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A SOILED REPUTATION

Adverse impacts of mineral fertilizers in tropical agriculture

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A fertilizer trader in Daloa, in the interior of Côte d'Ivoire. Cocoa farmers are among his best customers.

Foreword

With food prices high and nearly a billion people going hungry, calls are getting louder for big, rapid increases in food production through agricultural intensification.

And what better way to grow more food than by adding fertilizer? Especially in Africa, where yields are low and the demand for food is high?

The African Development Bank regards higher fertilization as one of the most promising ways to boost agricultural production and achieve food security. The Bank even talks of a "fertilizer crisis" in the continent, and calls on national governments to take immediate measures to overcome it. The "African Fertilizer Financing Mechanism", based at the Bank since 2007, encourages and supports the production and distribution of fertilizer.

But the idea that more fertilizer will produce higher yields is far too simplistic. On the contrary: industrial agricultural production is a major cause of lower soil fertility and rising soil degradation worldwide. The improper and disproportionate use of chemical fertilizers drives this trend. This study opposes the Bank's recommendations and offers a critical analysis of fertilizer subsidies. Instead, it focuses on various aspects of soil fertility. This is because the nature of soils in the tropics and subtropics present enormous challenges that must be faced when including fertilizer in a comprehensive soil management strategy. That is the only way to improve soil fertility and, ultimately, to rise yields.

Fertile soils are among our most important resources worldwide. Healthy soils store water, are home to a large share of biodiversity, and store carbon. Fertilizer subsidy programmes ignore the challenges and potentials of agriculture that conserves the resources on which it depends. Only healthy soils will be able to meet the food requirements of nine billion people in the future.

Berlin, April 2013
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Summary

Mineral fertilizers have never been used as much as they are today, and in developing countries they are experiencing a renaissance. But the efficacy of mineral fertilizers and the problems they entail have long been a matter of contention. This study provides an overview of the economic and ecological potential as well as the limitations and negative impacts of mineral fertilizers in the tropics and subtropics. It focuses on the situation facing smallholder farmers.

2 Over the past 60 years, agricultural intensification has relied on non-renewable resources, especially on the fertility of the soil. Many smallholder farming systems in Africa, Asia and Latin America, which are the source of income and food for several billion people, have been excluded from this development. The potential for raising productivity and production in many areas has yet to be exploited. The intensification strategies that have so far been pursued have been inappropriate. This study looks at the role that mineral fertilizers could nevertheless play in boosting agricultural productivity.

3 Our ability to produce enough food for an estimated 9 billion people in the year 2050 depends in part on an adequate supply of crop nutrients. Ensuring this supply is difficult because nutrients are unevenly distributed. Industrialized nations are oversupplied; many developing countries are underserved. The nutrient availability in soils is just as important. The soil's capacity to absorb nutrients and to release them whenever needed for plant growth depends on various soil properties. The claim that mineral fertilizer is necessary to even out nutrient balances in the soil ignores a large part of the picture.

4 Mineral fertilizer production has risen almost constantly since the middle of the last century. Yet the consumption of fertilizers varies greatly from one region to another. The areas with the highest consumption are East and South Asia, while use in Africa is comparatively low. Big differences exist in the intensity of fertilization: from an average of 344 kg per hectare a year in China, to 7.5 kg in Ghana and just 2.7 kg in Rwanda. At the same time, the proportion of nitrogen among the main nutrients (which also include phosphorus and potassium) has continued to rise; today, nitrogen accounts for 74 % of the fertilizer used globally. Much is wasted.

5 Mineral fertilizer subsidies for smallholders have been common in developing countries for many years, and subsidy programmes are still popular. Current programmes show that food production can be increased significantly in regions where the food supply is short, though they fail to improve the soil fertility in the long term. Subsidies have a short-term effect, they do not result in sustainable food security, and they are of minimal importance to an economy's profitability. What is more, subsidy programmes are a burden on national budgets. In some African countries, fertilizer subsidies account for up to 70 % of the funding assigned to agriculture.

6 Over the past decades, the economic efficiency of mineral fertilizers has fallen dramatically. This is because the price of fertilizers has risen much faster than that of food, transaction costs in developing countries are high, and soil fertility has fallen, which diminishes the efficacy of mineral fertilizers. In many tropical smallholdings, mineral fertilizer pays minimal dividends, if any at all.

7 The negative ecological consequences of mineral fertilizers have reached menacing proportions. This concerns synthetic nitrogen in particular. It reduces the humus content and biodiversity in the soil, causes soil acidification and gives rise to emissions of nitrous oxide, a potent greenhouse gas causing climate change that will harm future food production. The rise in soil acidity diminishes phosphate intake by crops, raises the concentration of toxic ions in the soil, and inhibits crop growth. The depletion of humus in the soil diminishes its ability to store nutrients. Greenhouse gases derived from excess nitrogen harm the climate. In summary, synthetic nitrogen destroys core fundamental principles of agricultural production and jeopardizes future food security.

8 The challenge, therefore lies in using mineral fertilizers in such a way that they are harmless for the soil and the environment and allow nutrients to remain within the system. The use of synthetic nitrogen should be dispensed with completely, and other nutrients must be integrated into a comprehensive soil fertility strategy. Techniques that maintain and enrich the soil's humus content will be key to this. Compost, animal manure, agroforestry, green manure and intensive fallowing will all play a major role. Innovations are needed in the production and application of mineral fertilizers. The dominant acidifying fertilizers (especially urea, ammonium sulphate and ammonium nitrate) should be replaced by physiologically neutral fertilizers.

9 Mineral fertilizer is the embodiment of the finiteness of natural resources, fossil fuels, mineral deposits and soil fertility. Today's use of nitrogen fertilizer poses a danger to tomorrow's food security. Current approaches need to be overhauled in favour of the sustainable use of resources, while also boosting production. Politicians face four tasks:

» Stop promoting synthetic nitrogen

» Develop national strategies for a soil-fertility infrastructure development programme

» Establish focal points of research to support such a reorientation, and

» Develop scenarios for the transition away from using mineral fertilizers as a short-term consumption item to a long-term investment in soil fertility.

1 Introduction

Mineral fertilizers have never been used as much as they are today. One reason for this because governments in Africa and Asia want to boost their agricultural production and become less dependent on imports because of erratic and rising global market prices. They are allocating large amounts of their agricultural budgets to subsidize fertilizers in the hope of improving national food production.

Many countries in Africa and Asia are using large amounts of their agricultural budget to subsidize fertilizers

At the same time, a debate rages among experts on the impact of mineral fertilizers and the problems they entail. There are those, on the one hand, who believe that getting smallholders in the tropics and subtropics to use more fertilizer is the best way to produce more food quickly, so overcoming hunger. Others think this is counterproductive. They argue that mineral fertilizers harm the environment, destroy soil fertility and are economically unviable for smallholder producers. They also claim that the public funding channelled into subsidizing fertilizers could be put to more economically profitable and sustainable use.

The negative effects of nitrogen fertilizers on the climate are undisputed. The production of nitrogen fertilizer uses a lot of energy, while fertilizing fields with nitrogen releases nitrous oxide – a gas that is 310 times more detrimental to the climate than carbon dioxide. And mineral fertilizer prices are linked to the price of oil because their production is so energy-intensive. As a result, the price of mineral fertilizers tends to rise along with oil prices.

The negative impact of nitrogen-based fertilizers on the climate is undisputed. Spreading nitrogen on fields releases nitrous oxide, a greenhouse gas 310 times more potent than carbon dioxide

Despite this, the discussion remains centred on the issue of whether smallholder producers, who often farm their land very intensively, ought to use far more mineral fertilizer so they can preserve the soil's fertility and produce more food.

In view of the renaissance that fertilizer subsidies are experiencing in many tropical and subtropical countries, this study provides an overview of the economic and ecological barriers and of the potential for using mineral fertilizers in such regions. It also focuses on the particular situation of smallholder producers and the importance of improving soil quality in the long term so as to attain food security.

Chapter 2 gives an overview of the possible ways of raising production in smallholdings and their importance for global food security.

Chapter 3 deals in general with the nutrient requirements of the agricultural sector. It takes a critical look at the oversupply of nitrogen and the impact this has on soil fertility, the environment and the climate.

Chapter 4 identifies the broad-ranging, intensive use of mineral fertilization. This ranges from farms that use no mineral fertilizers at all, to fertilizer intensities of as yet unknown proportions.

Chapters 5 and 6 look at the current practice of channelling state subsidies into mineral fertilizers and analyse their economic profitability at a business and economic level using specific examples.

Chapter 7 provides an overview of the scale of damage caused by mineral fertilizers, which even the agricultural sector is trying to counteract.

Finally, **Chapter 8** highlights alternative examples of sustainable land management and political measures that form elements of a sustainable agricultural policy, combining soil conservation and food security through forward-thinking approaches.

In the light of ecological limitations and ever-scarcer resources, current mineral fertilization practices are both economically and ecologically untenable for the future.

In the light of ecological limitations and ever-scarcer resources, current mineral fertilization practices are both economically and ecologically untenable for the future. Thus, mineral fertilizers pose a long-term threat to food security rather than improving it. This study seeks to illustrate this situation and show the close correlations between food security, environmental and climate protection, and soil fertility conservation.

The effect of intensive agricultural production on the ecosystem is visible in many parts of the world. Problems include a dramatic loss of biodiversity and soil fertility, and more soil erosion.

Since the middle of the last century, agriculture has undergone unprecedented intensification. But many smallholders – the majority of farmers – have barely profited.

2 Potential for raising agricultural production[1]

Since the middle of the last century, agriculture has undergone unprecedented intensification. Over a period of 50 years (1950–2000), global cereal production virtually tripled.[2] This trend was largely possible due to the enormous advances in plant breeding, the large-scale use of synthetic nitrogen fertilizer at relatively low energy costs, the expansion of irrigation systems, and the systematic use of herbicides and pesticides to control weeds, pests and diseases.

Apart from complex social and human-rights concerns, there are weighty ecological reasons and the law of diminishing returns that argue for not continuing existing intensification strategies. The relationship between intensive agricultural production and the burden on and destruction of ecosystems is visible in many parts of the world.

Problems include a dramatic loss in biodiversity, soil erosion, soil salinization and the loss of soil fertility. Nitrates pollute drinking water and over-fertilize lakes, causing algal blooms and killing fish. Less visible, but no less dramatic, are nitrous oxide emissions from mineral nitrogen that account for the bulk of greenhouse gas emissions caused by agriculture.[3]

A second argument against continuing the present intensification strategies is economic in nature. Rising costs for agricultural inputs and diminishing returns have slowed down the intensification trend; the increase in land productivity of high-input cropping systems is declining. FAO statistics on global food production confirm this trend: the annual yield increase was 3 % in 1950, but fell below 1 % in 2001.

