil fertility. In many strategic plans of large companies increased awareness of the responsibility for sustainable food production can be found. One realises that it is not so easy anymore to switch from one supplier to another so it becomes more important to invest in long term relationships and invest in soil as one of the major natural resources. Increasingly large corporates integrate eco-friendly criteria into their sourcing strategy emphasising issues like carbon, water, waste and soil next to social criteria.

Yet, international certification schemes aiming at sustainable agricultural production seem to have a blind spot for soil fertility decline. They tend to abandon mineral fertilisers (partly out of ecological reasoning, partly because of public opinion), but thereby ignore that when nutrient removal is not compensated for with organic fertilisers, organic production in this case accelerates soil fertility decline. Consequently, we argue to include a neutral nutrient balance[4] in criteria for certification of

[4] In fact, in depleted areas a positive nutrient balance is preferred, but for certification purposes the exact quantification of this target balance may be too complex and therefore a neutral balance is proposed.

sustainable production systems. Likewise, this criteria can (and should) be included in Global Gap criteria for areas at risk, i.e. areas with a negative nutrient balance (mainly SSA, see Figure 3).

6.5 Soil laboratories

There is a clear lack of reliable soil chemical laboratories in most developing countries and recently some companies started business in this sector. Often, they also produce a fertiliser recommendation together with the soil chemical analysis report. Yet, chemical analyses remain very expensive to smallholder farmers and the challenge persists to achieve attractive value to cost ratios. Notably, other factors may be limiting yield levels and/or farmers may adjust their plans according to unforeseen events. Therefore a good feed-back system, relating recommended fertiliser rates, actually applied rates and achieved yields is essential, but, to our knowledge, not applied. Another issue is that fertiliser recommendations are mostly recommended for mono-cropping systems, while smallholder farmers prefer intercropping for reasons of risk reduction and labour efficiency. Also, fertiliser recommendations are given for one season, while farmers need advice for longer term strategies regarding soil fertility. Hence, static fertiliser recommendations based on soil chemical data for smallholders in developing countries are valuable and needed, but without a local support system, it may bear some jeopardies, such as:

- Other factors than fertiliser recommendation may be limiting actual yields, i.e. the approach may not be targeting the root cause of the low yields;
- The recommended fertilisers may not be applicable and/or the recommendations cause distortion of the (local) markets, i.e. the supply chain is not functional;
- The fertiliser recommendation may not be geared to the preferred crop production systems;
- The fertiliser recommendation may not be geared to a longer term soil fertility strategy;
- The cropping calendar may change due of unexpected conditions of e.g. weather, seed germination and farm conditions (e.g. illness) which requires a certain level of flexibility in the recommendation.

7 Food security, soil fertility and green growth

In this chapter the relation between food security, soil fertility and sustainable economic growth is assessed, in order to put the interventions regarding soil fertility in a broader perspective. The issue of unbalanced nutrient flows between depletion and accumulation areas and the issue of low soil fertility levels in developing countries have received substantial attention for some decades. The 2008 food crisis put food security and thereby soil fertility in the spotlight once again. However, without clear prospects and rapid results policy makers tempt to lose their interest. Therefore it is necessary to present possible solutions for soil fertility decline in a perspective of sustainable economic growth. Moreover many stakeholders that need to be involved stress the role of markets and the level of external input availability.

Smallholder farmers have been and will be the worlds' largest food producers (Chapter 3.3). Paradoxically, smallholder farmers are the vast majority (~80%) of the billion people suffering hunger and malnutrition. Those producing food are the ones not having enough to eat. Lack of purchasing power in rural areas largely explains the limited investments in the quality of land (Addimassu *et al.*, 2013; Beekman and Bulte, 2012).

Current food insecurity is neither caused by low stocks nor by improper supply chains as has often been argued. Rather food insecurity is caused by poverty, i.e. being unable to buy food or the inputs to produce food (De Schutter, in UNCTAD 2013). Therefore, in order to find a way out of the poverty trap, interventions in agriculture should not only aim at increasing food production, but also aim at rural economic growth to reduce poverty. This includes fair and stable prices for agricultural products and alternative sources of income.

However, the trends have been quite different. In order to get World Bank loans, governments have been forced to open up markets to provide cheap, imported food to mostly urban consumers. Between 1980 and 2003 prices of food products dropped 73%, with serious impacts on the local economy. Even former USA president Bill Clinton has admitted the detrimental effects of the liberalization policies of the WB and IMF (Feyder, in UNCTAD 2013). The WB now acknowledges that increasing agricultural productivity is not similar to reducing poverty; its policy has locked smallholder farmers in developing countries in the downward spiral of less income, reduced investments in land quality and further yield reduction (Figure 2). In order to ensure inclusive economic growth, secured land rights are necessary to encourage smallholders to invest in the productive capacity of their own land, and fair and stable prices for their products are essential to provide the means to do so.

