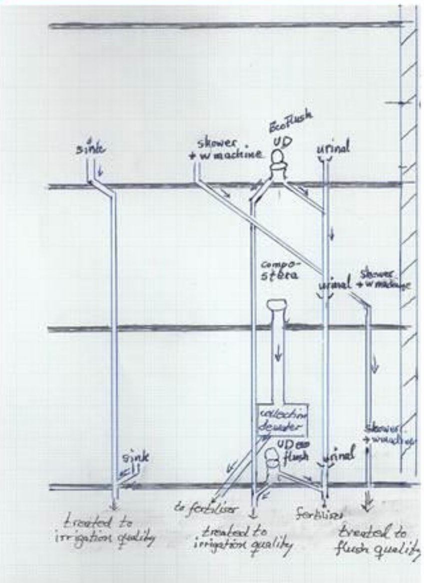
Ch. 5. Applications – sanitation in practice



Segregation of various liquid flows from household

Pupils prepare a meal with produce from school garden

Campaign in India to request bridegrooms to provide a toilet

Spreading chemical fertilizers in a field

The previous chapters and modules in the training material have dwelled on broad issues such as health, management and treatment methods. Remains more topical cross-cutting issues such as food production as part of nutrient loops, school sanitation, public toilets and toilet technologies.

In the wake of global resources boundaries, nutrients for agriculture has come to the fore. Module 5.1 deals with this important issue and applies recycling concepts on recycling of biowaste from utban areas back to agriculture as fertilisers and soil conditioners.

The issue of public toilets poses a challenge to all societies and communities, rich and poor. New planning and management tools are emerging which can enhance the provision and use of public toilets. The same goes for school sanitation. Module 5.3 develops the recycling idea to a local loop for nutrients back to food production and pupils preparing meals from school garden produce.

The last few decades have witnessed a proliferation of toilet designs and functions. Of late, large projects have been launched to address this issue and Japan has gone in the direction of fancy designs with focus on mechanizing wiping/washing the bottom. Gushing of leansing water and drying of bottom with warm air is part of this development. Others focus on reuse of nutrients in excreta and on improving basic hygiene and comfort.

This chapter comprises the following Modules:

5.1 Phosphorus- Food security &food for thought

5.2 Public "*away from home*" toilets

5.3 School toilets

5.4 Toilets and toilet systems

5.1 Phosphorus and food security i

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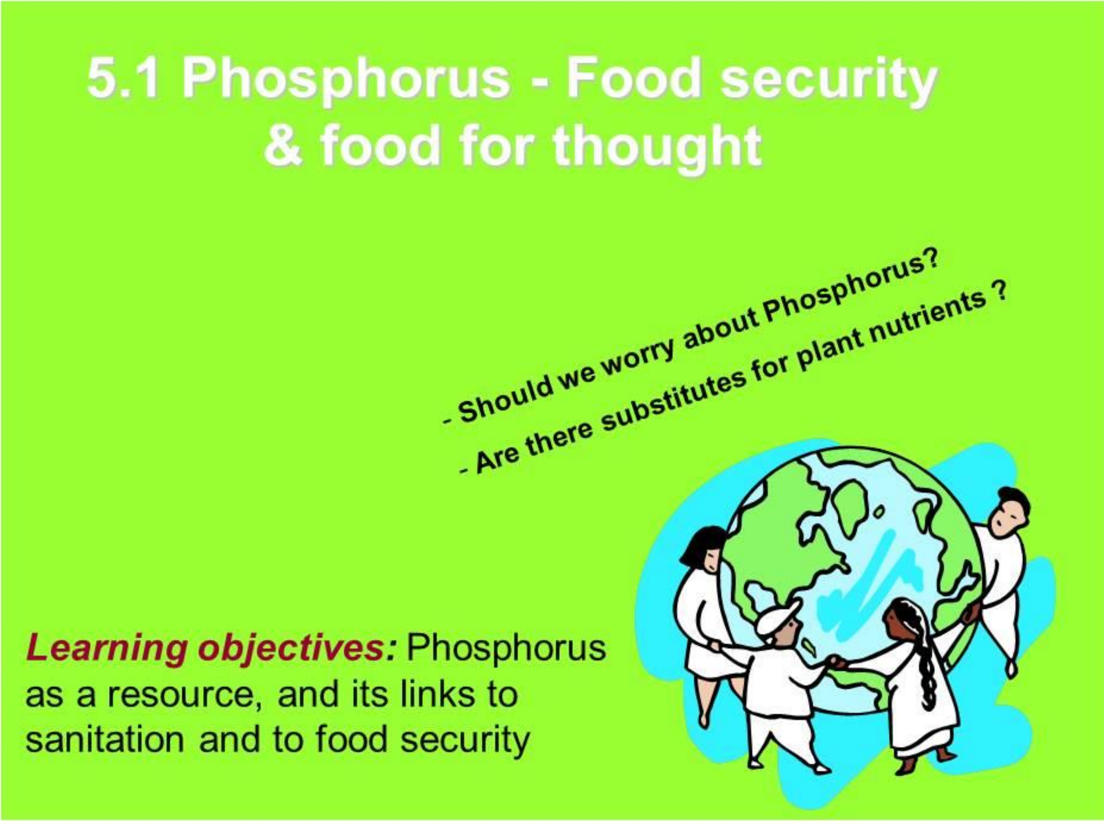


There are more than seven billion people on earth, and so our combined daily activities have a significant impact on the world's limited resources. If, for example, many people acquire and drive cars, oil reserves will eventually become scarce. As we continue to pump large amounts of groundwater for irrigation water tables recede. If we harvest too many fish from the oceans, fish stocks dwindle. The same applies for nutrients – if we all use mineral fertilizers to grow crops, the source of those fertilizers may become scarce. Further, if most humans move to cities where organic waste (such as excreta and food waste) is no longer returned to agricultural soils, we will face a shortage of nutrients (fertilizer) for crop production sooner rather than later.

This module focuses on a particularly important nutrient, phosphorus, or P for short. P is an essential mineral building block for all living organisms, including plants, animals and humans. Therefore, the future availability of P is as critical as energy and water resources for meeting the food demands of a growing global population. Up to now, global environmental challenges related to phosphorus have typically been associated with water pollution and eutrophication. Today we are on the brink of a new global understanding: phosphorus scarcity and the serious threat that this poses to future food security (Cordell, Drangert & White, 2009a; Foley et al., 2011; FAO, 2013).

This module outlines the challenge of increasing global scarcity of high quality and easily accessible phosphate rock. The module first discusses the important characteristics of phosphorus, its role in food production in the past, at present and in the future, including how humanity became dependent on phosphate rock. The increasing political power of countries controlling the world's phosphate rock reserves is highlighted. A simplified substance flow analysis and future scenarios analysis helps to identify potential measures and strategies to secure enough mineral and recoverable phosphorus for food for present and future generations in accordance with the solid waste hierarchy (slide 5.1-13).

The good news is that a crisis due to phosphorus scarcity can be avoided with a concerted effort by the world community. Since P cannot be destroyed there will not be a scarcity unless P is managed in a wasteful manner and is disposed of in places where it is difficult to access.
A world with an increasing population and growing per capita demand will require innovative strategies to use resources more efficiently and ensure their recovery and re-use. Recovery of resources also reduces pollution. Re-use and recycling are particularly critical for resources for which there is no substitute, such as phosphorus and water. Strategies to recover and re-use phosphorus from human excreta, food waste and animal waste are likely to provide a major source of phosphorus in the near future.

Urbanisation, sewered sanitation and global trade affected the flow of phosphorus in the 20th century. In the past, most people lived in rural areas where phosphorus was typically returned to soil in a closed loop (Drangert, 1998). Today, however, agricultural products are transported long distances to feed consumers in cities and in other countries. The organic 'wastes' generated from food consumption (mainly food waste and excreta), therefore, end up far away from where the plants they came from grew. Also, fertilizers are shipped around the world since the phosphate rock is only being mined in a few countries. The average distance a phosphorus molecule moves in the food system from source (such as a mine) to sink (such as lakes or oceans) has thus increased dramatically since the mid-20th century.

If all phosphorus were used efficiently in food production and recycled after use, much less additional phosphate rock would be required and phosphate rock scarcity would be of little concern. However, achieving this will require substantial changes to the way we think about and manage our resources and design our infrastructure and material flows (Module 2.1). Today there is a scarcity of good management of phosphorus resources rather than simply a physical scarcity of rock phosphate. If this is borne in mind, institutional and other constraints can be approached with a better understanding. The European Commission advocates a global strategy for the nutrients NPK (Malingreau, Hugh, and Albino, 2012).