The production increases were achieved mainly on fertile soils with optimal nutrient and water supplies. However, only a small portion of farms actually operate under intensive conditions. At the other end of the scale are large numbers of smallholdings, which provide around 2.6 billion rural people with food and a livelihood. This sector has barely profited from the intensification strategies of the past few decades. In many tropical and subtropical regions, land productivity among small-scale farmers has stagnated for years. Cereal yields of 1 t/ha or less are a far from rare, compared to the 8, 10 or even 12 t/ha achieved through highly intensive production. Given these figures, the findings of the Global Task Force on Hunger[4] study published in 2004 are hardly surprising: this came to the conclusion that 80 % of the world's hungry do not live in cities but in rural areas. Two-thirds of these are small-scale farmers. The term 'small-scale farmers' encompasses a very heterogeneous group. It ranges from medium-sized farms which see themselves as part of the market economy and are geared to its principles – a type very commonly found in many Asian countries – to the very smallest of smallholdings which are largely run as self-sufficient businesses and account for 75 % of the world's poor.[5] The common factor linking them all is the size of the farm: 2 ha of arable land or less.[6]

Table 2.1: Average farm size by region (hectares) *Source: von Braun 2005*

Africa	1.6
Asia	1.6
Latin America and Caribbean	67.0
Western Europe	27.0
North America	121.0

Across the globe, the percentage of all farms classified as smallholdings is estimated to be 85 % (Table 2.2).[7] At 1.6 ha per farm, the average size in both Africa and Asia is very low. The high value found in Latin America is due to the greatly divergent distribution of land between major landowners and small-scale farmers. It does not mean that the majority of farms on this continent are significantly larger than in Africa or Asia. In certain countries, holdings of 2 ha or less account for more than 90 % of all farms. In Vietnam, the figure is 95 %; in Bangladesh, 96 %.[8]

85 % of all farms world-wide are smallholdings

The global share of land farmed by smallholders is not known. In the 1980s, it was estimated to be 60 %.[9] It is currently assumed to be at least 40 %.

Table 2.2: Smallholdings as a percentage of all farms *Source: Nagayets (2005)*

	Percentage	Year
Ethiopia	87	2001/2002
Nigeria	74	2000
China	98	1997
Vietnam	95	2001
Ecuador	43	1999/2000
Peru	58	1994
Global	85	Estimated

Small-scale agriculture is vital for the livelihoods of over 2.6 billion rural people, most of whom have no alternative sources of income. Achieving global food security requires people to be able to earn enough income or to produce their own food. The IAASTD World Agriculture Report[10] confirms that two factors are key to improving global nutrition: producing enough food, and ensuring access to it for those in need. This entails increasing agricultural production and raising incomes in agriculture.[11] Food security can therefore only be achieved by intensifying small-scale agriculture.

Small-scale agriculture is vital for the livelihoods of over 2.6 billion rural people. Food security can only be achieved by intensifying small-scale agriculture

The potential to realize this is great in the tropics and subtropics where smallholdings are prevalent. Although the levels of soil fertility are only average or low in many areas, low cereal yields of 1 t/ha or less could be raised to 2, 3 or even 4 t/ha by systematically improving the soil fertility.[12] At the same time, small-scale farmers often achieve considerably higher land productivity than large-scale farms in the same environment.[13] This implies the need for strategies that meet the specific ecological and economic needs of smallholder producers. Organic production methods are especially well-suited for this purpose.[14] The role that mineral fertilizers could play in this regard is covered in the chapters that follow.

3 The nutrients issue

3.1 Unequal regional distribution of nutrients

Nutrients are a key component of soil fertility – the ability of the soil to host plants and to generate plant yields. The soil fertility, or soil productivity, depends on the soil's parent rock and its chemical, physical and biological properties. It also depends on climate, vegetation and the history of land use. Soil nutrients and their availability to plants are governed by all of these properties.[15]

Each form of fertilization serves to provide soil and plants with nutrients that enable them to grow as best as possible and produce the maximum yield. Plants, above all, require the "macro" nutrients of nitrogen (N), phosphorus (P) and potassium (K). Sulphur, calcium and magnesium are also needed, as are other trace elements. The nutrient extraction by crops can be significant. For example, an average wheat harvest in Germany of 8 t/ha takes 180 kg of nitrogen, 37 kg of phosphorus and 124 kg of potassium from the soil.[16] If only the grain is harvested and the straw is left on the land to be worked into the soil or spread in stables and returned to the fields as manure, the volumes that are taken from the system are significantly lower. They amount to 64 % of the original crop withdrawal in the case of nitrogen, 41 % of the phosphorus and 18 % of the potassium. Other crops and cropping systems differ, but this example shows that farming withdraws enormous amounts of nutrients from the soil, and the more intensively the land is farmed and the higher the yields, the greater the withdrawal.

Nutrients are also lost through soil erosion or seepage of the groundwater they are dissolved in. Significant amounts escape into the atmosphere as gas. Unfavourable soil conditions can result in nutrients in the soil becoming chemically bound (phosphorus) or physically fixed (potassium), making them virtually inaccessible to plants even though they remain in the soil.

If it is used extensively, soil can compensate somewhat for nutrient losses through weathering of the subsoil and deposits from the atmosphere. In the past, long fallow periods fostered this regeneration. Modern methods such as the cultivation of clover or alfalfa as part of the crop rotations used by organic farmers or agroforestry systems have a similar impact (see Chapter 8.1). Introducing additional nutrients from outside becomes all the more important the more intensively the land is farmed and the more nutrients the crop extracts. Nutrient deficits are commonplace in tropical smallholdings, caused by intensive cropping, a complete lack or minimal use of fertilizers over decades, as well as soil erosion and leaching. This over-farming of the land – which is also known as *soil mining* – has been verified in numerous scientific studies, above all those focusing on sub-Saharan Africa.[17] It is especially common in Africa, but it can also be found in numerous places in Asia and Latin America. Given the lack of alternatives available to smallholders and their limited land and capital, soil mining tends to be associated with poverty. Miller & Larson[18] have established that, worldwide, 135 million hectares lack sufficient nutrients: they are in undersupply. Virtually all (97 %) are situated in developing countries.

The soils in many industrialized countries have excess nutrients. Western Europe has big surpluses of nitrogen, potassium, and especially phosphorus

By contrast, soils in many industrialized countries have excess nutrients: they are in oversupply. Western Europe has considerable surpluses of nitrogen, phosphorus and potassium.[19] They are especially high in the case of phosphorus. These surpluses are not only the result of excessive mineral fertilizer input, but also sizeable nutrient imports brought about by the import of fodder. These enter the nutrient cycle via animal dung (especially liquid manure). On average, around 35 million tonnes of soy and soybean products were imported into the EU between the years 2008 and 2010. Soybeans are processed into soybean oil and soy flour. Virtually all of the soy flour goes into animal feed and mainly originates from Brazil and Argentina. An area of almost 15 million hectares is needed to grow the amount of soybean and soybean products that are imported to the European Union alone.[20] This equates to 90 % of Germany's entire farmed area. In Asia, high nutrient surpluses as a consequence of excessive nitrogen and phosphorus fertilization can, above all, be found in the paddy fields of south China[21] as well as in South Korea and Malaysia.[22]

Aggregated and on a global scale, it cannot be maintained that there is a high nutrient deficit. Scheldick et al.[23] calculate the theoretical availability of nitrogen to be 12 kg/ha per year. For phosphorus the figure was 5 kg/ha; for potassium, 20 kg/ha. Tan et al.[24] came up with similar levels when calculating the global production of cereals (maize, rice, wheat and barley). This means that a regional imbalance exists in the distribution of existing nutrients. While low-income countries with rapidly increasing populations have significant nutrient deficits, high-income countries with stable populations can count on sizeable surpluses.

3.2 Lack of nutrient availability

As important as the discussion on soil mining, regional inequalities and nutrient balance in the soil may be – this only highlights part of the problem. The relative proportions of nutrients also play a vital role. For example, applying high rates of nitrogen alone destroys the balance between the three macronutrients, N, P and K. This approach not only puts nitrogen to poor use; it also leads to increased humus depletion, rising soil acidification and, overall, a reduction in the nutrients available to the crops (see Chapter 7). Mineral NPK fertilization also frequently results in a lack of micronutrients, which is also due to an imbalance in the nutrient ratios.

Moreover, nutrient availability is influenced by numerous soil fertility parameters, such as aeration, the supply of water, structure, acidity and organic matter content. Nurturing the soil's fertility is therefore pivotal to nutrient availability. Two aspects are of particular importance in this regard: acidity and organic matter.

Soil acidification is a global problem and of special significance in the humid tropics. Severe weathering and leaching have made a large percentage of tropical soils very acidic. The pH value of agricultural land should range between 5.5 and 7.5. In the tropics, pH values are typically below 5.5, with pH values around 4.2 common. Low pH values mean acid soils: they reduce the nutrient availability and intake by plants; phosphorus in particular is fixed in the soil.

Degraded soils have low fertility and little organic matter. Applying mineral fertilizers on such soils has little effect on crop yields

In degraded soils – i.e. those with low soil fertility and minimal organic matter – the effect that mineral fertilizers have on crop yields remains low. This is because these soils have a low capacity to bind dissolved nutrients (from mineral fertilizers, for example) into the soil and make them available to plants. As a consequence, a large portion of the nutrients is washed out in the groundwater and is lost. Tropical soils, in particular, exhibit this property, as their heavily weathered clay minerals have a very poor ion exchange capacity. Oxisol soils alone, whose clay minerals are largely kaolinite (Table 3.1), account for 22 % of all the soil found in agricultural land in the tropics.[25] In such circumstances, organic matter takes on a vital role because it can retain nutrients and convey them to the plant. However, if degraded soils have very little organic matter left (e.g. 20–30 %[26] of the amount they had under natural vegetation), their potential to absorb nutrients is very low. In this case, the best part of any mineral fertilizers is washed out.

Table 3.1: Cation exchange capacity of soils and their components
Source: Young 1976

Common soils	meq / 100 g
Oxisol (tropics)	3–7
Parabrown soils (Central Europe)	20–30
Clay minerals	
Kaolinite (old clay mineral)	3–15
Montmorillonite (young clay mineral)	80–120
Organic matter	150–300

This example illustrates that the use of mineral fertilizers on heavily weathered tropical soils does very little to raise harvest yields. Instead, the soil's capacity to store nutrients and make them available to the crops needs to be improved.

In summary, it can therefore be said that the nutrients issue is highly complex and cannot be restricted to balancing withdrawal and supply, as the discussion surrounding mineral fertilizers repeatedly suggests. In order to raise yields, especially in areas with poor soil quality, the availability of nutrients for plants and thus the capacity of soil to store nutrients and release them when necessary is of utmost importance. This cannot be achieved by using mineral fertilizers.

Phosphate mining in the Negev Desert, Israel. Phosphorus is an irreplaceable resource whose maximum extraction rate ("peak phosphorus") may be reached in around 20 years.

4 Production and use of mineral fertilizers: An overview

4.1 Production

In 1840, a chemist by the name of Justus von Liebig discovered the growth-enhancing effect of nitrogen, phosphorus and potassium. He is therefore regarded as the founder of agricultural fertilization and laid the scientific basis for agricultural intensification. Potash was mined as a fertilizer as far back as the 19th century, and the basic slag extracted from iron and steel production was used as the first phosphate fertilizer. Guano (the excrement of seabirds) and Chile saltpetre (sodium nitrate) were mined in South America and exported to Europe for use as nitrogen fertilizer. In addition, clover was more intensely cultivated as a fodder plant and nitrogen organically enriched in the soil (the enhanced three-field crop rotation).

The Haber-Bosch process, invented in 1909, marked a milestone in development. This generates synthetic ammonia from atmospheric nitrogen. This process was used during the First and Second World Wars to manufacture poison gas and explosives. It was only in the aftermath of the Second World War, in the late 1940s, that the industrial production of synthetic nitrogen fertilizer was taken up at empty production sites. Supplies of organic and mined nitrogen that had been dominant until this time could now be replaced by synthetic nitrogen, and nitrogen fertilizer could now be used in unprecedented quantities.