Box 2. Green economic growth

Green economic growth is defined as a strategy to improve the quality of life by stimulating economic growth in rural and urban areas without overexploitation of natural resources: soil, water, biodiversity, energy and cultural capital. A transition from sustainable development towards a green growth strategy requires governments, businesses, research institutions and NGO's to work together to establish innovations for a green economy.

The approach is based on the three pillars Basis, Boost and Balance. BASIS: Sustaining future ecosystem and biomass production, including soil fertility, combating desertification and biodiversity protection. This involves the entire field of natural resources management. BOOST: Introducing new opportunities for economic and sustainable growth, bringing together technological innovations, innovations in business models and governance, new products, new markets, extension of the value chain, and the use of ecosystem services, to achieve new ways of production for high productivity with low environmental footprint. BALANCE: Enabling a dynamic allocation of land, water and other resources in a spatial context, to the links of the production chain and to different stakeholders. Sustainable innovations require definition of acceptable claims on natural resources, including land, and of acceptable production intensity. www.wageningenur.nl/greeneconomicgrowth

The figures presented by Feyder (UNCTAD, 2013) contrast sharply with the official national economic growth figures of many African countries. These growth figures are often dominated by economic growth resulting from foreign investments in urban areas, which is illustrated by the booming skylines of many capitals in SSA. However, agriculture is still the backbone of all economies in SSA. Therefore, declining soil fertility does not only reduce food security, but also deprives farmers of economic opportunities. Maintaining or restoring the productive potential of land is paramount for economic growth and food security (FAO, 2001).

Box 3. The Machakos example

The Machakos example (also referred to as Machakos miracle) of Kenya demonstrates the interaction between soil fertility and economic growth. After years of governmental efforts to reduce soil degradation and increase agricultural productivity in this area, it became effective only after interventions to create alternative employment, new roads, access to markets and to deal with price differentials. The Machakos example shows that technological change is functionally linked with income diversification and increase market participation: the sustainability of the farming system cannot be considered in isolation from the household economy as a whole. Small areas of cash crops allowed to generate income to purchase inputs and consequently created off-farm employment. At present more than half of the rural income is generated through off-farm employment, but at the same time the sustainability of the land, including soil quality, largely improved (Mortimore *et al.*, 1993).

8 Interventions to improve soil fertility and nutrient use efficiency

In the past many interventions have been introduced to increase the productive capacity of land. Basically, these can be subdivided into two distinct approaches: i) interventions aiming at increasing the availability of nutrients through import of organic and mineral fertilisers and ii) interventions aiming at increasing the use efficiencies of available nutrients. Clearly, both are needed to develop highly performing, high efficiency food production systems. Yet, the two types of interventions are often introduced in isolation.

Interventions aiming at increasing the availability of nutrients through import of organic and mineral fertilisers can be further subdivided into: A) Large-scale initiatives designed to increase the use of fertiliser, and B) Small-scale demonstrations to achieve local validation of a variety of practices or technologies. Both of these approaches have their advantages and disadvantages. Large-scale initiatives often lack the sense of ownership among farmers and tend to be expensive, whereas small-scale approaches tend to produce islands of success, with limited effects on the enabling environment (e.g. the supply chain and market access). We argue that there is no silver bullet. Rather, there are various ways to improve soil fertility that all have specific requirements for success. The challenge is to find the right package of interventions for a specific situation, as none of these interventions will solve the problem of low soil fertility on its own. In this chapter the different forms of interventions are discussed.

8.1 Improvement of fertiliser use

8.1.1 Promotion of chemical fertilisers

The promotion of chemical fertilisers to boost agricultural production in areas with low soil fertility has been subject to long and intense debates. The debate is intense, because of the commercial interests connected to chemical fertilisers, the political commitment to higher inputs in agriculture (e.g. Abuja declaration 2006), the ideological debate between subsidies and liberalization, and the discussion between advocates of industrial agriculture versus organic or ecologically based agricultural production systems. Our position in the debate is that we need both approaches. Some ‘natural’ soil deficiencies need to be compensated for with mineral fertilisers to sustain sufficient food production. The organic approach stressing the recycling of nutrients and organic matter is necessary to sustain sufficient organic matter levels for a healthy and fertile soil, and to prevent high input investments, particularly in remote areas.

According to the May 2013 issue of National Geographic half of the world population depends on chemical fertilisers for their food (Figure 3). The green revolution in South-East Asia is generally considered as a success because of the threefold production increase thanks to improved varieties, large scale irrigation and massive fertiliser inputs (Figure 7). Others argue that in fact through the use of fertiliser large areas of land are degraded and at the bottom line fertilisers are counterproductive (e.g. Kotschi, 2013).

A brief review on the use of chemical fertilisers learns that its popularity has been changing over time. During the 1960s and 70s many countries in Africa provided subsidized fertiliser to farmers through state owned enterprises, which generally operated in a monopoly on fertiliser distribution and import within the country. The fertiliser distributed by these enterprises was generally sold at a reduced (subsidized) price, between 20% and 60% of the market price. These fertiliser programmes were initiated to halt soil nutrient depletion, but often suffered from bureaucracies that delayed and/or distorted fertiliser delivery. Subsidized fertilisers were often not financially viable and in some cases over-fertilisation was reported (Morris *et al.*, 2007).