Large-scale application of chemical fertilizers since the 1950s has allowed food production to parallel the rapid population increase. Yields have increased dramatically over this period together with efficiency of phosphorus usage as seen in the table below:

Table: Increases in yield of winter wheat and phosphorus removal between 1862 – 1992

Period	Yield grain (t/ha)	Phosphorus off-take in grain plus straw (kg P_2O_5/ha)
1852 - 1871	2.70	25
1966 – 1 967	3.07	34
1970 - 1975	5.48	50
1991 - 1992	8.69	71

Source: EFMA Phosphorus essential element for food production (2000)

It is noteworthy that little was gained in the 100 years between mid-19th and mid-20th century, and a jump takes place in the second half of the 20th century. This is a reflection of the Green Revolution with irrigation, chemical fertilizers and new improved crop varieties.
In consequence, the off-take of phosphorus in grain plus straw has also increased. The same is true for all other crop nutrients. If soil fertility is not to go down the increased off-take of each nutrient must be matched by corresponding inputs of fertilizers and/or manure. Without mineral fertilizers, agricultural yields around the world would drop by between 30 and 85 per cent (EFMA, 2000b).

5.1 - 3

A global view can illustrate the human impact on the globe and the earth's responses. From a satellite, the globe looks blue, green, and generally hospitable in the daytime (left picture). However, the collective impacts of all our individual activities can be more readily seen and understood by looking at the globe in night-time (right). At night, large parts of the globe are illuminated by street, building and house lights. We can no longer tell ourselves that 'what I do has no effect on the globe', because the combined effect of what everyone does '*lit the globe*'. In addition, the emissions from the energy sources required to produce all this light have a great impact on the thin layer of atmosphere surrounding the globe – causing global warming.

A recent estimate by McMichael *et al*. (2007) tells us that 35% of global greenhouse gas emissions come from agriculture and land use. Livestock production alone accounts for about 18% of global greenhouse gas emissions. Livestock-related emissions are caused by: de-forestation to clear land for grazing and soya-feed production; soil carbon loss in grazing lands; the energy used in growing feed-grains and in processing and transporting grains and meat; nitrous oxide releases from the nitrogenous fertilizers; gases from animal manure (especially methane); and enteric fermentation. The greenhouse gases from these sources make up an estimated 9% of global emissions of carbon dioxide, 35–40% of methane emissions, and 65% of nitrous oxide emissions. Although they have shorter half-lives in the atmosphere, the near-term warming potential of methane and nitrous oxide is much greater per unit of volume than that of carbon dioxide.

There is little doubt today that the earth is experiencing unprecedented global environmental changes due to human activity – from climate change, widespread eutrophication, deforestation, loss of biodiversity, water scarcity and more (WWF, 2004; Wijkman and Rockström, 2012). Human impact has increased dramatically in the last 50 years, driven mainly by rapid population growth, and even faster increases in the production of goods. We now begin to comprehend that the hydrosphere, biosphere, lithosphere, and atmosphere are directly or indirectly interlinked and that the impact of human activity on one component can have far-reaching effects on the others. We adversely affect the very same components that we depend on. Without vital 'ecosystem services', human society could not exist – it would have no energy, no clean water and no food (slide 1.1-15–16). The following presentation deals with the global impacts of phosphorus usage on food security. Sustainable sanitation is highlighted as one way to ease P scarcity problems.

Water and phosphorus for food security

5.1 - 4

- Water molecules can be made by using a lot of energy
- Water is renewable (sun-driven cycle)
- Water is available in soil and replenished annually by rain
- 70% of global water use is for crop production
- A balanced diet results in the **loan** of 1300 m³/yr to each person on the planet based on current practice. This is 70 times greater than the 50 l/d per person for basic water needs.

- Phosphorus (P) cannot be manufactured or destroyed
- P is essentially immobile and is mined in only a few countries
- P is naturally available in soil and depleted by crops
- 90% of global P extraction is for crop production
- A balanced diet results in the **depletion** of 22.5 kg/yr of phosphate rock (=3.2 kg/yr of P) per person based on current practice. 0.5 kg of this reaches the average person's food.

Source: Cordell, Drangert & White (2009a)

Both are critical to food production, but need to be managed differently

The water molecule (H_2O) and phosphorus-containing molecule (P_2O_5) are vital for food production. The table above compares and contrasts them, and shows that while many similarities exist, the contrasting circulation properties of phosphorus and water mean that they require different approaches to manage them sustainably.

Elemental phosphorus (P) cannot be manufacture or destroyed, while the water molecule requires lots of energy to be formed. The two are similar in that humans can alter their location and affect their quality as they cycle naturally or anthropogenically on earth (see slide 1.2-3). Another common feature is that neither water nor phosphorus can be substituted in plant production. Plants require water to circulate nutrients and for photochemical processes to build cells, while phosphorus is required to build cells and enzymes, and to form fruits and seeds. Hence, deficiencies in plant-available phosphorus and water can severely reduce crop yields and fruit/seed development. An average human body contains about 650 grams of phosphorus. Most of this P is in our bones and teeth, and the rest is found in our DNA, cellular membranes and the molecule adenosine triphosphate, or ATP, which the body uses to process energy. We need an intake of 1 gram of P every day to maintain our body functions.

Soils naturally contain water and phosphorus to varying degrees and, depending on the form it takes, this P may be accessible to plants (P_2O_5). Water and phosphorus-containing molecules differ when it comes to their natural cycles and mobility in the soil and the atmosphere. The sun drives the water cycle and makes water a renewable resource which is partly cleaned through soil filtration and through evaporation and condensation. While water is renewable, the rain may not appear when and where farmers would prefer. Therefore, crops are increasingly irrigated by surface water or groundwater.

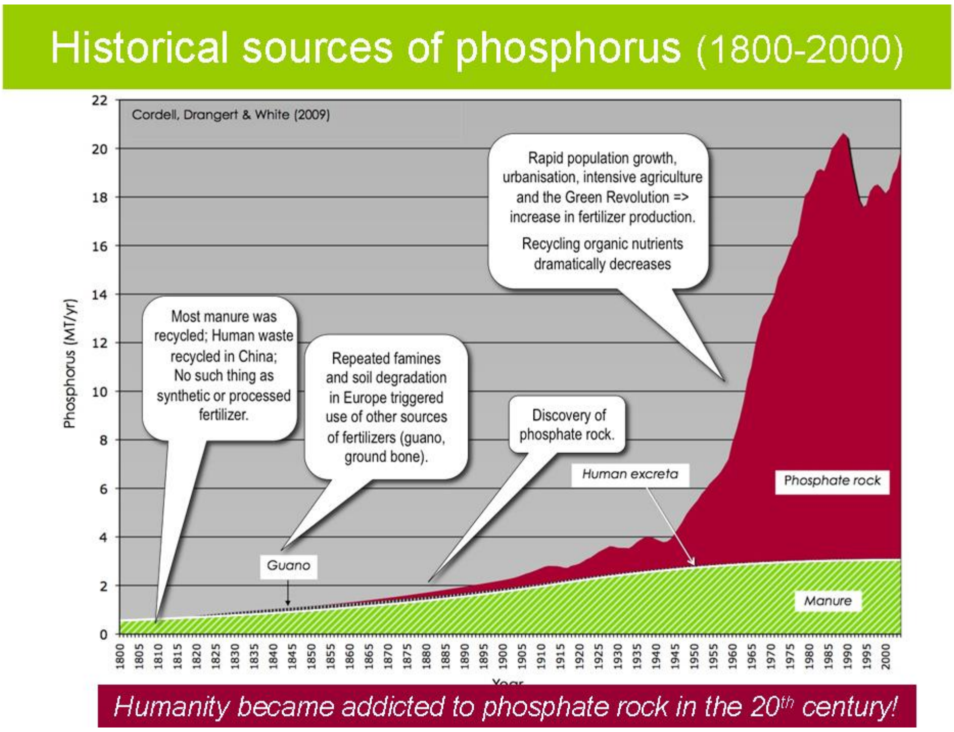
Unlike the water cycle, the phosphorus cycle has essentially no atmospheric phase and only cycles between the lithosphere, biosphere and surface and groundwater. It is practically immobile in soils unless washed away by stormwater or transported by groundwater flow.
In the biosphere P can stay in one place for periods which range from one day to many years.

Phosphorus in mineral fertilizers comes from phosphate rock (PO_4), which is a non-renewable geological resource that has taken around 10 million years to form. Rock phosphate is made from the remains of aquatic life on the bed of the sea and tectonic uplift has moved it onto land (White, 2000). The phosphorus in soils originates from long-term weathering and erosion of the parent rock. The mineral, through further weathering and runoff, makes its way into the ocean, where marine organisms may recycle it some 800 times before it passes into sediments (Vaccari, 2009). After tens of millions of years of tectonic uplift it may return to dry land.

The major human use of both water and phosphorus is in agriculture. Seventy per cent of the water used by humans goes to agriculture while the remainder is used for household and industrial activities (see slide 1.2-5). Based on current practice it is estimated that the agricultural sector will need to double the amount of water it uses, to feed humanity in 2025. However, this quantity of water is not available and thus innovative strategies to achieve 'more nutrition per drop' will be required (SIWI-IWMI, 2004). Similarly, almost all (90 %) of mined phosphate rock is for food production, mainly as fertilizer, animal feed and food supplements. The remainder is used in detergents and industrial applications. It is estimated that the agricultural sector's need for phosphate rock will increase by at least 50% by 2025 compared to the mid-90s (slide 5.1-12). The same goes for other essential macro-nutrients, e.g. nitrogen and potassium. Plants take up the nutrients via their roots, and once plants are harvested, the phosphorus leaves the topsoil for good – unless it is returned as fertilizer or organic waste. The easily accessible non-renewable phosphate rock reserves are likely to be near depletion in 100 or 200 years as for affordable mining and processing (slide 5.1-10). Meanwhile, demand continues to increase.