Since that time, the production of mineral fertilizers (nitrogen, potassium and phosphorus) has steadily risen (Figure 4.1). This trend was briefly interrupted only in the 1990s at the time of the breakup of the Soviet Union. Production has consequently risen five-fold within a period of 50 years.

Figure 4.1: Global production of mineral fertilizer (N, P_2O_5, K_2O) *Source: based on IFADATA 2012*

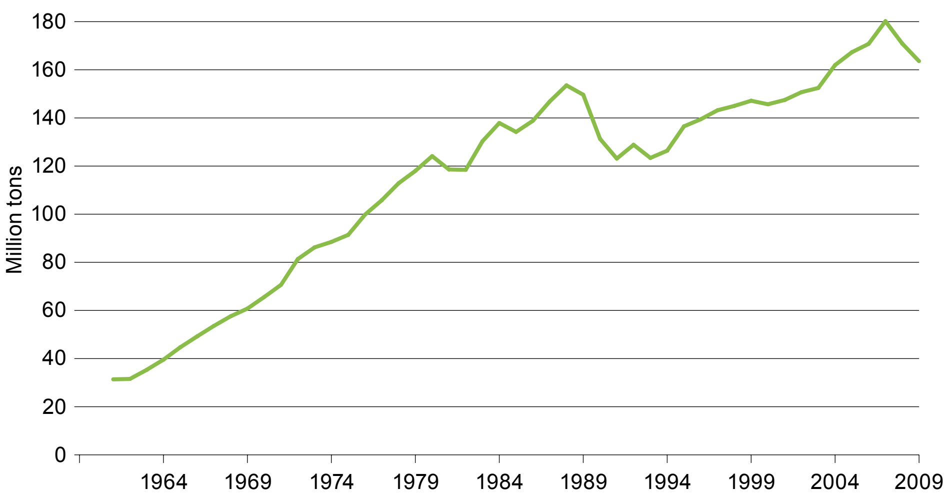
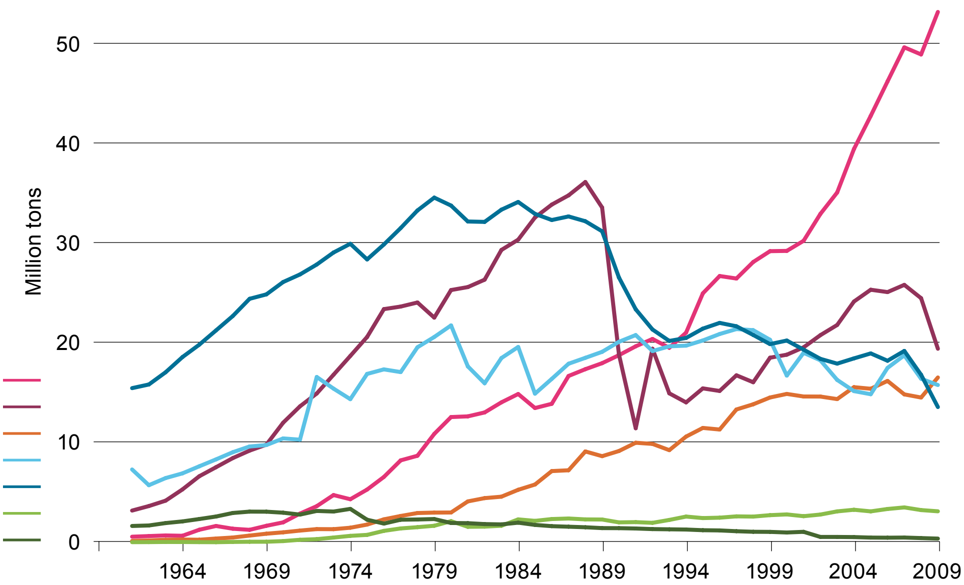


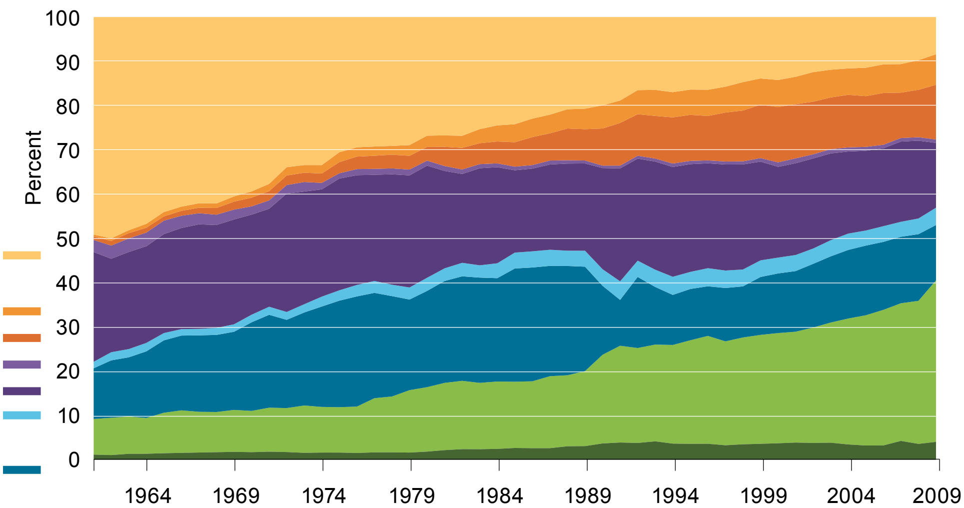
Figure 4.2:
Major producers of mineral fertilizer (N, P_2O_5, K_2O)
Source: based on IFADATA 2012



Developing countries now produce 60 % of all mineral fertilizers

It is interesting to note the regional shifts that have taken place in the production of mineral fertilizer (Figure 4.2). While fertilizer was initially manufactured exclusively in the industrialized countries of the North, the share of developing countries has steadily increased and currently stands at 60 %. The region with the largest production volume is Eastern Asia (with the People's Republic of China the largest producer country), followed by North America. By contrast, output in the European Union, once largest producer, has dropped significantly, to the extent that it has now been surpassed by India and the USA. Following the collapse of the Soviet Union around 1990, production in the CIS states has recovered to a medium level.

Figure 4.3:
Mineral fertilizer production by region
Source: based on IFADATA 2012



Because nitrogen production is exceptionally energy-intensive, it is located where fossil fuels are relatively cheap. These include North America, the main emerging countries of China and India, as well as countries with significant natural gas and oil reserves such as Russia, the Middle East, the Caribbean, Australia and Indonesia. Phosphorus fertilizers are produced particularly in locations that are rich in rock phosphate. The same is true of potassium fertilizers, 80 % of which are made in just five countries (Canada, Germany, Israel, Russia, and Belarus) all of which have sizeable potassium reserves.

Overall, the bulk of mineral fertilizers are nowadays produced in emerging and developing countries (Figure 4.3). At the same time, only a handful of multinational companies produce and trade in NPK fertilizers. Calculations by the Berne Declaration organization revealed that only ten firms accounted for 55 % of the market share in 2009. Of these, three groups, Yara (Norway), Mosaic and Agrium (both USA), held a combined share of 33 %.[27]

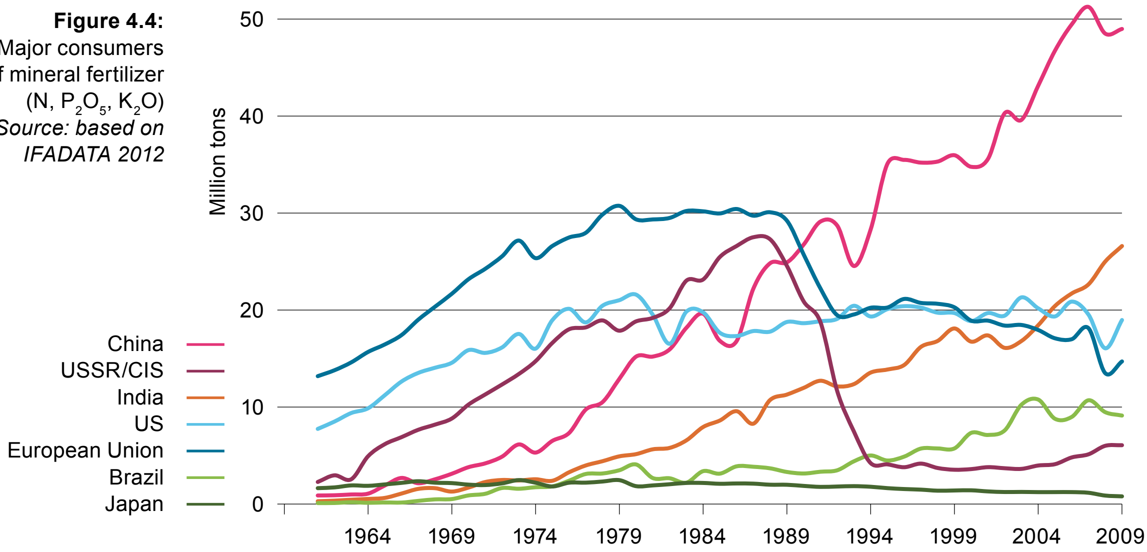
Their large-scale production at suitably favourable locations by just a few firms has turned mineral fertilizers into an internationally traded resource which most developing countries are forced to purchase using precious foreign currency. This exposes them to price fluctuations on the global market.[28]

4.2 Consumption

China now consumes one-third of the world's mineral fertilizers

On a global scale, mineral fertilizer consumption has largely developed in tandem with the considerable increases in fertilizer production. There are significant differences from region to region, however, and not all bulk consumers are bulk producers. The regions with the highest consumption are (in descending order) Southeast Asia, South Asia, Europe and North America. At the other end of the scale, consumption in Africa is especially low.

Figure 4.4: Major consumers of mineral fertilizer (N, P_2O_5, K_2O) *Source: based on IFADATA 2012*



Over the past fifty years, China has propelled itself to the top of list of fertilizer consumers (Figure 4.4). This country produced and consumed around 50 million tonnes in 2009, almost one-third of global consumption. In absolute terms, India is the second-largest consumer of mineral fertilizers, though, unlike China, it is heavily reliant on imports. The European Union, which until the late 1980s was the largest consumer as well as the second-largest producer of fertilizer behind Russia, has halved both its production and consumption.

Table 4.5: Annual mineral fertilization intensity by country (total nutrients N, P, K kg/ha) *Source: Calculated based on FAOSTAT, mean average for the period 2005–2009*

Industrial countries	
USA	99.76
Japan	239.27
European Union	73.64
BRIC states	
Brazil	295.56
Russia	11.66
India	113.38
China	344.39
Developing countries	
Bangladesh	163.57
Ghana	7.50
Kenya	21.50
Nepal	4.55
Rwanda	2.70
Tanzania	4.74
Global average	80.69

Nitrogen now accounts for three-quarters of the world's use of mineral fertilizers

With regards to the intensity of fertilizer use – i.e. the amount of fertilizer applied per unit area – the People's Republic of China is head and shoulders above the rest, with 344 kg per hectare per year (Table 4.5). Other top consumers include Brazil and Japan. With around 74 kg per hectare, the EU's consumption hovers around the global average. The average annual doses applied in many African countries amount to around 5 kg per hectare.