In the 1980s, partly under pressure of the Structural Adjustment Programs, more emphasis was given to free markets with a minimal state role in the economy, to achieve lasting development. Some of the African countries following the WB guidelines included Benin, Ghana, Madagascar, Senegal, Togo, Tanzania, Zambia, Cameroon, Malawi, and Nigeria. The results of this liberalization and subsidy phase-out were variable. According to a five year study by COMESA (2009) fertiliser use in Cameroon, Senegal, Tanzania, Nigeria and Ghana declined with 25-40%, but increased with 14-500% in Benin, Togo, Mali and Madagascar.

During the 1990s and the first decade of 2000 the combined use of organic and inorganic fertilisers was stimulated. During the 1990s organic resources were the starting point and additional mineral fertilisers were used for fine-tuning. Since 2000 it was the other way around, with mineral fertilisers as starting point and additional organic fertilisers to improve fertiliser use efficiency (Bationo *et al.*, 2012).

The main problem for smallholder farmers is the high price of fertilisers. In SSA, prices of fertilisers are at least 30% higher (far higher for inland locations) compared to e.g. Thailand, which also imports most of its fertiliser (World Bank, 2013). The main reason are the high shipping costs (approx. 20-40%) and inland transportation costs (Box 4).

Box 4. Supply chain of fertilizers , an example from Ethiopia

In Ethiopia, the purchase and shipping of fertilisers to Djibouti absorbs about 75% of the farm-gate price. Further transport to inland central warehouses in Addis Ababa, Nazarete, Shashemene takes up another 15% of the final cost of fertilizer. Distribution from warehouses to cooperative unions takes up 7% and the final 4% of cost is incurred by distributing fertilizer from cooperative unions to primary cooperatives (COMESA, 2009).

Consequently, many efforts aim at reducing farm-gate prices of fertilisers. Those in favour of liberal market development and against fertiliser subsidy programmes stress the high costs and limited effectiveness of fertiliser subsidies in the 1970s and 1980s programmes. Budget allocations to fertiliser subsidies divert public resources away from alternative useful expenditures like agricultural extension services, infrastructure building, or research and development. These opponents often refer to the example of Kenya, where maize yields rose considerably after economic reforms in the fertiliser sector. The key drivers were the active policy to promote free market and the reduction of the fertiliser programme's transaction costs, e.g. through removing import quota restrictions and licensing requirements for fertilisers (Sutton *et al.*, 2013). There was a rapid positive response in private sector investments and yields, although some abuse was reported as well, e.g. fertilisers with lower nutrient contents than reported on their labels (pers. comm. KARI, 2010; (Sanabria *et al.,* 2013).

Those in favour of subsidized fertiliser supply often refer to the example of Malawi, where farmers buy fertiliser vouchers at reduced costs and exchange them for fertilisers at a private firm or distributor who can redeem the voucher at a designated government facility (Box 5).

Box 5. The Malawi case

In the 1990s the government of Malawi introduced the Starter Pack Programme. In this programme all farmers received 10-15 kg fertiliser and enough seed to plant 0.1 ha. Later this program was converted into the Targeted Input Program (TIP) and finally in the Agricultural Inputs Subsidy Program. The AISP is a voucher based universal subsidy program that allows farmers to buy 100 kg of fertiliser at about one-fifth of the market price. Since then maize yields increased substantially, but the total cost of the voucher system reached US$91 million, equalling about 45% of the budget of the Ministry of Agriculture and Food Security and 5.2% of the national budget. An evaluation of the voucher system estimated that the benefits in terms of additional maize production were between 76% and 136% of the costs, leaving it ambiguous whether the program can be justified on efficiency grounds (Minot and Benson, 2012).

Although yields responded very positively to this system, abuse of the system has also been reported and the nutrient use efficiency was low, indicating waste of nutrients (Dorward *et al*., 2008). One of the reported jeopardies of the voucher system is that wealthier farmers are in a better position to take advantage of the subsidies and partly exclude other smallholders. It is hard to justify to use up to 28% of the public expenditures on fertilisers (Jayne and Rahid, 2013). Modified voucher systems that specifically target the rural poor and stimulate private inputs are called smart subsidies and include a well-designed exit strategy that gradually reduces the value of the voucher (Minot and Benson, 2012). These approaches still have to prove themselves. Fertiliser voucher programmes can contribute to economic development in poor rural economies provided that these subsidies target market failures in, for example, access to knowledge, input or capital and are accompanied with capacity building programmes for farmers to prevent misuse of fertilisers (Chirwa and Dorward, 2013).