An important difference between phosphorus and water use is that the water is returned to the water cycle (**renewable**) whereas the phosphorus from mined phosphate rock is usually immobilised in the sediments of rivers, lakes and oceans (or in landfills) and will take millions of years to cycle naturally back to agricultural soil (**non-renewable**). Therefore, different strategies are needed for sustainable use of these two resources. Water used by humans is essentially a 'loan' from nature's hydrological cycle. While the used water may not return to the same water catchment when it falls again as precipitation, it will reappear sooner or later through the water cycle. On average, a person requires some 1300 m^3/yr of water to produce her food, and this water can come in the form of rain or irrigation (SIWI-IWMI, 2004). Phosphorus fertilizer, on the other hand, is mined - but may soon be recycled also from urban hotspots. A balanced diet requires mining approx. 22.5 kg of phosphate rock (PO_4) per person per year. This rock is converted to 3.2 kg of elemental P. About 0.5 kg of this phosphorus is contained in the food we eat and excrete during one year (slide 5.1-15).

5.1 - 5



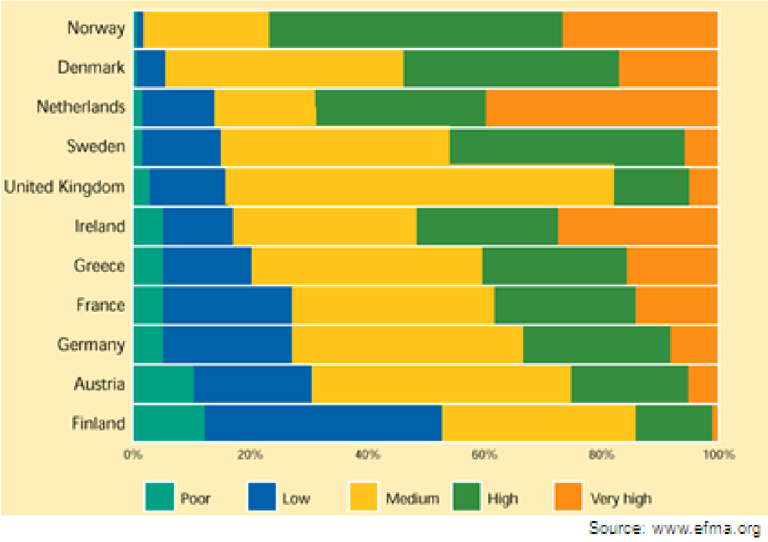
The graph shows the world’s usage of phosphorus fertilizers over the past 200 years, comprising manure, human excreta, guano and phosphate rock (in million tonnes of P per year). The graph displays vividly the world’s growing dependency on phosphate rock (dark red) over the past 60 years, since the Green Revolution in the 1950s.

Historically, crop production relied on natural levels of soil phosphorus, which comes from erosion of bedrock, with the addition of organic matter like crop residues and manure (shaded green) and, in parts of Asia and Europe, human excreta (‘night soil’). Repeated famines and gradual soil exhaustion in Europe triggered the search for other sources of fertilizers, such as ground bone and guano (bird and bat droppings). Island caves and land rich in guano were mined off the Peruvian coast and in the Pacific Islands. However, the obviously limited supply of high quality guano was depleted within decades and other sources of phosphorus were again sought. Already in 1840 the chemist Liebig had discovered that phosphorus deficiency limits plant growth. But, phosphate rock was not mined before the late 19th century. The first half of 20th century saw moderate use of phosphate-based fertilizers, and crop yields increased somewhat. There were still recurrent famines in many countries. The launch of the Green Revolution in the 1950s with large-scale irrigation farming using new varieties of rice and the application of chemical fertilizers improved yields tremendously (IFPRI, 2002; slide 5.1-1). Phosphate rock mining expanded rapidly to keep up with increased P demand due to rapid population growth and urbanisation (Smil, 2000b). Famines due to natural causes were substantially reduced and food security improved.

Thus, a dependence on phosphate rock for food production was established globally. By 1990 the demand and production of phosphate rock and mineral fertilizers dropped somewhat, due to a number of factors. One was an increasing awareness in Europe and the US that over-fertilisation was leading to phosphorus leakage causing algal bloom in lakes and estuarine waters. Another was that the Soviet Union collapsed, resulting in a sudden reduction in the phosphate demand from a previously high fertilizer-consuming region. While demand has receded in the developed world, the rising demand in developing and emerging economies has resulted in an overall increase in the global demand for phosphorus fertilizers. This has occurred despite many poor farmers not gaining access to world phosphate fertilizer markets (Cordell et al., 2009a).

Phosphor status of soils in Europe

5.1 - 6



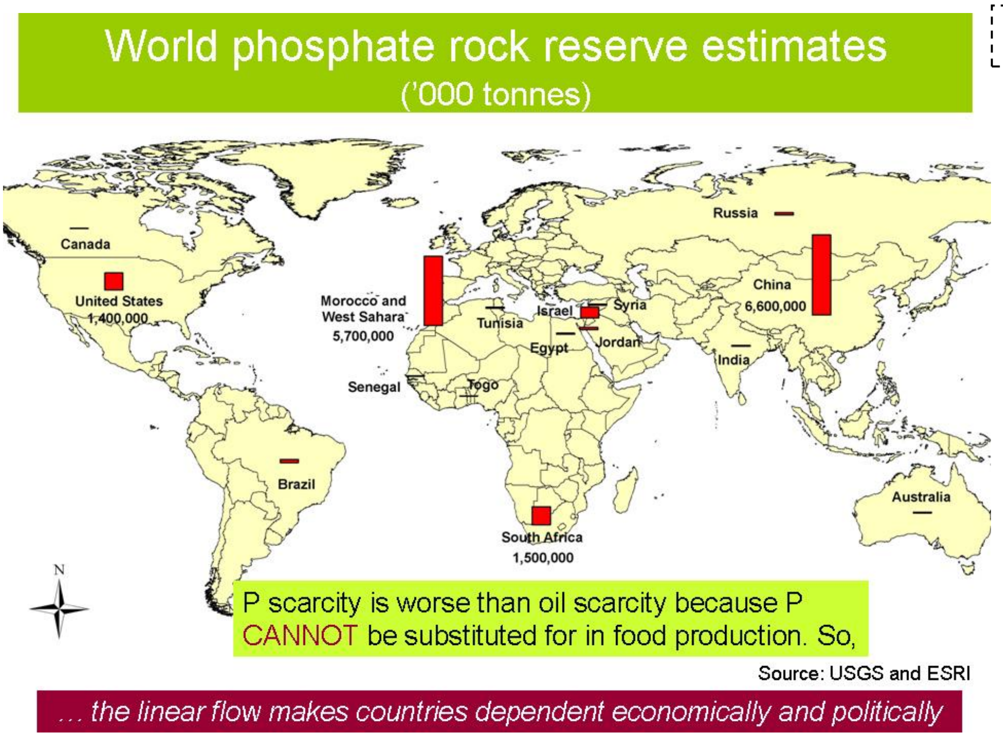
Phosphorus is one of the most common minerals on Earth, but often in low concentrations. The P availability in soils in eleven EU countries is given in the diagram above. A striking impression is that the P status differs quite a lot. For instance, half of the Finnish soils are poor in P, while the P content in the Netherlands is very high in half of the soils. The latter is explained by the fact that Dutch farmers operate large pig farms and have applied huge amounts of manure for many years, while they import the feed from other countries.

In many countries some 25% (5-55%) of soils are very low or low in readily available soil phosphorus. Such soils require application of significantly more phosphorus than is removed by the crop to increase soil reserves and thus soil fertility. Soils with medium phosphorus test values may require a small extra amount of phosphorus over and above that removed in the harvested crop. For many countries some 40% (15-70%) of soils are high or very high in readily available phosphorus. When crops with small, inefficient root systems and a large daily intake of phosphorus at critical growth stages, are grown on such soils it may be necessary to apply more phosphorus on such occasions (EFMA, 2000b). Farmers increasingly take these differences in P availability into account now that the price of P is increasing. They try to strike a balance between application of P and the anticipated yield (slide 5.1-20).

It is well known that African soils are poor in P due to naturally poor parent rocks, or the phosphorus is not readily available to plants because iron oxides (common in African soils) hold the P too tightly. Unsustainable cropping practices further reduce soil P, so that the amount removed through harvesting crops, soil erosion and other factors, exceeds the amounts put in through fertilizers. The Africa Soil Information Service started a project in 2008 to monitor and map changes in soil phosphorus across Sub-Saharan Africa to be able to make suggestions for improving levels of the mineral in the soil. The advocated integrated soil fertility management measures relate to fertilizer application rates, soil organic matter management, use of legumes, and tillage operations in cropping systems. So far, they do not suggest adding human urine (pH>9) to the soil despite that it could raise its pH-level which in turn will weaken the bond of P to iron and magnesium ions and make more P available to the plants (slide 4.6-21). Moreover, socio-economic factors need to be taken into consideration as well (see Module 2.4).