Of no lesser significance is the question whether fertilizers contribute to a balanced nutrient ratio.[29] Not accounting for plant-specific differences, the average ratio of the main nutrients required by plants is 1 N to 0.44 P to 1.25 K.[30] Accordingly, the appropriate average share of nitrogen is 37 %. The actual situation looks very different, as Table 4.6 shows: the amount of nitrogen has risen disproportionately compared to phosphorus and potassium. Whilst it amounted to less than 50 % in 1961, it had risen to 74 % in 2009; in many developing and emerging countries, the share of nitrogen frequently exceeds this level. In China, the average value is over 80 %. Compared to the nutrient requirements, these values are exceptionally high. This incongruity can be explained both by the relatively low price – especially of urea – and the direct yield-enhancing effect of synthetic nitrogen fertilizers.

Figure 4.6: Global applications of N, P and K *Source: Based on IFADATA, 2012*

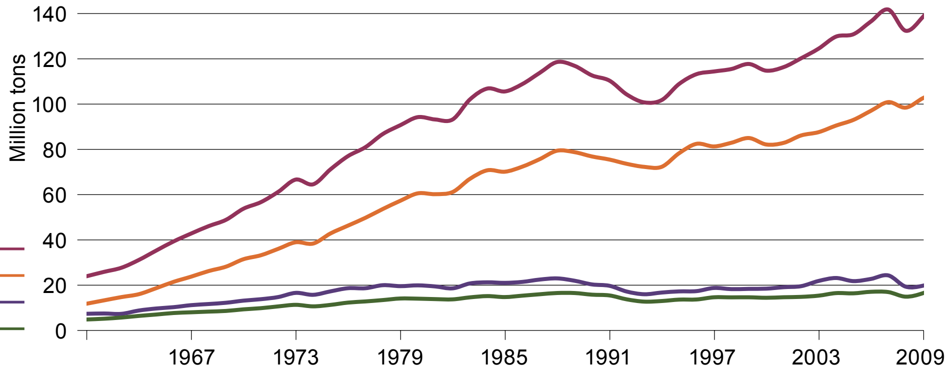


Table 4.7: Share of nitrogen (%) in the consumption of N, P, K fertilizers *Source: Calculated based on FAOSTAT 2012*

Year	1961	1971	1981	1991	2001	2009
Globally	49.2	58.6	64.5	68.4	71.2	74.0
China	93.5	86.7	84.8	79.6	76.0	80.1
Tanzania	52.6	71.9	75.3	79.1	75.6	94.7
Bangla-desh	94.1	80.6	76.9	81.3	82.1	81.3
Nepal	unknown	81.3	83.2	83.8	81.6	65.2

The world uses twice as much nitrogen as necessary – with catastrophic effects on the environment, soil fertility and the climate

Worldwide, the average share of nitrogen is therefore twice as high as necessary – with catastrophic effects for the environment, soil fertility and the climate (see Chapter 7). Given this oversupply, a significant portion is washed out in the form of nitrates, or escapes as nitrous oxide gas into the atmosphere. The use efficiency of this nutrient consequently remains minimal.

Over the past 50 years, China has risen to the top of the list of fertilizer consumers. With around 50 million tonnes in 2009, the country had almost one-third of global consumption.

Large fertilizer storage facility in China. Mineral fertilizers in developing countries are particularly expensive because they have to be transported inland and are sold in very small quantities. Remote locations far from a port are at a particular disadvantage.

5 Subsidies: Sense or nonsense?

Subsidizing mineral fertilizers is common in many developing countries. Governments hope that this will boost agricultural production, improving the country's food situation and reducing poverty in rural areas.[31]

Subsidy programmes pursue a variety of objectives: above all, they should enable a larger proportion of farms to use mineral fertilizers. In particular, subsidies are designed to benefit smallholdings that have little liquidity, poor resources and no access to agricultural loans.[32] Government subsidies also provide a boost to medium-sized and large farms; stepping up the amount of fertilizer used enables them to expand their own production[33], lift incomes and achieve more effective market ties.[34]

In addition, subsidies aim to stabilize fertilizer prices for end-users in times of big price fluctuations.[35] They can also help to compensate farmers for low food prices (which are held down by the state).[36]

Restoring soil fertility is another cited objective.[37] Mineral fertilizers are supposed to increase the production of biomass, enrich the supply of humus to the soil, cut down on soil erosion and create carbon sinks in the soil that help protect the climate.[38] But research to date disproves these assertions (see Chapter 7). Current mineral fertilization strategies are not suited to enriching soil fertility and sequestering carbon dioxide. On the contrary, they have far-reaching negative effects on the environment and the soil, the most vital capital for agriculture.

Mineral fertilizers have been subsidized in developing countries for five decades

Mineral fertilizers have now been subsidized in developing countries for five decades. Restriction-free subsidies for mineral fertilizers were widespread during the Green Revolution between 1960 and 1980, above all in Asia and sub-Saharan Africa. In Asia, the expansion of the irrigation infrastructure combined with an increased use of fertilizer resulted in significant production increases.[39] Since prices for agricultural produce continued to fall at the same time, however, the subsidy programmes did little to grow the economy and combat poverty.[40] The programmes in sub-Saharan Africa were even less convincing, as they were marked by abuse and corruption.

These failures, coupled with calls for structural adjustment programmes, led many countries in the 1990s to cut back on their fertilizer subsidies. A number of programmes initiated by international donors were shut down, and cutbacks were also made in rural development efforts. Instead, a focus was placed on privatization and business promotion.

A shift in course occurred around the turn of the millennium. In the light of rising prices for agricultural produce and a fall in food security, various African governments and private foundations such as the Gates Foundation again began promoting the use of mineral fertilizers. This trend was stepped up as a result of food crises (2005/6 and 2007/8) and increasing price volatility in food markets. The breakthrough for large-scale subsidy programmes in sub-Saharan Africa came by virtue of the African Fertilizer Summit in Abuja, Nigeria, in 2006, which saw the establishment of the African Fertilizer Development Financing Mechanism. This was matched by two initiatives founded in the same year, the Alliance for a Green Revolution in Africa[41] (AGRA) and the Millennium Villages programme, both of which focused completely on agricultural intensification using mineral fertilizers. Thus, extensive private and public funding is being ploughed into fertilizer subsidies in African countries in particular, and mineral fertilizer is once again regarded as a key resource for raising inland food production.

In the meantime, the first assessments of this latest mineral subsidization phase have been made available for six African countries (Ghana, Kenya, Nigeria, Malawi, Zambia and Tanzania).[42] All of them seek to optimize food production as a means of effectively combating hunger in their own country. For this reason, staple foods such as maize are a particular focus of the funding.[43]

Many governments and donor organizations vest great hopes in the new subsidization concepts, collectively known as "smart subsidies". Fertilizer vouchers issued to smallholdings above all aim to enable poorer sectors of the population access to fertilizer and promote the private market for mineral fertilizer.[44] Using these vouchers, fertilizer can be purchased for a reduced price or even be acquired in small quantities ("starter packs") free of charge.

The smart subsidy programme in Malawi began in 2004 and reached its peak in 2008/9 with a financial volume of US$ 265 million.[45] The subsidized supply of fertilizer has led to a significant increase in smallholder maize production and to national food security. But it remains to be seen how the high costs can be financed over time, so it is unclear if the country can produce sufficient food in the future. Nevertheless, the experiences in Malawi have encouraged other African countries such as Ghana, Kenya and Tanzania to adopt similar subsidy programmes or to extend existing ones.

In all six countries, the subsidy programmes experienced significant weaknesses: for example, smallholdings situated in remote areas, which should be the main target of the subsidies, frequently could not get enough fertilizer at the right time.[46] Contrary to the aim of enabling small-scale suppliers to provide fertilizer to remote areas, the subsidies in Malawi, for example, led to small-scale traders being forced off the market[47], the strengthening of an oligopoly of a few larger suppliers[48] and corruption among middlemen and administrative departments.[49]

It is difficult to channel subsidies to those really in need. In general, wealthier farms have benefited

Furthermore, a conflict of goals ensued in all of these countries. On the one hand, the governments sought to raise national production, and on the other hand, they aimed to help poorer farms improve their income.[50] In reality, however, larger farms and more fertile regions were supplied with subsidized fertilizer rather than smaller farms and remote areas, mainly because the former could reap higher yields.[51] Fundamentally speaking, it is difficult to channel subsidies to those really in need. In general, wealthier farms have benefited.[52]

The smart subsidy programmes are weak from an ecological perspective. Although all six national subsidy programmes had the declared aim of enriching soil fertility, in practice this did not occur. This omission had an especially profound effect in regions where soil fertility is already low and was further harmed by incorrect fertilizer use.

Another source of criticism of the subsidy programmes is their low economic efficiency. Mineral fertilizer subsidies have a very poor benefit-cost ratio. No

Subsidies for mineral fertilizers have low economic efficiency and a very poor benefit-cost ratio

long-term positive effects are to be expected from the funds used. On the contrary, the annual costs are rocketing at the same time as soil fertility is declining and mineral fertilizer prices are rising. The benefit-cost ratios in Malawi were calculated to be between 0.76 and 1.36.[53] These findings correlate with figures published in an IFPRI study in India, which investigated the impact of various investments and subsidies in the agricultural sector over a period of four decades (1960–99).[54] The study concludes that agricultural research, agricultural consultancy and infrastructure development render a high return on capital. The return on mineral fertilizer is very small in comparison, or as was the case in the 1980s and 90s, can even be highly negative: in 1980–89, one rupee invested led to 0.88 rupees worth of growth (a return of –12 %); in 1990–99, an investment of one rupee led to only 0.53 rupees worth of growth (a return of –47 %) (Table 5.1).

Table 5.1: Return on public investment in the agricultural sector in India. Growth in the agricultural sector in rupees per invested rupee
<1 = net loss
>1 = net benefit
Fan et al. (2007)

	1960–69	1970–79	1980–89	1990–99
Agricultural research	3.12	5.90	6.95	6.93
Training	5.97	7.88	3.88	1.53
Infrastructure development (roads)	8.79	3.80	3.03	3.12
Mineral fertilizer subsidies	2.14	3.03	0.88	0.53

Table 5.2: Burden of subsidies on national agricultural budgets in sub-Saharan Africa
Mössinger (2012)

Ghana[55]	46 % of the 2012 national agricultural budget is spent on mineral fertilizer subsidies.
Kenya[56]	An estimated 37 billion KSh (~US$ 44.1 million) spent over three years.
Malawi[57]	91 % of the mineral fertilizer costs were subsidized due to the high fertilizer prices in 2009. This was 74 % of the agricultural budget and 16 % of the national budget.
Nigeria[58]	Up to 25 % of fertilizer costs are subsidized and accounted for an average of over 43 % of the agricultural budget between 2001 and 2005.
Zambia[59]	Up to 70 % of the agricultural budget is spent on fertilizer subsidies and maize price support.
Tanzania[60]	Up to 50 % of fertilizer and seed prices are subsidized. Anticipated costs: approx. US$ 110–150 million.

Given the low profitability of mineral fertilizer subsidies, the scale of public funding channelled into them is startling

Given the low profitability reaped from mineral fertilizer subsidies, the scale of public funding channelled into them is startling. The subsidy programmes pose a massive burden on national agricultural budgets. At times, 74 % of Malawi's entire agricultural budget were spent on mineral fertilizer, with similar figures applying in Zambia (Table 5.2). Ghana's figures convincingly show how the expenses of a national agricultural budget are geared towards funding mineral fertilizer and how their share – in absolute and relative terms – is rising continuously (Table 5.3). These funds that are no longer available for promoting other agricultural activities.