8.1.2 Differentiated fertiliser recommendations

Fertiliser recommendations need to be tailored to the nutrient demand of the crops in their cropping systems and the nutrient supply by the soil: the higher the demand the higher the recommendation, and the higher the supply by the soil the lower the recommendation. Fertiliser dressings that exceed demand minus supply will cause losses without extra production. The agro-ecological zone represents the set of physical conditions (soil, water, and climate) that determine the potential yield of the crop and can be derived from land evaluation studies. A typical result would be a suitability map for different crops. These kinds of maps are often supportive for policy making processes, but tend to have a high desk-factor and emphasis should be given to local level verification.

Fertiliser recommendations should also take into account the product availability. It makes little sense to recommend an ideal compound or blend of NPK and micronutrients if it these are not available on the local market. Under such circumstances the available products should be the starting point for the best possible fertiliser dressing. The availability of organic manures, mulches, crop residues and waste from the food processing industry need to be determined on the basis of farming systems and industrial assessments. Market access of smallholder farmers to affordable fertilisers is also related to farmers' risks and ability to produce for the market. Micro-credit and insurance systems may therefore stimulate the purchase of fertiliser products (and inputs in general).

Fertilisers come in different forms and qualities. To select the most appropriate fertiliser type, a balance has to be made between cheap fertilisers with drawbacks like being unspecific and acidifying, and more expensive compounds or blends, tailored to specific soil deficiencies and crop demands. Current procurement methods under the responsibility of national authorities often uses last year's consumption plus some economic prognoses to set-out the tender for fertiliser imports. These tenders are not innovative and tend to go for the cheapest option, e.g. inferior urea-based fertilisers with generic recommendations. The fertiliser industry advocates the '4R Nutrient Management Stewardship' the Right fertiliser, the Right amount, the Right time of application and the Right placement. We stress that 'Right' implies tailored to crop type, agro-ecological circumstances and farming system. Hence, there is no clear-cut answer on how to differentiate fertiliser recommendations to local conditions, but it is clear that still major improvements can be made.

8.2 Ecological intensification

8.2.1 A new form of agriculture

Considering the problems of making fertilisers work for smallholder farmers, a considerable body of mass argue that the entire western oriented way of agricultural production is not applicable to Africa. Their main argument is that, apparently, the process of the green revolution as realized in Asia does not apply to Africa. Tittonell (2013) argues that this is caused by what he calls the intensification gap. For conventional (also called western, industrial or modern) production systems circa 1500L of oil equivalents are needed per year for fertilisers (30%), field machinery (19%) and transport (16%). For a complete transformation towards modern agriculture the global oil reserves would be exhausted in 12 years. Hence, worldwide industrial agriculture is basically impossible because of energy constraints.

Moreover, he argues that if all costs are considered, including those caused by environmental deterioration, industrial agriculture becomes unaffordable. Because of those reasons Tittonell and many others argue that a different green revolution is required based on ecological principles, viz. agro-ecology or ecological intensification.

Also UNCTAD (2013) launched a catch-cry for a paradigm shift towards more eco-friendly production systems. Yet, the large-scale implementation of such an approach is still far from operational as many agro-ecological practices are still in its trial and error phase (pers. comm. Brussaard, 2013). Some authors aim for a total abandonment of (mineral) fertilisers (e.g. Kotschi, 2013). And indeed, under some very poor soil conditions, biological farming practices without using mineral fertilisers outperformed business-as-usual scenarios (e.g. Pimentel *et al.*, 2005). The ability of organic agriculture to feed the current and future world populations is heavily debated. Soil fertility plays a crucial role in this debate, since the availability of sufficient crop nutrients at the regional, national and global level is the most critical factor in reaching and maintaining high levels of production in organic production systems (de Ponti *et al.*, 2012). In the following subsections some often applied agro-ecological best-practices are discussed.

8.2.2 Biological nitrogen fixation

There are different forms of biological N fixation (BNF) of which the one through symbiosis with leguminous crops (e.g. beans, clover, soybean, alfalfa, peanuts) is most well-known. These crops form symbiosis with rhizobia bacteria that fix N_2 from the atmosphere in the root nodules. The fixed N is available for the crop and when the plant is harvested, the remaining N in stubbles and roots may become available to fertilise the soil. Successful implementation of BNF strategies depend on i) the legume genotype, ii) the rhizobium strain, iii) environment and iv) management. BNF is gaining popularity (amongst others because of the N2Africa project, www.n2africa.org) for contributing to the need for N without energy consuming N fertilisers, and for its positive effects on nutrition and gender participation. Yet, BNF cannot be a full substitute of fertilisers (Giller *et al.*, 1994) and leguminous crops still need considerable amounts of P, K and Ca.

There are also some leguminous trees, but Bationo *et al.* (2012) warn for low adoption, especially after termination of projects. They state: *'A rule-of-thumb is that green manure legumes must yield at least 2 t/ha dry matter or roughly 50–60 kg N/ha –which is likely to give an extra 1 t/ha of grain in the following cereal crop, to take into account the potential loss of land productivity. (...) Participatory evaluations of legume technologies for soil fertility improvement conducted with smallholder farmers in Ghana, Kenya, Uganda and Zimbabwe indicate that farmers value most legumes that give direct benefits of food, cash income or fodder for animals. Benefits of legumes in terms of soil fertility improvement are recognized, but regarded to be of secondary importance'.*

8.2.3 Conservation agriculture and minimum tillage

Conservation agriculture (CA) aims to achieve sustainable and profitable agriculture through application of three key principles (Jat, 2013):

- Minimum mechanical soil disturbance to maintain nutrients within the soil, reduce erosion and loss of water;
- Create a permanent organic soil cover to allow to stimulate decomposition of mulch that is left on the soil surface;
- Crop rotation with more than two species to prevent pests such as insects and weeds to enter the system.