In this module we focus on P but much of the conclusions apply also to other macro nutrients. A deficiency of any nutrient is not only, in itself, detrimental to the plant, but it also affects the plant´s ability to use the other nutrients effectively.

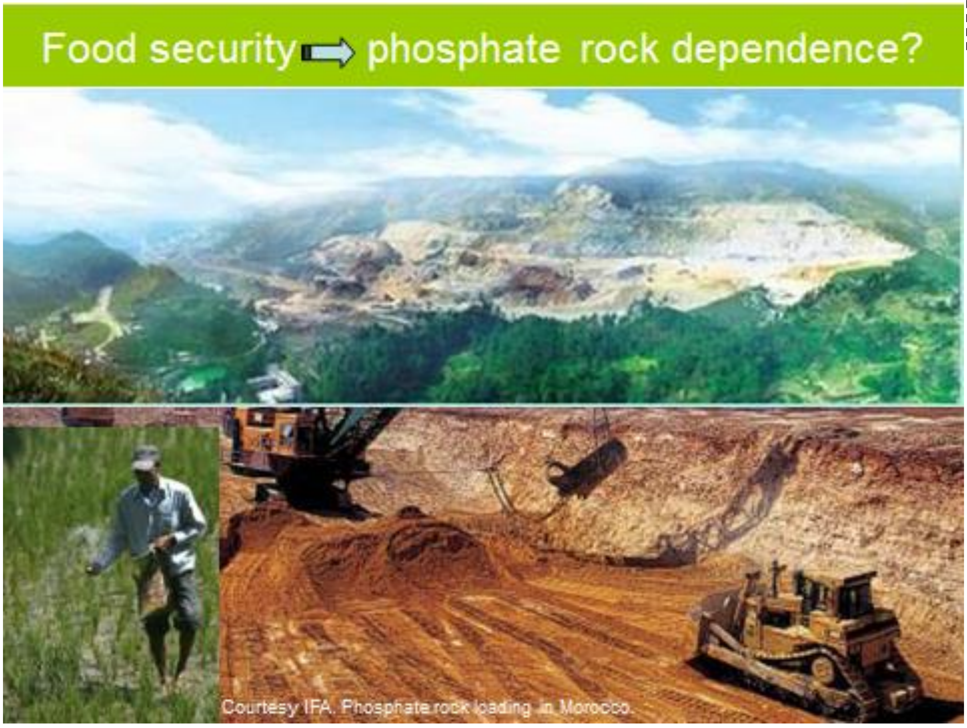
5.1 - 7



While all farmers need access to phosphorus fertilizers, just six countries, China, South Africa, Morocco with its occupied Western Sahara, the US and Jordan are endowed with 90 % of the world's reserves and account for more than two thirds of annual production (Vaccari, 2009). In October 2010, the International Fertilizer Development Centre (associated with the industry) issued new estimates for Morocco and Western Sahara P reserves, claiming the reserves to be ten times bigger (IFDC, 2010). This uneven geographical distribution of phosphate rock resources should concern countries that rely on imports of mineral fertilizers for food production. Imagine if all the world's freshwater resources were controlled by just a handful of countries – national leaders would be much more concerned with securing water from alternative sources to avoid such dependence on imports. Other important global resources subject to geographical concentration, such as oil, can be substituted by other forms of energy, such as hydropower, natural and biogas, nuclear power, wind power, water-current power, or biofuels. However, there is no substitute for plant nutrients such as phosphorus, nitrogen, potash, and sulphur. Yet, up to now there are no widespread political discussions about phosphate rock dependency.

In 2006, China surpassed the United States as the world's leading producer of phosphate rock and China produces 30.7 Mt (million tonnes), the United States 30.1 Mt, and Morocco/Western Sahara 27.0 Mt (USGS, 2008). U.S. marketable phosphate rock production and reported usage dropped to their lowest point since 1965. However, the United States remained the world's leading consumer and importer of phosphate rock and also the leading producer and supplied about 37% of the world P_2O_5 exports. Most of the phosphate shipments from Morocco/West Sahara were used by three phosphoric acid producers located in the US along the Gulf of Mexico (USGS, 2007). This is geopolitically sensitive as Morocco currently occupies Western Sahara in violation of international law and controls its vast phosphate rock reserves. Trading with Moroccan authorities for Western Sahara's phosphate rock is condemned by the UN, and importing phosphate rock via Morocco has been boycotted by several Scandinavian firms due to corporate social responsibility (Hagen, 2008). Western Sahara's P reserve is, in per capita terms, infinitely bigger than the reserves of any other country. However, the world community has not been able to ensure that the people of Western Sahara gain their rightful income from this resource. Instead, a portion of the population is in refugee camps.

5.1 - 8



The first step in making a fertilizer is to grind the mined phosphate rock. The next step is adding sulphuric acid (H_2SO_4) to extract the phosphorus as phosphoric acid H_3PO_4 through heating. This has been the conventional method for much of the 20th century and is still being widely used for high-purity phosphoric acid (EFMA, 2000a). Presently some 50-70 % of the phosphorus in the rock is extracted, and technical development could increase this proportion (Villalba et al., 2008). Typically, each tonne of phosphate (P_2O_5) produced from phosphate rock generates 4-5 tonnes of hazardous phosphogypsum waste (11.5 tonnes per tonne P), which must be stockpiled because its radioactivity levels are considered too high for use. Global phosphogypsum stock-piles are growing by over 110 million tonnes each year. Workers, as well as ecosystems, can be seriously affected and the local groundwater is likely to be contaminated (Wissa, 2003).

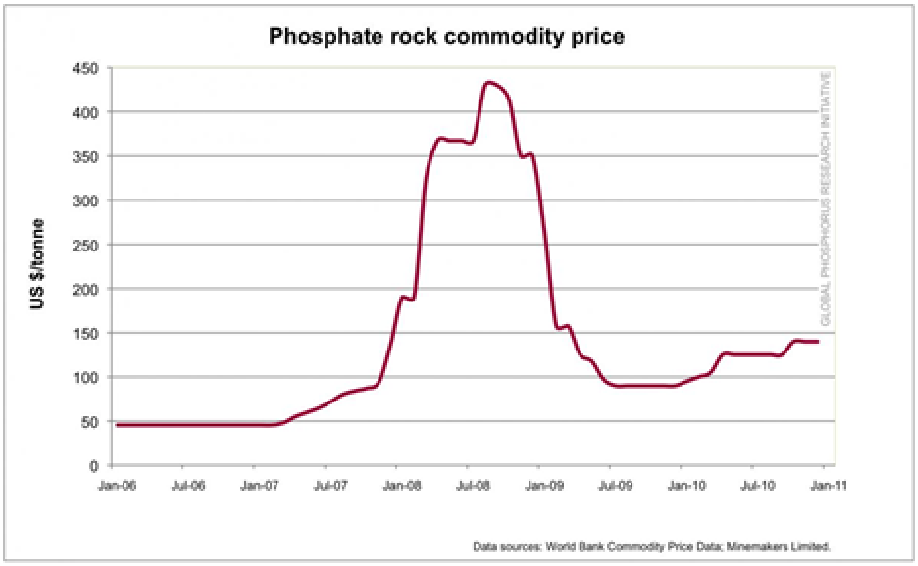
Worldwide, there has been a gradual shift to manufacture high-purity phosphoric acid from a wet-process using chloric acid. This process has lower operating costs than the older thermal process which required large amounts of energy. The wet process actually produces energy. It also discharges less rest product such as phosphogypsum, and contains low levels of uranium, and the sulphuric acid can be reused in the process. The sulphuric acid process has a further advantage being able to use rather low concentration of P_2O_5 (range 25 – 28%), whereas other processes may require 31.5 %. In any case, the phosphoric acid requires further concentration (beneficiation) to provide a good fertilizer. A typical P_2O_5 content ranges between 50-60% of the fertilizer.

Depending on the final use of the phosphorus, the quality grading descends from electric batteries, to food and pharmaceuticals, via animal feed to fertilizers. Fertilizer still dominate the market (some 88%), and the slump for P in detergents has been compensated for by increased usage in animal feed (1.5%) and food additives (OCP, 2009).

New phosphoric acid and fertilizer plants have been built in Brazil, China, Morocco, and Saudi Arabia. OCP also has joint ventures with direct investment by Indian, Pakistani and Brazilian manufacturers who produce their fertilizers at adjacent plants at Jorf Lasfar in Morocco (OCP, 2009).