Table 5.3:
National costs of mineral fertilizer subsidies in Ghana
Calculated based on data from MoFA (2012)

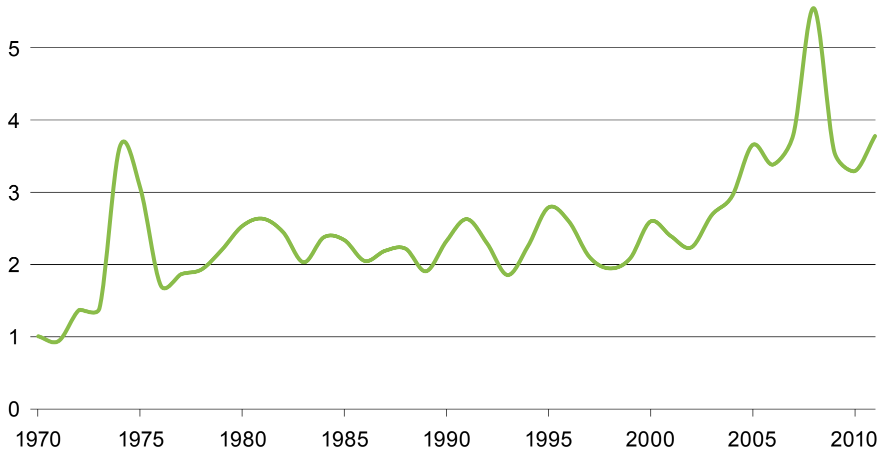
Year	Fertilizer subsidies (US$ million)	Agricultural budget (US$ million)	Fertilizer subsidies as a percentage of the agricultural budget (%)
2008	19	114	16
2009	24	140	17
2010	20	175	12
2011	50	142	36
2012	66	144	46

Fundamental problems consequently remain unresolved in spite of the supposedly improved concepts. Fertilizer subsidies result in production increases in the short term, but have a negative long-term effect on soil fertility. This is confirmed by the very low return on funds invested. In economic terms, they can only be justified as provisional, makeshift measures. In the short run, they can cushion temporary price increases and boost food production, but they cannot serve as a sustainable food security strategy.[61] Mineral fertilizer subsidies are therefore a high-cost tool designed to provide immediate relief. In reality, however, once subsidies are initially ploughed in, they are continued for many years; once set up, their termination is met with heavy resistance even though they pose a considerable burden on the budgets of numerous countries.

6 Economic viability of mineral fertilizers for smallholdings

The economic viability of fertilizer is the ratio of additional costs to additional yield. Numerous studies in smallholder regions of Africa, Asia and Latin America have shown that additional yields achievable through mineral fertilizers are often marginal. This is especially well documented in the case of sub-Saharan Africa.[62] The reason for this lies in the widespread low fertility of the soils that have for decades been overused, leached, acidified or abandoned to erosion. Their ability to make nutrients from fertilizers available to plants and to create beneficial growing conditions is often minimal.

Figure 6.1: Terms of trade for fertilizer and food
Note: Fertilizer price index divided by food price index (1970=1)
Source: own calculation



Compared to food prices, the world market price for mineral fertilizers has risen by over 250 % in 40 years

On the cost side, the "terms of trade" (a comparison between the costs of two items) in agriculture, and especially the ratio between mineral fertilizer and food products, have deteriorated steadily from one decade to the next. Figure 6.1 compares the global fertilizer price index[63] with the World Bank's food price index[64] between 1970 and 2011. It shows that the world market price for mineral fertilizers has risen disproportionately when compared to the price of food – by over 250 % in 40 years. Other studies reveal similar trends.[65]

The disproportionate cost increase for mineral fertilizer reflects the rising costs for fossil fuels (oil and natural gas) as well as minerals, notably phosphorus. This global trend is intensified in the majority of developing countries by other costs. The price an individual farmer in a remote area has to pay for mineral fertilizer is a lot higher than the world market price (or would be, if there were no subsidies) because of transport, distribution and other transaction costs. The prices that the same farmer gets for his or her farm produce, on the other hand, is far below the price in places with good market links.[66] Moreover, fertilizer prices are prone to wide fluctuations,[67] especially if they are imported and are priced in foreign currencies, as is the case in most developing countries.

63 The fertilizer index (calculated by the author) is a weighted average of the annual prices for urea (weighting: 63.9 %), triple superphosphate (20 %) and potassium (16.1 %). The weighting was calculated on the basis of the respective average share of the three components in worldwide production. The worldwide production data comes from the International Fertilizer Industry Association.

64 The World Bank's Food Price Index calculates a goods price index for countries with low and middle incomes. The index comprises three components: fats and oils, cereals and other food products (meat, sugar, etc.). It is index-linked to 2005 and the weighting of the components was determined on the value of exports between 2002 and 2004.

Mineral fertilizers cost such a lot in developing countries because they have to be transported inland and are sold in very small quantities. They are often bought on credit that has to be repaid after harvest. Locations far from a port are at a particular disadvantage. By way of example, the retail price for urea in Lusaka (Zambia), Lilongwe (Malawi) or in Abuja (Nigeria) was 41–48 % above that charged in cities in the USA (Table 6.2). In the inland city of Huambo (Angola), the price of NPK fertilizers was 150 % higher than at the port.

Table 6.2: Impact of transportation costs on fertilizer prices in rural areas of Africa (US$/tonne, 2003)
Source: Gregory and Bump (2005)
fob = free on board, cif = cost insurance freight

	Inland transportation route	Price (fob)	Price (cif)	Retail trade
USA (urea)		135	160	227
Nigeria (urea)	Lagos – Abuja	135	165	336
Malawi (urea)	Beira – Lilongwe	145	170	321
Zambia (urea)	Beira – Lusaka	145	270	333
Angola (NPK)	Luanda – Huambo	226	323	828

These findings have been confirmed by a comprehensive study conducted on behalf of the Gates Foundation.[68] This found that the retail price for urea in Lilongwe, Malawi in 2006 was US$ 496 per tonne, compared to an fob price of US$ 191. Further mark-ups are to be expected for remote regions. For Malawi, Sanchez[69] anticipates the urea price to be six times higher than that at the port of Beira (Mozambique).

A World Bank study compiled numerous proposals for lowering the high transaction costs in imports, transportation and commerce. It recommends, for example, providing easier access to agricultural loans, establishing market information systems, simplifying the product range, extending the distributor network and stepping up governmental control mechanisms.[70] With respect to East Africa, agronomists estimate that the retail price charged to consumers could be cut by 11–18 % as a result.[71] This is not much and does nothing to alleviate the fundamental problem of disproportionate mineral fertilizer costs in developing countries and their remote rural areas in particular. Product prices are too low, and fertilizer costs too high.

These high prices mean that for smallholder farmers, mineral fertilizer is frequently only profitable in small quantities, if at all. Even though the fertilizer doses recommended by the national advisory services are often much higher, farmers are usually very aware of the low profitability. Accordingly, they fertilize their soil very purposefully and economically. The practice of fertilizing plants individually is widespread. Many farmers in southern Africa use crown caps from beer bottles to apply the right amount of fertilizer.

The benefit-cost ratio is frequently taken as an indicator of the profitability of mineral fertilizer. In this case, the sales value of the additional yield is divided by the cost of the fertilizer consumed. Benefit-cost ratio studies have proven that mineral fertilizer profitability in smallholder regions is marginal. For example, the average benefit-cost ratio of maize yield to nitrogen fertilizer in Tanzania and Zambia in 2000 was found to be 1.1, compared to values of 5.2 and 6.5 respectively in 1980.[72] In theory, the use of mineral fertilizer is deemed to be profitable if the benefit-cost ratio is greater than 1. According to agricultural economists at the International Maize and Wheat Improvement Centre (CIMMYT), however, farmers in the tropics should expect a value of at least 2,[73] while in locations with increased production and sales risks, a benefit-cost ratio of 3 or higher is even thought to be necessary.[74]

Whatever the case may be, the situation is far more complex in practice: the poorer the household, the lower the amounts of mineral fertilizer that are used.[75] The more degraded the soil and thus the smaller the yield increase through mineral fertilizer, the lower the amount that is deployed.[76] Less fertilizer is used on fields further away from the farmhouse than those nearby, and on farms further away from the market than on those nearby.[77] Finally, cash crops tend to be fertilized more often than subsistence-based food crops. All this highlights the wide range of decision-making at farm level.

The profitability of mineral fertilizers is on the decline especially in sub-Saharan Africa. Generally, it can be established that:

» For many farms in developing regions, mineral fertilizer is a very expensive and barely profitable production resource. In smallholdings, it is usually applied only in very small quantities – if at all. From a business perspective, this behaviour is very rational given the low soil productivity.

» In the long run, the price of mineral fertilizer has risen disproportionately, as can be seen in the price ratio of maize to fertilizer at the farm level. The long-term decline in the price ratio of food to fertilizer is coupled with a loss in the economic viability of using mineral fertilizer. This can only be offset through a more efficient use of fertilizers.

» In times when prices rise, for example during the food crisis in 2008/9, fertilizer prices in many developing regions increase more than the food prices. This explains why during times of food crisis, fertilizer use tends to decline rather than rise, especially in remote areas.

The economic viability of mineral fertilizer in smallholdings has shrunk continuously

In summary it can be said, that the economic viability of mineral fertilizer in smallholdings has shrunk continuously from one decade to the next. A change in this trend might be achievable only if the price ratio of mineral fertilizer to food products were to be adjusted in favour of the food products, or if the impact made by fertilizers were significantly enhanced by enriching soil fertility. Under present conditions, neither is to be expected.

Mineral nitrogen stimulates the decomposition of organic matter in the soil. The more nitrogen is applied, the faster the decomposition. The damage caused by mineral nitrogen poses a threat not only to the environment but also to agriculture itself.

7 Nitrogen fertilizer: Impact on agricultural sustainability

Under established doctrine, mineral fertilizers, along with plant breeding, are seen as the most important steps towards increasing yields and securing food. This argument is so powerful that the negative impact of fertilizers on the soil, environment and climate are often suppressed or treated as external costs, which simply have to be accepted. By the same token, all mineral fertilizers are usually put into the same pot, and the differences between the individual nutrients and their fertilizer forms all too rarely discussed.

It is synthetic nitrogen that especially has a negative impact. It poses a threat not only to the environment but also to the agriculture itself. Most nitrogen fertilizers cause soil acidification, soil humus depletion and greenhouse gas emissions, which are big contributors to climate change. And climate change is likely to result in a significant drop in agricultural yield in the tropics and subtropics.

7.1 Nitrogen and soil acidification

Soil acidity is an outstanding parameter in the complex soil fertility system (see Chapter 3). In strongly acidic soils, the availability of nutrients, above all phosphate, is limited, and the concentrations of toxic metals in the soil solution rises. At the same time, the life of microorganisms in the soil is heavily impaired and overall soil productivity is lower.

Acidification has a major impact on the supply of phosphorus to plants and on the effectiveness of phosphate fertilizers. Phosphate is readily fixed in acidic soils, making it unavailable to plants. Nitrogen applications thus reduce the efficient use of this scarce and costly nutrient. Phosphorus is an irreplaceable resource whose maximum potential extraction rate through mining ("peak phosphorus"[78]) may be reached in around 20 years. That makes phosphorus a particularly precious nutrient.