There is a lot to say about CA of which most comes down to differences in temporal scales. Notably, ploughing (not 'allowed' in CA) increases the amount of readily available nutrients, because of rapid mineralisation of soil organic matter. This is positive for the current crops, but increases depletion rates in the long run. CA can have many beneficial effects, but running up costs are high, because it takes considerable time and labour before CA systems are established and productive. Therefore adoption in Africa is still limited. Minimum tillage reduces labour, but may put more labour on the shoulders of women, as weeding efforts increase which is commonly a women task, whereas ploughing is often a men task (Yihenew G Selassie, 2013 pers. comm.). Most disadvantages of CA may be overcome by using herbicides during the first phases of implementation and by applying fertilisers. In various SSA countries, including fragile regions such as D.R. Congo and Northern Uganda, farmers spontaneously developed a variety of CA, combined with herbicides and fertilisers (pers. comm. Van Til of ZOA). The potentialities, environmental sustainability and effectiveness of these initiatives have not yet been assessed.

8.2.4 Compost

Compost is organic waste that has been decomposed and recycled as fertiliser and soil amendment. Decomposition is a continuous process and therefore compost is not a stable product and its composition changes in time. Generally, organic waste is considered compost when it has gone through a period of controlled aerobic bio-degradation, resulting in a humus-like material. When applied to soil, the decomposition continues until the organic matter is either decomposed or is stabilized in soil aggregates.

The use of compost as a plant fertiliser goes back to the medieval times, but it has recently received renewed attention for its potential to reduce greenhouse gas emissions, sequester carbon and release nutrients (www.UNFCCC.int, Africa agriculture status reports).

Vermicompost is a speciality compost in which worms create a heterogeneous mixture of decomposing vegetable or food waste, bedding materials, and vermicast. The quality of the compost is often very good, but the practice is typically applied at small-scale specialities because of considerable labour demands.

8.2.5 Soil amendments

Soil amendments, sometimes also called soil conditioners or soil primers, are products that improve the physical quality of the soil to increase the nutrient and water holding capacities. Most amendments contain one or more of the following constituents: bone meal, peat, coffee grounds, compost, coir, manure, straw, vermiculite, sulphur, lime, blood meal, hydro-absorbent polymers and/or rock fertilisers (see section 5.4). Soil amendments may be an effective way to rehabilitate degraded soils, but often costs are high and the public opinion may be against external inputs of ‘technoproducts’. So far, the adoption in SSA is low and applications are limited to niche markets.

8.2.6 Integrated soil fertility management (ISFM)

Integrated Soil Fertility Management (ISFM) can be defined as ‘A set of soil fertility management practices that necessarily include the use of fertiliser, organic inputs and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at optimizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic and economic principles’ (Bationo *et al.*, 2012). In ISFM mineral fertilisers are the main entry point to increase yields and organic fertilisers are used to improve the efficiency of the mineral fertilisers. Since the 2000s ISFM is generally accepted as the most relevant paradigm for soil fertility management in the tropics. We also see ISFM as the entry point to raising agricultural productivity in the tropics, but on-top suggest to enrich it with other interventions as described above.

8.2.7 The basket of options

Above-mentioned interventions show there are various options to improve soil fertility, but each intervention has its unique set of conditions for success. Hence, there is no one size fits all solution. Basically, the different interventions can be plotted in two dimensions:
- The economic dimension: interventions requiring low inputs versus those requiring high inputs;
- The temporal dimension: fast resulting interventions versus slow resulting interventions.

Typically, the high input and fast responding interventions reflect a market driven development pathway, whereas low input, slow response interventions typically reflect the more ecological pathway of development. In Figure 12 a conceptual visualisation is made of the position of the different interventions within the economic-temporal dimensions. Further elaboration of Figure 12 will provide a guideline for the development of best-fit site specific packages of interventions.