Access to phosphate markets

5.1 - 9



Future fertilizer price spikes are also possible

Farmers around the world demand 17 million tonnes of phosphorus to fertilise their crops each year. The cost of phosphorus alone represents nearly 30 per cent of farmers´ budget (SPI, 2010). While the quantity and quality of existing high-grade phosphate rock reserves are decreasing, the cost of extracting this resource is increasing. Economic theory of demand and supply predicts an increase in the market price. The graph above shows that in 2008 the world had a first wake-up call when the price of phosphate rock rose dramatically from about US$50 to US$430 per tonne – an 800% increase from previous years (World Bank, 2011).

Analysts indicated the price spike was due to a number of global demand-side factors, including the rising demand for food, increasing trends towards more meat-based diets (particularly in emerging economies such as China and India), and the expansion of the biofuel industry (biofuel crops compete with food crops for fertilizers). Farmers were also holding off purchasing fertilizers, in the hope that prices would come down, and this further reduced the price (Heffer and Prud'homme, 2009).

On the supply side, the International Fertilizer Industry Association suggested the price rise was partly due to an under-investment in new capacity which created a short-term scarcity. Also, unfavourable exchange rates (resulting in the value of the US dollar pushing up quoted prices) contributed to the price spike (IFA, 2008). China imposed a 135% export tariff on phosphate in 2008 to secure domestic supply for food production, which essentially stopped exports overnight (Fertilizer Week, 2008). This step is thought to have exacerbated the 2008 phosphate price spike.

The global financial crisis late in 2008 led many commodity prices, including phosphate prices, to crash (graph). However, the graph shows that prices stabilised at a level three times as high as before the spike.

The fertilizer market is characterised by mergers and acquisitions. Canada refused to sell out its Potash Corp to US bidders in a move to stabilise the fertilizer market. Investments are presently made to increase production. The Moroccan phosphate group "Office Chérifien des Phosphates" (OCP) is the world's number one exporter of phosphate rock and phosphoric acid and one of the major exporters of phosphate fertilizers. OCP embarked 2010 on a major investment programme to triple its production capacity by 2020 from the current 3 million tons per year to more than 9 million tons, making Morocco by far the largest supplier of phosphate rock, phosphoric acid and DAP/ADP (OCP, 2009). OCP already controls around 45 per cent of the world market for lime phosphate, and controls more than 30 per cent of global phosphate exports. It operates three mines and exports around 15 million tons of phosphate rock to markets in Asia, Australia, Europe and the United States. The remaining phosphate is transferred to the company's chemical complex in Jorf Lasfar.

The OCP program also aims to increase the mining capacity from 30 to 50 MT/year, the beneficiation (more concentrated P) capacity gradually from 9 to 38 million tons a year, and expand the port facility at Jorf Lasfar to handle up to 35 million tons of products. Also, in 2013 a new 187 km slurry pipeline replaced the inefficient train transport.

The OCP's CEO explained that "this major investment in increasing our capacity is a prudent response to long-term market trends, and a strong sign of OCP's commitment to do its part to assure stable, reliable supply of this vital resource to global markets." (OCP, 2009). He continued saying that global phosphate demand is projected to grow steadily in coming years, due to the combined pressures of population growth, changing diets among a growing middle class, and the urgent need to improve agricultural yields in developing countries, particularly in Africa, and thereby combat hunger.

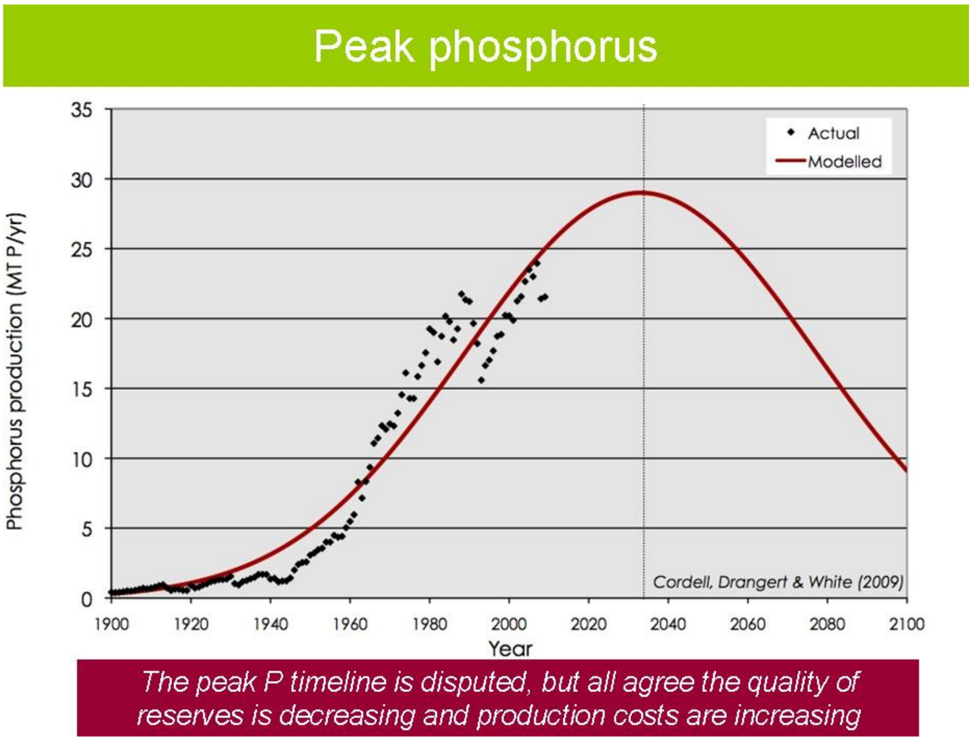
OCP officials and foreign traders hold contradictory views and the latter maintain that the Moroccan company OCP has used its market clout to boost global phosphate prices (Reuters, 2010). Unlike many commodities whose price is determined on a futures exchange, phosphate transactions are mostly negotiated directly between producers and industrial users. According to some sources, the monopoly that IFDC and the US are trying to create in Morocco will give the US considerable control over the global price of this commodity (Rognlien, 2010).

OCP has faced criticism from some foreign civil society groups over its operations in Western Sahara, an area about the size of Britain that was annexed by Morocco in 1975 in violation of international law and is the subject of Africa's longest-running territorial conflict. Critics say the firm should not be exploiting Western Sahara's mineral resources until the sovereignty issue is settled. The CEO of OCP said his company was not in Western Sahara to pursue profits. Company officials say the territory has less than 2 per cent of Morocco's phosphate reserves, and that between 1976 and 2008 the firm made net losses there of about $580 million.

The lack of reliable global phosphorus statistics and analysis prevents farmers, policy makers and urban planners from making informed decisions. Unlike many other mineral commodities, no standard domestic or world price for phosphate rock exists. Average ranges of world prices are published in World Bank Commodity Price pink sheets (e.g. World Bank, 2011) and various industry trade journals (such as Fertilizer Week) are based on a sample of transactions. But the US Census Bureau withholds tonnage and value information for some phosphate rock and fertilizer product shipments, which necessitates the use of other sources of data.

The fertilizer companies that mine ore and produce phosphate rock from Morocco and Western Sahara will be able to influence the market prices as other countries run out of high grade phosphate rock or decide to use it for their own consumption. This means that countries that are dependent on imports, and who continue wasting phosphorus to landfills and water bodies, will be increasingly economically and politically dependent on Moroccan and US fertilizer companies. However, P-deficient countries can improve the efficiency of their phosphorus usage and make use of recycled phosphorus (see slide 5.1-14). An illustration of this is that in industrialized regions, almost half of the total food is squandered, around 300 million tonnes annually, because producers, retailers and consumers discard food that is still fit for consumption. This is more than the total net food production of Sub-Saharan Africa, and would be sufficient to feed the estimated 870 million people hungry in the world (FAO, 2011). Less dumping would increase the supply and dampen market price increases.

5.1 - 10



According to peak minerals theory, first formulated by Hubbert (1949) in relation to US oil reserves, the important point regarding mineral availability is not when the resource is depleted, but when high-quality, highly accessible reserves have been depleted. In this case – peak phosphorus – is the point after which the quality of remaining reserves is lower and they are harder to access, eventually making them uneconomical to mine and process. A peak phosphorus analysis based on US Geological Survey and industry data (see picture) suggests that production of phosphate rock could peak by 2035 (Cordell et al., 2009a). The static reserve life of phosphorus is estimated to be 107 years (USGS, 2008).

The exact timeline of the peak is currently disputed. The fertilizer industry, on one hand, claims that USGS reserve data is unreliable, and that more phosphate reserves exist (Prud'Homme, 2010). Other scientists dispute the timeline because they believe peak phosphorus occurred in 1989 (Dery and Anderson, 2007). In October 2010, the International Fertilizer Development Centre (associated with the industry) issued new estimates for Morocco and Western Sahara P reserves, claiming the reserves to be ten times bigger (IFDC, 2010). Regardless of the exact timeline, there is general consensus that in the remaining reserves, P concentrations (expressed as P_2O_5) are declining, that the presence of contaminants such as cadmium, uranium and thorium is increasing, and that these remaining reserves are physically more difficult to access.