Applying synthetic nitrogen fertilizer drastically accelerates soil acidification

By far the largest part of synthetic nitrogen fertilizers is based on ammonia. This comprises urea, ammonium nitrate, ammonium sulphate and ammonium phosphate. All of them accelerate soil acidification. Table 7.1 provides an overview of their acidifying effect. The acidity index indicates how much calcium (in the form of lime $CaCO_3$) must be added to the soil in order to neutralize 1 kg of N fertilizer. To neutralize the acidifying effect of a kilogramme of urea, which makes up 67 % of global nitrogen fertilizer consumption,[79] 0.71 kg of lime is required.

Table 7.1: Soil acidification due to fertilization
Source: Hart (1998)

	Acidity index[80] kg $CaCO_3$/kg fertilizer
Urea	0.71
Ammonium sulphate	1.10
Ammonium nitrate	0.62
Monoammonium phosphate	0.58
Diammonium phosphate	0.37

Lime is expensive, however, especially because it has to be transported to where it is needed. Ground limestone is often not available at all. As a result, the practice of systematic liming is generally restricted to wealthy countries such as those in Western Europe, whereas the routine use of lime in tropical smallholdings is virtually unknown. There, the soils that are naturally already acidic acidify further as a result of nitrogen fertilization. The pH value here is frequently below 5.5, and values between 4.2 and 4.5 commonplace.

This circumstance is especially apparent in the People's Republic of China. Analysis of over 8,000 soil samples from the southeast of the country has revealed that, in the period 1980–2000 – i.e. within a timeframe of 20 years – the pH value in rice soils had fallen by an average of 0.5 points.[81] Other studies even recorded a fall in pH values of up to 2.2 points.[82] Yield declines of 30–50 % induced by soil acidification were recorded at the same time.[83] Nitrogen is seen as the main cause of this, since the practice of nitrogen fertilization has rocketed since 1980. The 32.6 million tonnes of nitrogen applied nationally in 2007 represent a 191 % rise over the level in 1981. China tops the league table of fertilizer users, with 344 kg per hectare a year. Some 80 % of this is nitrogen (Tables 4.5 and 4.7).

7.2 Nitrogen and soil humus

A second key parameter of soil fertility and sustainable production is the amount of humus in the soil. Humus relies on the supply of organic matter such as plant residues and animal manure. It is formed by specific groups of microorganisms and decomposed by others. Sustainable soil fertility therefore relies on the balance between humus build-up and decomposition, and the supply and consumption of organic matter.

Soils with high humus content can utilize mineral fertilizers especially well. The yield-increasing effect of well-dosed mineral fertilization can be very high. This is linked to the fact that organic matter in the soil acts as a key temporary storage for nutrients from fertilizers (see Chapter 3, Table 3.1), whereas in soils with low humus content and low nutrient storage capacity, a large portion of the nutrients dispensed via mineral fertilizers is lost to leaching.

Some therefore argue that the role of mineral fertilizers is not just to raise yields but also to produce biomass, which is not withdrawn from the field but rather fed to the soil as organic matter (root mass and harvest remains).

They furthermore maintain that, through an extensive and balanced supply of nutrients and the resulting rise in biomass production, significantly more straw and other crop residues, such as root biomass, will ensue and enrich the humus in the soil. Were this assumption to hold true, mineral fertilizer would represent an investment in the long-term preservation of agricultural soils.

The opposite is the case, however. Numerous long-term trials have concluded that routine NPK fertilization, unlike organic fertilization, depletes the humus content in soil in the long run despite supplying significant amounts of crop residues.[84] It has also been established that higher nitrogen dosages, in order to maximize yields, correlate to greater levels of humus decomposition.[85]

Mineral nitrogen stimulates the decomposition of organic matter in the soil. The more nitrogen is applied, the faster the decomposition

In a famous set of continuous field trials, the "Morrow Plots" in Illinois (USA), certain fields were fertilized with N, P and K for half a century (1955–2001), and this form of mineral fertilization was linked to significant amounts of crop residue that had been fed into the soil. Although mineral fertilization enables higher plant densities, which, in turn, supplies the soil with more biomass, the soil humus content fell continuously and significantly. It is also interesting to note that the lower layers of soil (at depths of 15–30 cm and 30–46 cm) were far more affected. This means that the fertility of the soil had clearly declined overall and its storage capacity of carbon dioxide had diminished.[86]

Why is this so? Numerous studies[87] confirm that mineral nitrogen stimulates the decomposition of organic matter in the soil; the higher the N applications and surpluses, the faster the decomposition. Very high nitrogen surpluses are produced worldwide, while the use efficiency of nitrogen has fallen considerably. Recent estimates show that this efficiency has fallen significantly within a period of 40 years.[88] For global crop production, the efficiency is calculated to be only 33–36 %.[89] This wasteful use of resources is systematic: mineral fertilizers are not used to supply the plant's needs, but rather to achieve the highest-possible economic yields.

7.3 Nitrogen and the climate

Today, global agriculture accounts for around 12 % of all greenhouse gas emissions.[90] It thus ranks among the prime originators of climate change. Of this amount, about half (47 %) are caused by forest clearance and burning to clear land for farming. Another 17 % (or one-third of the remaining agricultural emissions) are attributed to nitrous oxide released into the air as a result of nitrogen fertilization.[91,92]

Mineral nitrogen fertilizer is a major source of greenhouse gases

These levels do not include emissions arising from the production of mineral fertilizers. Large quantities of carbon dioxide are generated during this manufacture of nitrogen fertilizer. Nitrogen synthesis is one of the industrial processes with the highest energy consumption. Around 1.2 % of the world's energy demand is required to produce ammonia using the Haber-Bosch synthesis,[93] and 90 % of the energy used in the fertilizer industry goes into the manufacture of synthetic nitrogen. In addition, large volumes of nitrous oxide are released into the air during the manufacture of nitric acid, another vital material for making N fertilizer.

Soil acidification is a global problem and is of special significance in the humid tropics. Systematic liming – like here in a mango plantation in Ghana – is necessary to regenerate highly acidic soils and to improve crop yields.

7.4 Summary

The damage caused by mineral nitrogen poses a threat not only to the environment but also to agriculture itself

Nitrogen brings about enormous short-term yield increases but is, at the same time, harmful to the soil and climate – two elements that are fundamental to agricultural production. It is like a drug that drives an athlete to peak performances in the short term, but ruins his or her body in years to come. The high levels of nitrogen fertilizer consumption in China and the resulting acidification of the soil is a prime example of how a global agricultural system founded on synthetic nitrogen squanders scarce resources (energy, phosphate) and, at the same time, is systematically destroying the agricultural resource base and diminishing food security. Subsidy programmes which seek to supply poorer farms with mineral fertilizer – preferably nitrogen-based – heighten their poverty in the medium to long term instead of eliminating it, because nitrogen destroys the soil's fertility.

Yet, organic alternatives to mineral nitrogen are already waiting in the wings: of the three main nutrients, nitrogen is the only renewable resource. Atmospheric nitrogen can be fixed biologically and enriched in soil by microorganisms, whereas the reserves of phosphorus and potassium in the soil are very limited. Most tropical soils in particular are reliant on the return or replacement of phosphorus and potassium.

The negative impact of nitrogen fertilizers has meanwhile reached a dimension that can no longer be ignored. The damage caused by nitrogen poses a threat not only to the environment but also to the agricultural sector itself. Alongside carbon dioxide emissions and the drop in biodiversity, nitrogen is a third parameter that has already far exceeded the planetary boundaries.[94]

Fertilizer is valuable. A Zambian farmer fertilizes each plant individually, using a bottle cap to ensure the right dosage.

8 Using mineral fertilizers for sustainable intensification

Agriculture faces the major challenge of combining intensive production with sustainability. Producing in a more sustainable way means using natural resources efficiently, recycling them as much as possible for further use, and avoiding negative impacts on the environment and soil. The aim is to maintain these resources on a sustained basis. With respect to nutrients, the objective is to minimize losses that occur for example through erosion, leaching and soil fixation, and to fortify nutrient cycles by returning the substances that have been removed back to the soil.

Organic manure, which can help to restore or revive nutrient cycles, has great potential, but cannot meet the sizeable nutrient requirements alone. This is especially true for soils that have been depleted of their nutrients for decades by harvesting and erosion. The fertility of such soils has to be regenerated systematically. The use of organic fertilizer from within the farm quickly reaches its limits here. Unless nutrients can be added externally, a leap into more intensive production is unlikely.[95]

For this reason, it is not possible to forego the use of mineral fertilizer entirely. But a fundamental shift in the way people believe it should be used is required. Supplementing mineral fertilization with a soil humus management component does not go far enough. Instead, the reverse argument should apply: mineral fertilizer should be treated as a supplement within a comprehensive soil fertility strategy. Looked at from this point of view, the immediate aim of fertilization is not to increase yields and fertilize plants, but to build up soil fertility. This is exactly what Rudolf Steiner (much like other developers of organic agriculture) meant when he coined the famous phrase: “Fertilization means nurturing a living soil”.[96]

Mineral fertilizer should be treated as a supplement to organic fertilizer and as part of a comprehensive soil fertility strategy

Especially for smallholders this is a big challenge, given their outstanding role they play in food security. Farmers with limited resources must be empowered to invest in soil fertility in order to raise production, secure food, increase marketing surpluses and reduce production risks.

8.1 Soil humus is paramount

On the path towards intensification, precedence should be given to measures that raise the humus content in the soil and enhance nutrient and energy cycles. This is where technology comes into play. Collectively, these fall under the practices of **sustainable land management**[97] and are used systematically in organic agriculture. Sustainable land management ranges from the use of animal manure and compost to green manuring, intensive fallowing and establishing agroforestry systems. Equally important are **soil and water conservation** measures which prevent soil erosion, harvest water, raise the water storage capacity of soil, and increase biomass yields. Sustainable land management and soil and water conservation bring organic matter to the soil, create a means of compensating for continuous humus mineralization and present an opportunity for raising the level of humus content in the soil. This, in turn, improves the soil’s nutrient storage capacity and nutrient availability to plants (see Table 3.1). At the same time it lays the foundation for further fertilization. The increased activity of soil microorganisms that accompanies the build-up of humus is of particular significance in this regard. Through heightened mycorrhizal activity, for example, much higher quantities of phosphorus can be mobilized in the soil and absorbed by the plant's roots. The additional supply of phosphorus and lime can play a vital role in this build-up phase, as degraded soils commonly suffer an acute lack of phosphate and are very acidic.

Precedence should be given to raising the humus content in the soil and enhancing nutrient and energy cycles

Sustainable land management methods can be exceptionally efficient if applied systematically. Numerous studies have confirmed that they can lead to improved soil fertility and higher productivity.[98] This especially holds true in ecologically demanding production environments.[99] The suitability of these technologies for building up tropical soils – as individual measures or in conjunction with others – is site-specific and depends on the natural, economic and sociocultural conditions. The sections that follow briefly present a number of individual examples to illustrate the principles and the effects of such technologies.