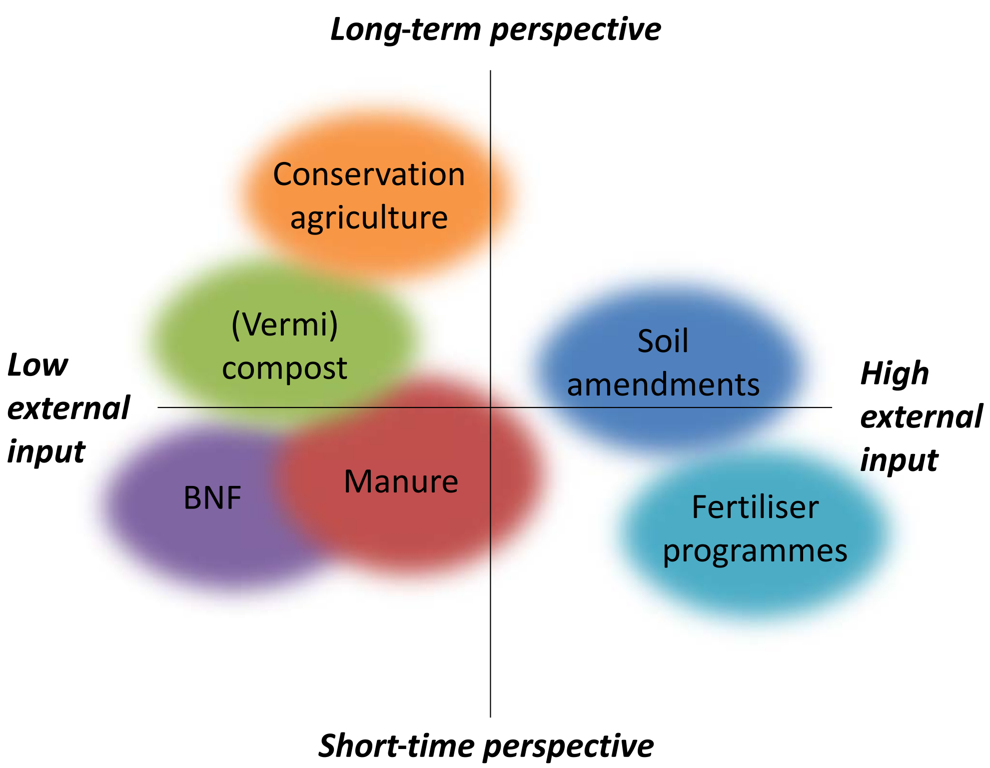

Figure 12 *Conceptual visualisation of interventions that address soil fertility based on differences in time perspective (short term versus long term) and input levels (low inputs versus high inputs). BNF = biological nitrogen fixation.*

9 The Fertile Grounds Initiative

9.1 Introduction

The interventions listed in Figure 12 may alleviate low soil fertility levels to a certain extent, but it will not solve the problem of disconnected nutrient flows and parallel approaches of the 'organic' world and the 'mineral' world. Therefore additional action is required that enables farmers in developing countries to improve soil fertility levels through optimization and redistribution of locally available resources, supplemented with external inputs. For farmers in resource poor conditions increasing the nutrient use efficiency is a means to raise farm productivity. For developed countries the same process contributes to improving environmental quality. Consequently, a consorted action is required based on the findings of the preceding chapters:

- Many stakeholders are involved in transporting and transferring nutrients, but they act on different spatial scale and are often ignorant of each other's demands and supplies;
- Costs for transportation, logistics and transaction make fertilisers (too) expensive for resource poor farmers and hamper the broader adoption of fertilisers;
- The district level provides best opportunities for matching nutrient supply and demand to improve the availability of nutrients. It bridges the gap between too little availability at the lower scale levels and too large distances at the higher scale level;
- Integrated Soil Fertility Management and sound land and water management are key to sustainable development and the improvement of nutrient use efficiency. Organic and mineral nutrients should be combined to increase their value for improving the resilience of farming systems;
- Nutrient management is closely linked to energy and climate change, both locally and globally. Locally there is competition for organic matter between fuel for cooking, animal feed and soil amendment. Globally, soil organic matter represents one of the largest carbon stocks that can be depleted or restored, while N fertilisers required energy for their production and release GHGs during production and application. Urbanisation and the growing need for energy and protein pose new challenges, also for nutrient management;
- Current chemical fertilisers are insufficiently targeted to the needs of smallholder farmers;
- Since nutrients have a value, and can be traded, it should be possible to design ways to improve nutrient distribution.

These observations show that there is no single solution that can solve the problem of low soil fertility, but it is the alignment of actions at the various levels of spatial scale (field, farm, district, and national scale) that can make the difference. Based on these conclusions a new modality for stakeholder collaboration to secure healthy and productive soils was developed, which we called the Fertile Grounds Initiative (FGI).

9.2 Description of the Fertile Ground Initiative

Nutrient use efficiencies at the local scale can only be increased through better use and distribution of available nutrient sources. This understanding is the very basis of the Fertile Grounds Initiative (FGI). The FGI aims at bringing together organic and mineral nutrient flows to increase nutrient availability, efficiency and value and at enhancing ownership and independency of smallholder farmers.

The Fertile Grounds Initiative consists of the following eight components:

- Inventory of demand: farmers define their nutrient demand based on soil and crop specific fertilizer recommendations.
- Inventory of potential supply: pools of organic matter within the sphere of activity are identified in terms of quality and quantity.