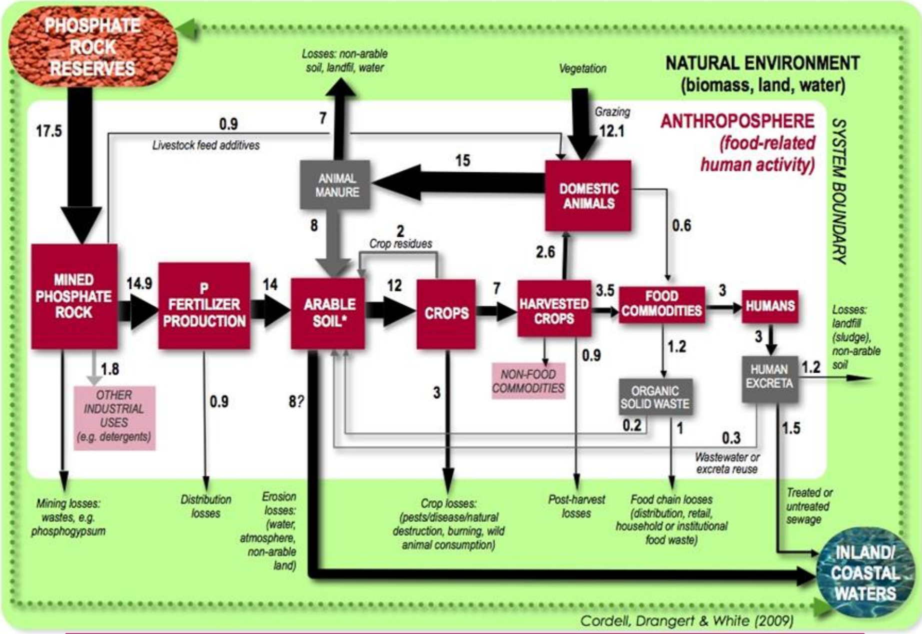
The peak P discussion has helped to put phosphorus issues on the international agenda (Gilbert, 2009). Instead of getting stuck in a debate over the exact timeline for a limited resource, we argue that a prolonged time slot is positive and should be used to gradually lower the present substantial wastage of P in all phases from production to final disposal. It is no human right to waste valuable resources whether they are being exhausted or not.

An on-line tool, the US Minerals Databrowser, allows users to create a variety of plots based on data from the USGS dataset: Historical Statistics for Mineral and Material Commodities in the United States. The data browser includes phosphate and potash as well as 84 other minerals.

The following slides provide examples on how the lifetime of P rock resources can be extended by reducing the rate of losses of phosphorus from the mine to the toilet.

Phosphorus through the global food system

5.1 - 11



Only 1/5 of the P in mined rock reaches the food on our forks!

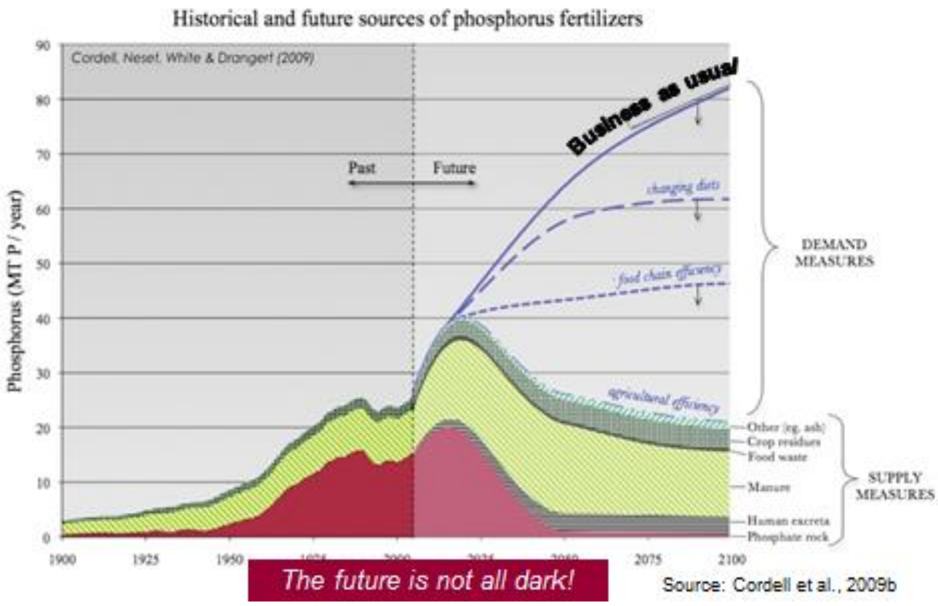
A simplified Substance Flows Analysis (see also Module 1.3) can help us estimate the flow of phosphorus in the global food system. It traces the flow of P from mined phosphate rock via fertilizer and crop production to human and animal consumption (Cordell et al., 2009a). The quantities of phosphorus (in millions of tonnes per year) flowing between these major stages and the losses on the way are shown above.

While some 14.9 million tonnes of phosphorus is used in fertilizer production, only 3 million tonnes end up in human excreta some of which originates from soil P. The flow analysis indicates that there are substantial phosphorus losses that occur throughout the food production and consumption system – from mine to field to fork to toilet. Most of these losses, such as the losses due to the wastage of edible food and loss of P in animal manure, are avoidable (see 5.1–20). Other losses, such as the loss of P through soil erosion, can potentially be reduced if the P is managed wisely. The graph shows that more phosphorus ends up washed away by erosion than ends up in food. In the Illinois River basin, for example, about 1.2 kg of soil with its P is eroded for each kilogram of corn produced (Vaccari, 2009).

A substantial amount of phosphorus is lost as phosphogypsum waste in the fertilizer production. Transport, storage and other production losses also occur between the mine and the farm gate. Phosphorus must be in solution in the soil for plants to be able to take up the nutrient. However, once applied to agricultural soils, phosphorus in fertilizers can quickly adsorb to other particles, making phosphorus unavailable for use by plant roots (FAO, 2008). It has been estimated that plants only take up around 15–25% of phosphorus in fertilizers applied that year (FAO, 2006). The remaining phosphorus is either temporarily locked up in soil (slide 5.1-22), or lost to water bodies via erosion and runoff. Once harvested, crops are either processed for food, feed, fibre or fuels - or traded globally. A substantial amount of phosphorus is lost in these processes, for example through conversion to feed which is then consumed by animals. Only a fraction is returned to the food system as animal protein products due to misuse of animal manure (Cordell, et al, 2009a). Furthermore, the organic waste from households, restaurants and disposal in supermarket dumpsters and household bins, can also be large (FAO, 2011). Only a small proportion is recovered and re-used.

Securing a sustainable phosphorus future

5.1 - 12



This graph combines past and anticipated future sources of phosphorus fertilizers for meeting global food demand. The graph for the future presents results from a ‘preferred’ scenario generated from a futures scenario analysis (Cordell et al., 2009b). The ‘business-as-usual’ scenario takes into account factors such as population growth, likely changes in preferred diets, and improved efficiencies. The result is a demand that grossly exceeds anticipated supply.

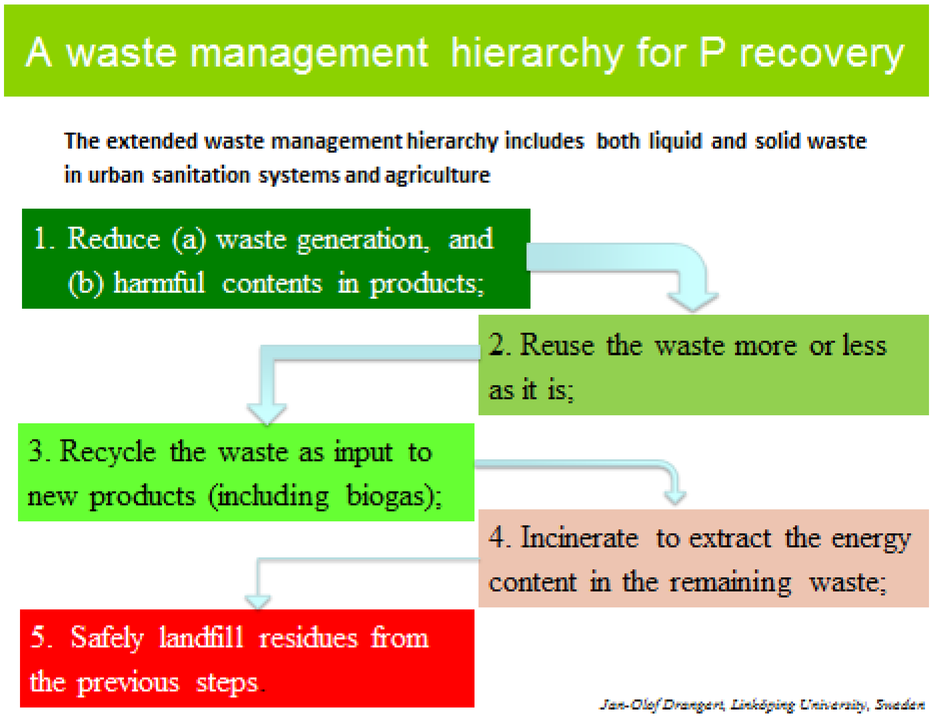
The situation is not as grim for food security as it may first appear, however. Due to the substantial mismanagement and inefficient use of phosphorus in the current food system, there are numerous opportunities to improve current practices in order to avert a crisis. However, there is no single quick-fix solution for ending the dependency on phosphate rock. A scenario analysis shows that a number of different supply- and demand-side measures can together close the growing gap between supply and demand for phosphorus.