8.1.1 Significance of animal husbandry for arable cropping

In many agrarian land-use systems, the link between crop and animal husbandry is viewed as the basis for preserving soil fertility. Animals do not only provide milk, meat and hides. In some regions, the manure they produce takes on even greater significance. This is true, for example, in many parts of Rwanda and in the Usambara mountains of Tanzania. Despite an acute shortage of land in these regions, cattle use feed sources that do not conflict with food production (fallow, meadows, trees, bushes and shrubs). Through this, nutrients are gathered and converted to manure that can be used to fertilize arable land. The current trend is to step up manure production through indoor housing of cattle and forage cropping and convert the manure into high-quality fertilizer (such as compost). Table 8.1 provides an overview of the nutrient content of a variety of fresh manures. The figures reveal a relatively high phosphorus content, which is of special value given the widespread shortage of this element. In addition, the manure contain a significant amount of calcium, which can counteract acidification.

Table 8.1: Nutrient content and organic matter (%) in fresh manure from various farm animals
Sources: Sauerlandt (1948), Jaiswal et al. (1971)

	Water %	Organic matter	Nitrogen N	Phosphate P_2O_5	Potassium K_2O	Calcium CaO
Cattle	80	16	0.3	0.2	0.15	0.2
Horses	73	22	0.5	0.25	0.3	0.2
Pigs	78	17	0.5	0.4	0.07	0.07
Sheep/ goats	64	31	0.7	0.4	0.25	0.4
Hens	57	29	1.5	1.3	0.8	4.0

Applying manure can maintain or increase the soil's humus content

The properties of manure have been the subject of numerous studies. Manure not only raises yields but can also significantly enhance the impact of mineral fertilizers (Table 8.2).[100] Of far greater significance, however, is the fact that the humus content in soil can be kept at a constant or even an increased level through the regular application of manure, as has been verified in recent work conducted in sub-humid and semi-arid locations.[101] Moreover, in heavily acidic soils, it helps to enhance the effect of phosphate fertilizers[102] and to raise the pH value.[103]

Table 8.2:
Effect of farmyard manure and mineral fertilizers on maize yield (kg/ha per year)
Site: Samaru, Nigeria, ferric luvisol
Source: Abdullahi (1971) cited in Mokwunye (1980)

N – P – K	Preceding long-term treatment with manure (t/ha of manure per year over 20 years)			
	0	2.5	7.5	12.5
0 – 0 – 0	33	584	2,543	3,145
124 – 28 – 56	1,016	2,316	3,775	3,821
268 – 56 – 112	2,056	3,311	4,108	4,247

8.1.2 Compost

In most cases, animal manure alone is not sufficient to feed the soil. Plus, many farming systems do not include any livestock. Therefore, the composting of plant material takes on particular significance. High-quality humus fertilizer can be produced by managing the biological and chemical decomposition and conversion of animal and plant waste. This method, which was underestimated in the past and often pejoratively dismissed as an activity "just for the amateur gardener", is now experiencing a veritable boom among smallholdings in the tropics. Its efficiency can also be significantly enhanced by adding animal manure to the compost. By the same token, the composting of human faeces will also need to be given greater consideration in the future.

Vermicompost is currently enjoying widespread popularity. This process works with large earthworm populations and leads to high-quality humus compounds. Numerous research findings published over the past ten years attest to the exceedingly positive effects of vermicompost on the plant yield – on its own[104] and in conjunction with mineral fertilizers.[105] In addition, numerous works have confirmed the positive effects this process has on the humus content,[106] biological activity in the soil,[107] the pH value and phosphate availability.[108]

Table 8.3:
Organic carbon, microbial biomass and enzyme activity in topsoil after 18 years of manure or mineral fertilization

	Carbon % dry matter	Proteinase activity mg/g Tyr	Microbial biomass mg/100g C	Dehydrogenase activity µg/10g TPF
Composted farmyard manure	0.91 %	0.27	34.9	109.1
Composted farmyard manure treated with biodynamic preparates	1.00 %	0.26	37.8	121.9
Mineral fertilizer	0.79 %	0.20	36.1	75.9
Reference	Raupp 1998	Bachinger 1996		

The main challenge facing any form of fertilization is how to maintain and build up the humus content in soil, despite farming the land. In terms of humus reproduction performance, composts come out on top, followed by animal manure.[109]

The main challenge facing any form of fertilization is how to maintain and build up the humus content in soil, despite farming the land

It goes without saying that the humus formation depends on the quantity of organic material. Recent findings have shown, however, that it is not just the quantity that is of decisive importance to the build-up of humus; the microbiological processes required for humus synthesis also play a major role. This begins with the dung in the animal's alimentary tract and ends with the work performed by the microorganisms in the soil. The more effectively this process can be managed for the formation of stable humus compounds, the more valuable the fertilization. Thus, during their long-term trials on bio-dynamic farming, Bachinger und Raupp[110] were able to prove that applying bacteria preparations ("compost preparations") led to a significant increase in humus content and biological activity in the soil (Table 8.3).

Composting is a next-generation technology and the potential for further sustainable intensification looks very promising if the composting processes can be further refined.

A farmer in Colombia using compost made from manure and plant residues. The main challenge facing any form of fertilization is how to maintain and build up the humus content in soil.

8.1.3 Green manuring and intensive fallowing

Green manuring and intensive fallowing generate more biomass and bring nutrients from the subsoil into the topsoil. Numerous methods exist:

» Undersowing in food crops, as is done with maize and other cereals

» Second crops, which are planted after the main crop and then turned under

» Forage crops such as grass-clover mixtures, which, as part of the crop rotation produce fodder for the farm's own livestock

» Intensive fallow periods with fast-growing plants spanning one or two years for the exclusive purpose of allowing the soil to regenerate.

With all of these methods, the objective is to provide the soil with additional biomass and biologically fixed nitrogen in order to help the soil humus regenerate, cover the soil, avoid water loss and humus decomposition, and keep a better grip on weeds.

In all of these cases, legumes play a central role, as they are fast-growing plants that generate large amounts of biomass in a short period and that can create considerable amounts of organic nitrogen. In a 23-year-long trial in Zimbabwe, Rattray and Ellis[111] showed that a one-year maize-intensive fallow rotation with a mixture of the legumes *Mucuna* and *Crotalaria* produced more than double the maize yield compared to continuously cropped maize. Rodriguez achieved similar results during his trials with *Dolichos* in Colombia.[112]

To the extent that it is possible to provide a general assessment of the impact of green manuring and intensive fallow as a soil fertility parameter, it can be said that their impact on the yields for successive crops is high. The vast majority of plants used in green manuring are legumes, which organically bind significant amounts of nitrogen in symbiosis with microorganisms. Given its high nitrogen content, biomass from green manure can usually be readily mineralized and provides successive crops with a source of nutrients. However, the humus from green manure decomposes more quickly that that resulting from manure or compost applications.

8.1.4 Agroforestry

Agroforestry methods have proven to be highly successful in intensifying smallholder farming systems. This is one of the reasons why they form part of the traditional methods used by smallholders in many tropical countries. The physical divide between fields and forests is dispensed with. Using "multi-storey cultivation", annual and perennial crops, shrubs and trees are combined in such a manner that the individual vegetation elements compete for nutrients, water and light as little as possible above the soil and around their roots, and thus achieve the ideal output per unit area.

By adopting such an approach, a field trial conducted over a number of years in Rwanda with 250 trees per hectare managed to reap higher yields of maize and beans grown as mixed crops despite the smaller acreage. Moreover, the total income derived from food crops, timber and forage was 140 % higher than the reference crops.[113] The persistent leaf litter from deep-rooted trees not only provided the fields with nutrients but also organic matter (Table 8.4). Thus it contributed to balance soil humus and soil nutrients.

Table 8.4:
Annual supply of nutrients through leaf litter in the field
Source: Neumann and Pietrowicz (1985)
Site: Nyabisindu (Rwanda), 190–250 trees/ha older than 4 years (Grevillea robusta)

Organic matter (foliage)	4.0	t/ha
Nitrogen (N)	34.0	kg/ha
Phosphorus (P)	0.4	kg/ha
Potassium (K)	16.0	kg/ha
Calcium (Ca)	36.0	kg/ha
Magnesium (Mg)	4.8	kg/ha

Through such activity, the nutrient balance can be improved and soil acidification counteracted – though only to a small degree. This example illustrates how low the amount of mobilizable phosphate content is and highlights the importance of phosphate fertilizers.

8.2 Mineral fertilizers – generating innovations

Analyses of the impact of mineral fertilization on smallholdings pose various challenges to current fertilizer products and practices. Alternatives are needed that make mineral fertilization more economically viable and ecologically compatible. Innovations are required mainly in the following three areas.

8.2.1 Rethinking the phosphorus supply

For many farms, phosphorus is the single-most yield-limiting nutrient. New solutions need to be found in order to overcome the, at times, acute shortage of phosphate in the agricultural sector and the finiteness of large phosphate deposits. The recycling of nutrients, plus alternative means of manufacturing fertilizer from local deposits, offer great and, as yet, untapped potential. Domestic waste and human faeces are valuable raw materials in terms of their nutritional elements (P, K and trace elements). Feeding them back to the agricultural industry via sewage sludge and urban compost is urgently needed, especially in the tropics, in order to restore nutrient cycles. For this to happen, however, the widespread challenge of separating heavy metals, residual pharmaceuticals and other chemicals from this waste must also be resolved.[114]

At the same time, van Straaten[115] points out that local phosphate deposits could be tapped far more than is currently done. Alternative technologies could be used in the small-scale production of phosphate fertilizers. Instead of using sulphuric acid to manufacture highly-soluble single and triple superphosphates, as occurs in large-scale production, partially solubilized rock phosphate could be used. The decisive factor here is how to solubilize low-soluble rock phosphate to make the phosphorus available to plants and to exploit its full fertilization potential. For example, mechanically crushing and powdering the rock would increase the surface area of the material and make it more soluble for acids. Adding ground phosphate to compost exposes it to humic acids and increases the amount of soluble phosphate in the compost.[116, 117] In addition, fostering specific microorganisms (*Mycorrhizae,*[118] *Aspergillus niger*[119]) can further optimize the organic solubilization of phosphate. Although partially solubilized phosphate rocks have lower phosphorus solubility, they can match or even outperform superphosphates in terms of their fertilization effect. The fertilization effect also lasts longer, and the risk of phosphate being fixed in the soil is lower.

Domestic waste and human faeces are valuable raw materials. Feeding them back to the soil via sewage sludge and urban compost is urgently needed

Significant benefits can also be derived from an economic and macroeconomic perspective. By opting for more cost-effective manufacturing processes and avoiding long transportation distances, phosphate fertilizers can be manufactured at far less cost, and dependency on the global market and exposure to price fluctuations can be reduced.

8.2.2 Moving from synthetic to organic nitrogen

The supply of nitrogen is another story and so needs to be assessed differently. Nitrogen can be supplied either biologically via microorganisms that bind atmospheric nitrogen, or as a mineral fertilizer. It is an undeniable fact that, as food production rises, so too does the need for nitrogen fertilization. What is not so clear-cut is whether an adequate nitrogen supply is possible only with synthetic mineral fertilizers. Badgley et al. (2006) counter that by applying biological nitrogen-fixation methods involving leguminous plants (forage crops, green manuring, agroforestry) as well as other techniques (*Azolla* in wet rice agriculture, etc.), more than enough nitrogen can be created – enough to fully replace the use of synthetic nitrogen for food production now and in the future. Table 8.5 provides an insight into the biological nitrogen-fixing potential, taking individual plants as examples. Some crops happen to produce nitrogen anyway, while other plants can easily be integrated into cropping systems in a way that does not compromise actual production.