- Product formulation and processing: sources of organic nutrients are converted into compost and supplemented with single or multiple compound mineral fertilizers to produce optimal compositions of nutrients (e.g. Figure 13) as integrated fertilizer products.
- Brokerage: supply and demand of nutrients are brought together and arrangements for trade are developed.
- Trade and logistics: business case design, nutrient trade and transport.
- Capacity building: farmers, extension workers, brokers and salesmen receive training in best practices for optimal nutrient management.
- Institutional arrangements: cooperating with existing farmers' organizations and/or setting up farmers' cooperatives, defining the role of a nutrient bank, legal and institutional embedding, as well as government and policy support.
- Creating an enabling environment for economic growth: mobilising support for market access, micro-credits, insurances, etc. for smallholders.

Nutrient supply and demand are brought together by brokerage, physical transport and valorisation of nutrients through nutrient banks that serve as a 'Nutrient Exchange Facility' (NEF) platform. Nutrient brokerage is based on matching the amount and quality of the supply with the nutrient demand of the farming system and the ambitions (targets) of the farmer. Since organic nutrient sources are generally not readily applicable as fertiliser nor readily available at the right time, collection, pre-treatment, composting, storage and transport are to be integrated within the FGI for a well-organized nutrient supply. It therefore requires the concerted actions of various stakeholders and at different levels of scale.

In Table 4, each component of the FGI is explained in more detail. It provides a brief description, associated activities, expected results and requirements. Figure 14 shows the interaction of scales above field scale, and the FGI steps at these scales. At field scale only steps 1 and 4 occur.

Figure 13 *Piles of rice husk, perfect basic material for making compost, in the streets of Gitega, Burundi.*

Table 4

Details of the eight components of the Fertile Grounds Initiative.

		Short description	Results
I	Inventory of demand	Based on the farming plans of the coming season fertiliser recommendations are developed together with the farmer. These recommendations are crop type and soil type specific and the farmer determines the target yield scenario. The recommendations within a certain area are aggregated towards a total need for (different types of) nutrients is obtained.	• Records of planned crops and target yields of farmers specified per agro-ecological zone Crop and target yield site specific recommendations • Linkages and interaction with fertiliser voucher programs • An app is envisaged that can assist extension services and/or innovative farmers to calculate these recommendations him/herself[1].
II	Inventory potential supply	Nutrient stocks are identified and screened in terms of quantity, quality and availability (conditions for use, accessibility). These stocks include common sources, but also alternative sources of nutrients like wastes, rock fertilisers and residues. The fertiliser industry is involved for mineral nutrients and blending of products.	• Quantification and qualification of available nutrients within the FGI area.
III	Product formulation	Not all organic material can be readily applied to the soil. Some will need to be composted prior to application. This is done is physical compost plants. In these processing units optimum mixing of organic and mineral resources is required to obtain good quality compost in general. In this step also nutrient units are determined that are optimum combinations of nutrients (N, P, K, S, Zn) for a specific crop. These units will facilitate the trade of nutrients. The compost may be further enriched with additional chemicals to get optimum combinations of fast and slow release fertilisers for crop specific requirements.	• Certain amounts of good quality compost. • Certain amounts of the optimized combination of organic and mineral fertilisers.
IV	Brokering	The Nutrient Exchange Facility (NEF) is the intermediate agency between demand and supply. It facilitates entrepreneurs to play an effective role in a district nutrient management plan by developing feasible business cases that contribute to recycling of nutrients, energy and organic matter within that district. The NEF sets up arrangements between supply and demand and certifies products that contain nutrients.	• NEF with a client management system. • Accounting nutrient trade/credit accounts.
V	Trade	The actual trade of fertilisers to the farmers.	• FGI-Fertilisers (organic and mineral) arrive at the farm households accompanied with the recommendations (of step I). • Specialized SME in nutrients (producing, selling, transport)
VI	Capacity building	The introduction of a NEF will be a major challenge. Training will be needed: Farmers are trained on the principles of quantification of inputs and outputs, the value of nutrients, composting, proper nutrient management and ecological sound practices. Extension services will be trained in the required skills to assist farmers in the above and how to measure the impact of what they do.	• Training courses for farmers and extension services • National Fertiliser Recommendation Service as part of the national soil research institute.
VII	Institutional arrangements	Not every stockholder is expected to be acquainted with nutrient management and the importance of soil fertility in relation to food security. For each stockholder specific arrangements with regard to supply, management and finance will be developed.	• Agro-finance products (micro credit and insurances schemes)
VIII	Enabling environment	With increased knowledge and awareness, the current policies and other legislations that cover nutrient management at national and district scale should be revised.	• Improved policies and other legislations

[1] we do believe internet will also be accessible in remote areas in a time span of 5-10 years.