The graph shows that ***demand-side measures*** are crucial. The almost universal trend towards eating more meat- and milk-based food doubles the demand for P for an equivalent food intake. Also, the animal husbandry releases 18% of the global greenhouse gas emission. High meat intakes are found to cause health problems. These are three reasons for society to advocate a more cereal-based diet. The demand for P can also be substantially reduced through minimising losses of edible food through wastage during transport, storage, food processing and disposal (slide 5.1-14). A third important demand-side measure is to improve efficiency in agriculture which would contribute to a substantial reduction in demand for fertilizer. Stalks and stems should be returned to the soil to prevent erosion.

The main ***supply-side improvements*** are reuse and recycling measures. The collection and return of animal manure and human excreta to the soil reduces the need for chemical fertilizers. Incentives to change agricultural practices are likely to be more effective than incentives to change diets. More efficient mining processes would prolong the lifetime of rock phosphate reserves, and a higher market price would make more sources economical to exploit. Implementing these measures will require substantial changes in behavior in industry, in agriculture, and among individuals, in addition to new physical and institutional infrastructure.

The demand- and supply-side measures are presented as steps in a waste hierarchy that starts from reduced waste generation and ends with undesired landfilling step (Drangert *et al.*, 2013).

5.1 - 13



In this study material, this extended waste hierarchy includes solid waste and also wastewater in order to developing measures for improved nutrient management in urban sanitation systems.

In a sanitation context the above steps are interpreted as follows. **Step 1** reduces generation of waste-containing nutrients, and thus the need to tap mineral nutrient reserves. This includes reduced volumes and, perhaps more importantly, to minimise harmful and unwanted contents in products and materials. For example, banning the use of phosphorus in detergents fulfils both reduction of used volumes of phosphorus and lessens a harmful content causing eutrophication. By not mixing various waste streams, it becomes both easier and safer to directly reuse (**step 2**) products right away. For example, the nutrients in human urine may be applied directly on farmland through irrigation. However, if the desired compounds in the waste is not safe or not in a state that allows reuse, some kind of conversion into a new product is required (**step 3**). Such recycling will save on virgin resources. For instance, organic waste such as faecal matter and treated sludge could be composted, hygienized and turned into a multi-nutrient fertilizer product. Such recycled inputs often save on energy usage for production and transport of mineral nitrogen and phosphorus in fertilizers. Organic waste may in addition be anaerobically digested to produce methane and biogas while retaining the nutrients in the sludge and slurry for subsequent agricultural use.

Incineration of organic waste is also an option (**step 4**) mainly used to reduce the volume of solid waste and to recover the energy. The ashes and smoke contain phosphorus and potassium (do not burn), but in a form that requires additional energy to become plant available. Also, all carbon and nitrogen are lost which makes the products less valuable for agricultural use. If no components of the remaining waste are possible to recover, at least the energy content may be of interest – if the incinerator is perceived to be affordable. Putting waste on a landfill (**step 5**) should be resorted to only after having exhausted the previous four steps. Even landfilling is made safer by implementing the first step of reducing harmful components and not mixing waste streams. Currently, the most common practices employed in the world´s sanitary systems are steps 5 and 4. But, in many countries there is a rapid evolution towards the first three steps and this study material focuses on these steps.

Can I eat climate-smart and phosphorus-smart?

5.1-14

- ***Think twice when shopping***
  Don't buy more food than you have time to eat
- ***Eat up the food you cook***
  Serve reasonable portions and use the leftovers
- ***Use your senses***
  Look, smell, taste and feel the food. Most foodstuffs last longer than their 'use-by' date if they are stored properly
- ***If you want to eat meat***
  Choose local produce and try to eat fish, chicken and no beef
- ***Eat more vegetarian food***
  Especially root crops and legumes
- ***Choose fruits and vegetables of the season***
  Preferably local products

Source: Sweden's National Food Adminstration Report 2008:9

"In a world of seven billion people, set to grow to nine billion by 2050, wasting food makes no sense - economically, environmentally and ethically," said UN Under-Secretary-General and UNEP Ex. D. Achim Steiner. "Aside from the cost implications, all the land, water, fertilizers and labour needed to grow that food is wasted - not to mention the generation of greenhouse gas emissions produced by food decomposing on landfill and the transport of food that is ultimately thrown away," he added. "To bring about the vision of a truly sustainable world, we need a transformation in the way we produce and consume our natural resources." (FAO, 2013)

According to (FAO 2011), roughly 95 per cent of food loss and waste in developing countries are unintentional losses at early stages of the food supply chain due to financial, managerial and technical limitations in harvesting techniques; storage and cooling facilities in difficult climatic conditions; infrastructure; packaging and marketing systems.

However, in the developed world, the end of the chain is far more significant. At the food manufacturing and retail levels, large quantities of food are wasted due to inefficient practices, quality standards that over-emphasize appearance, confusion over date labels, and consumers being quick to throw away edible food due to over-buying, inappropriate storage and preparing meals that are too large.

Per-capita waste by consumers is between 95 and 115 kg a year in Europe and North America/Oceania, while consumers in sub-Saharan Africa, south and south-eastern Asia each throw away only 6 to 11 kg a year.

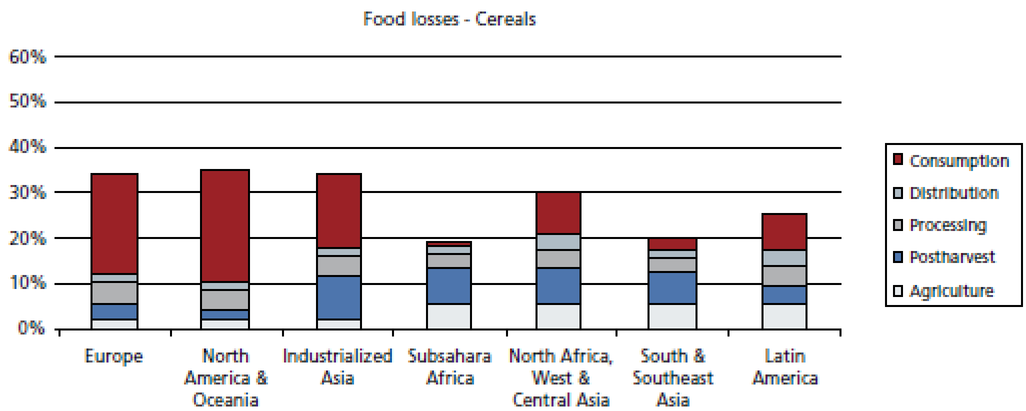
The slide talks about what households and individuals can do to enhance the availability of phosphorus fertilizers and reduce emissions of greenhouse gases. Such climate and phosphorus smart activities are in the hands of all individuals. The following everyday activities will have a tremendous positive impact on the globe if most persons adhere to them:

Measures to reduce volumes include not buying more than what will be eaten up. Expiry dates for products are quite short and can be extended with proper storage. However, milk, meat, fruit, juice, etc. are often flushed away. In a recent review of global food wastage, Parfitt *et al*. (2010) concluded that available data suggest that between 10 to 40 % of the total amount of food produced is wasted, but data are quite uncertain, and figures up to 50 % have been cited. Recently, Quested and Johnson (2009) estimated that about 40 % of the household wastage in U.K. was due to cooking and serving more food than could be consumed. Additionally, a recent study in Sweden estimated that about 20 – 25% of the food wasted in households could be related to packaging, *e.g.* too big and difficult to empty packages (Williams *et al*., 2012). Studies of such food waste give figures from 50% (USA) to 25% (Sweden), and the European Union aims to reduce edible food losses to 20% by 2020 (FAO, 2013).

Eating a diet with less meat and dairy products will reduce the number of animals on the earth, which allows for more forests, and cuts down inefficiencies in food production and emissions of carbon dioxide and methane gas. If you want to eat meat, fish is the most P smart diet followed by chicken and pork which all require less phosphorus per produced kilogram than beef. The medical profession is also getting worried that a heavy meat diet is causing health problems.

The 'Think. Eat. Save.' global campaign (www.thinkeatsave.org/) provides simple tips to consumers and retailers, which allow users to make food waste pledges, and provides a platform for those running campaigns to exchange ideas and create a truly global culture of sustainable consumption of food.

FAO (2011) provide estimates of losses for several food categories, and the graph below presents losses for cereals from agriculture to consumption:



Nutrients in human excreta

5.1-15

Amount of nutrients from an average Swede per year

Important nutrients	Urine 500 Lt/year	Faeces 50 Lt/year	Total
Nitrate (N)	kg	kg	kg*
Phosphorus (P)	kg	kg	kg
Potassium (K)	kg	kg	kg
Total amount i.e. N+P+K	kg %)	kg)	kg %)

The Urine Equation:

An adult eats 250 kg of cereals per year, which has been grown on less than 250 m² and fertilised to more than fifty per cent by the person's urine.