Table 8.5
Annual organic nitrogen fixation by crops

Grain legumes	kg N/ha	Reference
Mung bean (green gram)	63–342	Nutman 1976
Cajanus cajan (pigeon pea)	168	Cited in Hamdi 1982
Soybean	64–206	Ayanaba and Dart 1977
Forage and green manuring plants		
Centrosema pubescens	126–395	Ayanaba and Dart 1977
Desmodium intortum	406	Whitney 1982
Leucaena leucocephala	74–548	Nutman 1976
Azolla pinnata (water fern in wet rice cultivation)	600–1,000	Hamdi 1982

A complete conversion from synthetic to organic nitrogen cannot be realized overnight, but the transition should begin as soon as possible. Extensive research and development in this field can be drawn on to develop cropping systems where biological nitrogen production does not compete with cropping.

8.2.3 Taking action against soil acidification

The first step that should be undertaken to counteract soil acidification is to completely dispense with mineral fertilizers with acidifying properties. This concerns the most common nitrogen fertilizers, notably ammonium nitrate, ammonium sulphate and urea. Replacing synthetic by organic nitrogen would eliminate the key source of soil acidification. During the transition phase, in which it will not be possible to fully dispense with synthetic nitrogen, alkaline nitrogen fertilizers such as calcium cyanamide, calcium ammonium nitrate and calcium nitrate should be deployed.

Replacing synthetic by organic nitrogen would eliminate the key source of soil acidification

At the same time, ways must be found to regenerate highly acidic soils through systematic liming. In-house calcium resources such as wood ash or the earth from termite mounds are valuable local resources but can usually only make a very small contribution. A more important step would be to inspect local rocks for limestone, check its quality and calculate the costs of making and transporting ground lime.[120]

Agroforestry, the integration of trees into cropping, is widely used in the tropics to maintain soil fertility, like on this farm in Vietnam.

9 Political demands

The nitrogen fertilization of today is jeopardizing the food security of tomorrow

The limits to growth are becoming increasingly apparent, especially in agriculture. There is hardly a better example of this finiteness than mineral fertilizer. Manufactured using large quantities of fossil fuels (mineral oil and natural gas) and relying in part on mineral deposits, the prices of mineral fertilizer have risen disproportionately as these resources become scarce.

Other limited resources are equally being wasted by mineral fertilizers. Synthetic nitrogen lowers soil fertility and reduces the impact of other fertilizers. The nitrogen fertilization of today is jeopardizing the food security of tomorrow. Both developments lead us to a dead end. Unviable fertilizer subsidies that eat up public funds will be unable to do anything to change this.

A change in mindset both towards a sustainable use of resources and production intensification is needed. In terms of nutrient use, fundamental changes are the order of the day. Decentralized and low-cost strategies that take care of the needs of smallholders are of key importance. The most important tasks facing policyholders today can be summarized as follows:

1 Synthetic nitrogen subsidies should be discontinued as a matter of principle. Instead, government or private subsidy programmes should be directed at building up soil fertility – as part of the infrastructure development of regions with degraded soil. This also includes incorporating organic nitrogen fixation into production systems through the cultivation of legumes.

2 Some of the most urgently required activities of a national "sustainable soil fertility infrastructure development" strategy include:

» Economic promotion aimed at tapping national phosphate and lime deposits; the build-up of production capacities and distribution systems for domestic mineral fertilizers.

» Economic promotion aimed at establishing urban composting facilities, which generate organic fertilizers for farms around cities, so enabling nutrients to flow back from urban to rural areas.

A change in mindset both towards a sustainable use of resources and production intensification is needed

» Supporting farms that produce seed and planting stock for nitrogen-binding plants in order to allow agricultural land-use systems to make the wide-scale conversion to biological nitrogen supply.

» Re-focusing agricultural advisory services in which agricultural specialists are trained in sustainable land management to enhance and preserve soil fertility, and are mandated to make these a focal point of their activities.

3 A new, significant area of work will also open up for agricultural research. Great emphasis will be placed on fundamental research as well as issues of applied research; existing technologies need to be further developed and optimized and adapted to local environments. Key areas that need to be addressed when it comes to introducing sustainable intensification of cropping systems include:

» Improving the quality of soil humus content and its humic acid composition by managing and controlling composting processes.

» Developing mechanical, chemical, microbiological and organic processes to solubilize phosphate rocks for small-scale mineral fertilizer production facilities as an alternative to the large-scale processes that use sulphuric acid to make superphosphate.

» Developing cropping systems which not only achieve high yields but also fix sufficient quantities of nitrogen so that the synthetic version can be dispensed with (leguminous underseed, mixed cultures, agroforestry systems).

» Optimizing composting processes for domestic urban waste and analysing the fertilizing impact of this material.

» Developing processes to recycle human faeces back into agricultural land use systems.

4 All in all, such a change in strategy towards sustainable intensification is the result of a longer-term process, because technologies need to be tested and further developed, and the conditions adapted. Only by doing so can a collapse in food production be averted. Realizing this requires the development of strategies and concepts of transition. Strong resistance is to be expected. After all, the outlined system change runs contrary to a number of corporate interests (including a powerful oligopoly of fertilizer companies) which make a pretty penny from the current system of publicly-funded mineral fertilizer.

Enabling mineral fertilizers to contribute meaningfully to food security requires a full and complete realignment of production, commerce and fertilization. Such a realignment has to make smallholder agriculture a focus. The results of this study show that the use of mineral fertilizers in the tropics and subtropics is only then justified if it is embedded in a concept that seeks to build up long-term soil fertility.

Two farmers in Tanzania admire pigeon pea in their field. Such legumes play a central role in increasing soil fertility. Best are fast-growing plants that generate large amounts of biomass in a short time and can fix considerable amounts of organic nitrogen.

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Endnotes

1 This chapter is based on Kotschi 2010
2 Dyson 1999a
3 Bellarby et al. 2008
4 Task Force on Hunger 2004
5 Nagayets 2005
6 ibid.
7 von Braun 2005
8 Nagayets 2005
9 Francis 1986
10 IAASTD 2008
11 Schmidtner and Dabbert 2009
12 Harris 2001
13 World Bank 1975, IAASTD 2008
14 Kotschi 2011
15 Scheffer-Schachtschabel 1970
16 LFL 2006
17 e.g. Van der Pol 1992, Stoorvogel & Smaling 1990 and 1998, Henao & Baanante 2006
18 Miller & Larson 1992
19 Bach & Frede 1998
20 von Witzke et al. 2011
21 Lin et al. 1996
22 Tan et al. 2005
23 Scheldick et al. 2002
24 Tan et al. 2005
25 Sanchez 1976
26 Nye & Greenland 1960, Sanchez 1976, Siband 1972
27 Berne Declaration 2011
28 Ariga et al. 2009
29 Liebig 1862, Liebscher 1895, Mitscherlich 1909
30 Mengel 1968
31 Dorward & Chirwa 2011; Gregory 2006; Minde et al. 2008; Odame & Muange 2011; Pan & Christiaensen 2011; Yawson et al. 2010
32 Dorward 2009; Wiggins 2010
33 Dalrymple 1975
34 Ellis 1992
35 IFDC 2003, Kherallah et al. 2002
36 Ellis 1992
37 Crawford et al. 2006
38 Donovan 2004, Gladwin et al. 2002
39 Morris et al. 2007
40 Fan et al. 2007
41 Predominantly funded by the Bill & Melinda Gates Foundation, the Rockefeller Foundation and the UK Department for International Development
42 Mössinger 2012
43 Denning et al. 2009; Minde et al. 2008; Odame & Muange 2011
44 Poulton et al. 2006
45 Dorward & Chirwa 2011
46 Banful 2009; Minde et al. 2008; Odame & Muange 2011
47 Dorward & Chirwa 2011

48 Banful 2009
49 Morris et al. 2007
50 Pan & Christiaensen 2011
51 Banful 2009; International Center for Soil Fertility and Agricultural Development 2005; Minde et al. 2008; Odame & Muange 2011)
52 Donovan 2004, Kherallah 2002
53 SOAS et al. 2008
54 Fan et al. 2007
55 MoFA 2012
56 Odame & Muange 2011
57 Dorward & Chirwa 2011
58 Mogues et al. 2008
59 Minot et al. 2009; Pan & Christiaensen 2011
60 Bigsten & Tengstam 2008
61 Morris et al. 2007
62 e.g. Adesina 1996, Marenya & Barret 2007, Townsend 1999, Voortmann et al. 2000, Weight & Kelly 1999
63 The fertilizer index (calculated by the author) is a weighted average of the annual prices for urea (weighting: 63.9 %), triple superphosphate (20 %) and potassium (16.1 %). The weighting was calculated on the basis of the respective average share of the three components in worldwide production. The worldwide production data comes from the International Fertilizer Industry Association.
64 The World Bank's Food Price Index calculates a goods price index for countries with low and middle incomes. The index comprises three components: fats and oils, cereals and other food products (meat, sugar, etc.). It is index-linked to 2005 and the weighting of the components was determined on the value of exports between 2002 and 2004.
65 Dorward & Polton 2008, Pender 2009 and Lines 2013
66 Yanggen et al. 1998, Guo et al. 2008
67 Ariga et al. 2009
68 Chemonics & IFDC 2007
69 Sanchez 2002
70 Gregory and Bump 2005, Kelly 2007
71 Crawford et al. 2005
72 Meertens 2005
73 CIMMYT 1988, Guo et al. 2008
74 Morris et al. 2007
75 Ariga et al. 2008
76 ibid.
77 Adesina 1996
78 "Peak phosphorus" is the point in time when the maximum level of phosphorus mining is reached. Use will decline after this time due to a drop in supplies.
79 IFADATA 2010
80 The acidity index indicates the quantity of lime (kg $CaCO_3$) required to neutralize 1 kg of physiologically acidic mineral fertilizer.
81 Guo et al. 2010
82 Miao et al. 2010
83 Guo et al. 2010
84 Khan et al. 2007, Mulvaney 2010
85 Khan et al. 2007
86 Mulvaney 2010
87 Cited in Khan 2007
88 Tilman et al. 2002, Raun & Schepers 2008

89 Raun & Johnson 1999 und Ladha et al. 2005
90 Smith et al. 2007, Rogner et al. 2007
91 Bellarby et al. 2007
92 Wegner & Theuvsen 2010
93 Kongshaug 1998
94 Rockström et al. 2009
95 Sanchez 1997
96 Steiner 1924
97 Depicted e.g. in Müller-Sämann & Kotschi 1994.
98 Pretty and Hine 2001, Parrot and Marsden 2002
99 Kotschi 2011
100 Abdullahi 1971, Rodel et al. 1980
101 Martius et al. 2001, Manna et al. 2007, Gatsi and Muzari 2010
102 Agboola et al. 1975, Godefroy 1979, Prasad and Singh 1980
103 Bache & Heathcote 1969
104 Huerta et al. 2010
105 Sharma et a. 2008, Singh 2011
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108 Singh 2005, Tharmaraj et al. 2011
109 Reinhold 2008
110 Bachinger 1996, Raupp 2001
111 Cited in Webster & Wilson 1980
112 Rodriguez 1972
113 Kotschi et al. 1991
114 Simon et al. 2009
115 van Straaten 2006
116 Singh & Amberger 1998
117 Odongo et al. 2007
118 Blum et al. 2002, Hagerberg et al. 2003
119 Arcand & Schneider 2006, van Straaten 2011
120 van Straaten 2002

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