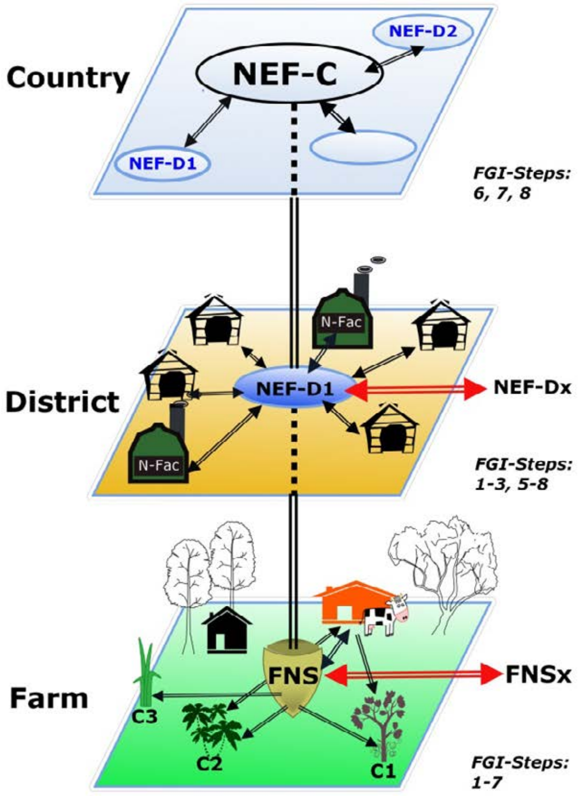

Figure 13 *The interaction of Fertile Ground Initiative at the three scales. NSE-C = Country Nutrient Exchange Facility; NEF-D = district Nutrient Exchange Facility; FNS = Farmer Nutrient Stock.*

FGI is not 'just another new intervention' that can be positioned in Figure 12. Rather it aims to strengthen other existing initiatives and actions, i.e. it goes hand in hand with the basket of solutions proposed in Chapter 8. To avoid distortion of local markets fertiliser shops play a key role in the brokering and trade components.

9.3 FGI - Implications and requirements

The viability of the FGI depends on the economic prospects. Although we are in a preliminary stage, a qualitative profit model is provided in Table 5. Obviously, the FGI won't be profitable from start-on; three phases with different profit models were distinguished:

- Phase I: Local adaptation and proof of principle. This phase is expected to last about 2 years (4-6 seasons) to make local adaptations and demonstrate the benefits of the system;
- Phase II: Continuity in results, yields and nutrients increase. This phase is expected to last from year 2-5;
- Phase III: Phasing out; FGI has proven itself and runs on its own. From year 5 onwards.

Table 5
Qualitative profit model for the Fertile Grounds Initiative.

Costs		Benefits	
FGI implementation guideline	Before actual implementation a site specific plan is elaborated.	Nutrient bank	Farmers pay for their fertilizers (like they are currently doing).
Personnel costs for national stock exchange	The stock exchange will have to be managed.	Increased yields	Yields are expected to increase and farmers pay for membership of the FGI after the proof of principle phase.
Compost processing plant	Running up costs are high, but decrease in time.	Higher efficiency of nutrients lead to opportunity costs for mineral fertilisers and environmental degradation is reduced.	Unknown who is actually paying for environmental degradation.
Transport costs	Will be high, but may be reduced because of smart logistics.	Possibly climate finance?	

We do realize that this Fertile Ground Initiative is ambitious, but to our view, it is the only way to really make a change in current disconnected nutrient flows at various spatial scales, with all its detrimental consequences.

10 Conclusions and recommendations

An estimated US$4 billion worth of soil nutrients are lost each year in SSA, thereby severely eroding its ability to feed it's growing population. At the same time Europe, America and China are struggling with the consequences of excess nutrients. An apparent paradox, but in fact two sides of the same coin. Due to globalization, urbanization, population growth, diets change, increasing costs of energy and climate change, the issue of resolving disconnected flows of nutrients is more urgent than ever. Not by one 'silver bullet', that does not exist, but by a multiple approach of improved farm practices, local brokering of organic nutrient stocks and imports of mineral fertilisers to bring together the best of different worlds. Notably no region of the world has been able to expand agricultural growth rates and tackle hunger without increasing nutrient use.

To make this happen, the Fertile Grounds Initiative was developed as an approach of brokering supply and demand of nutrients with a certain spatial scale. In this report the concept of the Fertile Grounds Initiative is presented, which is now ready for proofing of principle in pilot areas. To our expectations this will increase nutrient use, nutrient use efficiency and, most importantly, crop yields. Hence, it is a true implementation of the 'more with more but smarter' philosophy to enable food security.

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Annex 1 Interviewed persons

For the project ‘Soil fertility in a changing world’ the following key-informants were interviewed.

Informant	Organization
Iemke Bisschops	LeAF
Ben ten Brink	PBL
Gerrit Holtland	Fair&Sustainable/Agri Profocus
Sikke Meerman	Unilever
Bram Wouters	WUR
John Liu	VUA/IUCN
Volkert Engelsman	EOSTA
Myrtille Danse	BOP Innovation Centre
Willem Ferwerda	Rotterdam School of management
Rob Groot	IFDC
Peter van Erp	BLGG
Rene Rietra	WUR
Nadia Scialabba	FAO
Nicolai Fuchs	FIBL
Lijbert Brussaard	WUR
Ken Giller	WUR

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