Jan-Olof Drangert, Linköping University, Sweden

Just like plants, the human body requires phosphorus to build cells, enzymes, etc. A normal body contains about 0.6 kg of phosphorus (equals two years´ intake), mainly in the bones and teeth. Since our bodies do not grow indefinitely, an adult excretes about the same amount of nutrients that is eaten. Primarily, the adult body makes use of energy in the eaten food.

The table shows that most of the nutrients are found in human urine, and thus the first priority is to reuse urine (Drangert, 1998). The total nutrient content in human excreta is – in theory – possible to recycle and can fertilize enough soil to produce the same amount of food that has been eaten. In practice, there are some losses but these are small compared to the losses of P in the present chemical fertilizer chain (slide 5.1-11). In addition, P in human urine is in a plant available form and contains only background levels of heavy metals etc.

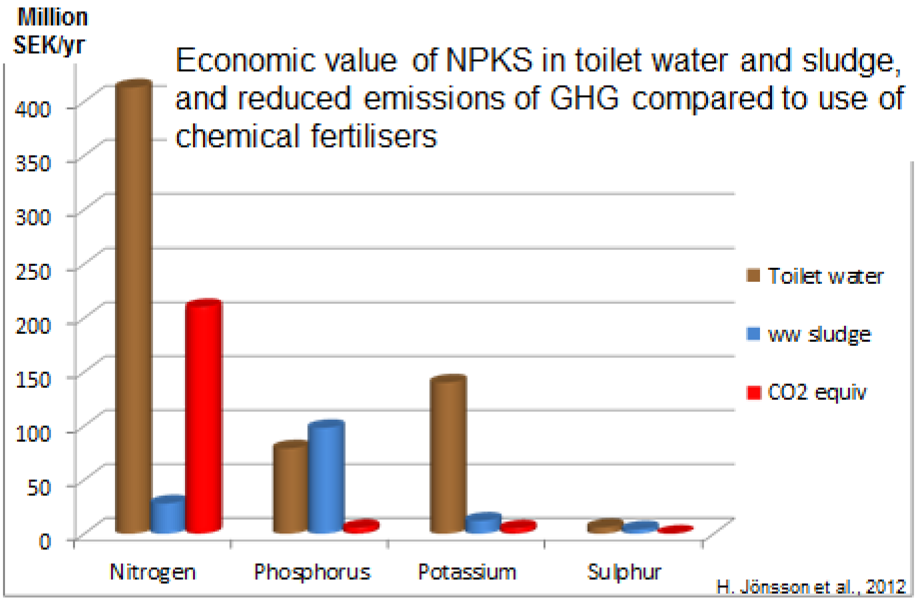
Allowing for some losses of nutrients, it is possible to formulate a Urine Equation (see picture) that connects urination to fertilizer requirement and food production. An adult eats equivalent to some 250 kg of cereals per year, which has been grown on less than 250 m^2 and fertilised to more than fifty per cent by the person's own urine. If treated faeces are also applied, there would be little need to add more fertilizers.

A simple calculation helps to indicate the impact of a urine collection and reuse system. In a city with, say, one million inhabitants, human urine itself could fertilise more than half the food crops needed. Some cities do produce that proportion of their food intake within the city limits e.g. Lusaka, Dar es Salaam and Moscow (UNDP, 1996). The larger the part of the food production that takes place in the city (urban agriculture) the less energy is used for transporting urine as well as the food crops and fertilizers. A town may be planned from the criteria that a certain percentage of the land area is set off to agricultural activities. Collection arrangements would be required and transport to the fields as discussed in module 2.1 and slides 5.1-17&18.

Urea is a naturally occurring compound contained in urine from mammals. It is manufactured in the body by combining carbon dioxide with ammonia and is the most commonly used nitrogen fertilizer worldwide. With more than 46% nitrogen, it has the highest nutrient concentration among the commercially available solid nitrogen fertilizers. It can be applied in a solid prilled or granulated form (EFMA, 2000c).

Nutrient fertiliser values and CO_2 emissions

5.1 - 16

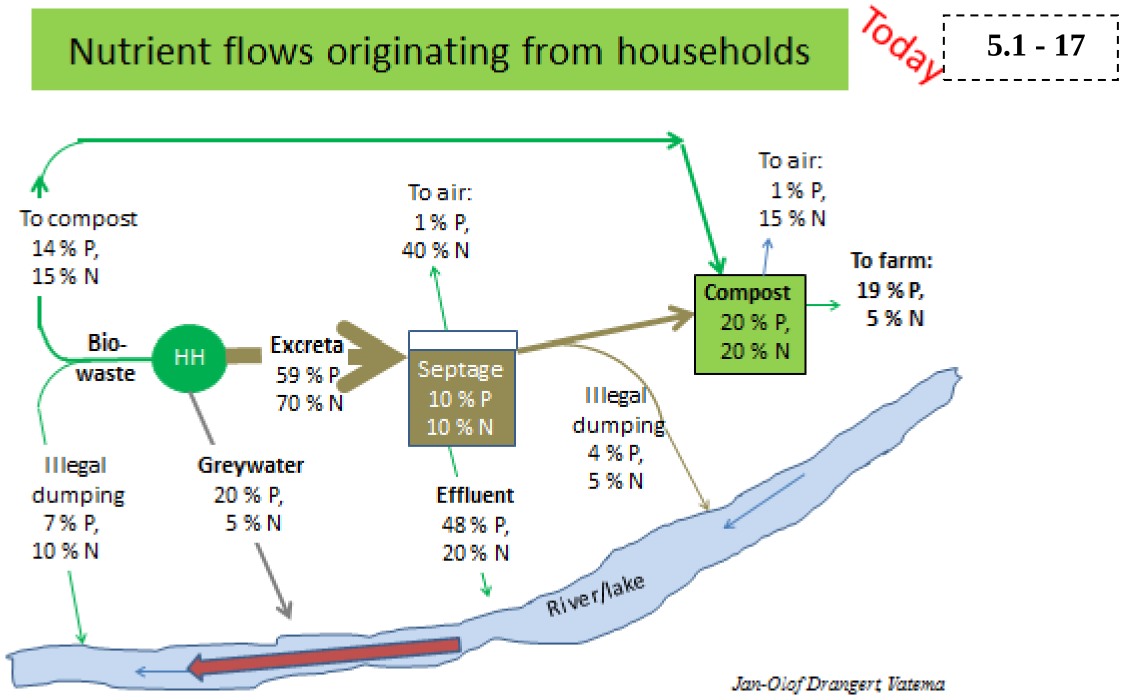


Cities are fast becoming 'phosphorus hotspots' in two senses – as centres of demand for phosphorus (to prepare food to be consumed in cities) and as location of large amounts of phosphorus in excreta and food waste. For example, urine is the largest single source of phosphorus emerging from cities (Vinnerås *et al*, 2006). However, most nutrients in urban waste are not recovered and re-used (see slide 1.3-13). Many town councils collect and transport organic waste to landfills, where the nutrients will remain for uncounted years unless leached to groundwater or emitted to the atmosphere. The situation is similar for urban toilet waste, which in the best of cases ends up as sludge in a wastewater treatment plant. However, sludge is also often sent to incineration or landfills due to its perceived or real toxicity. The more the flow of phosphorus from mine to field to toilet is linear and in one direction only, the greater our dependence on mined phosphate rock and the faster high-grade phosphate rock resources will be depleted. Recirculating urban nutrients such as urine back to agriculture therefore presents an enormous opportunity for the future.

Jönsson *et al*. (2012) calculated the economic value of four nutrients in two theoretical systems for Sweden: for all toilet water (black water) and for all municipal mixed wastewater sludge. The annual values (see slide) are calculated as the value of the corresponding replaced chemical fertilizers (in Million Swedish Kronor). A bit more phosphorus could be extracted from sludge than from blackwater, given a removal rate of 100% in the wastewater treatment plant. This is due to wastewater containing not only the blackwater but also detergents and food scraps with P.

A striking feature is that the economic value of potassium, and more so of nitrogen, is very high in blackwater compared to sludge. This reflects the fact that nitrogen disappears to air on its way from the toilet through the treatment plant. This loss of nitrogen has to be replaced by the very energy-intensive production of nitrogen from ammonia and hydrogen. Also, dissolved potassium is not captured in the treatment plant and is therefore not found in the sludge. The total amount of N, P, and K in blackwater is equivalent to 20%, 50%, and 55% respectively of the amounts of these nutrients in chemical fertilizers sold in Sweden in 2009/2010.

The red bars in the graph represent how much the CO_2 emissions are reduced, if the chemical fertilizers were to be replaced by recycled nutrients from blackwater and sludge: 203,500 tons of CO_2 equivalents per year and 17,000 tons respectively. Again, the nitrogen in the blackwater dominates with 196,500 tons.



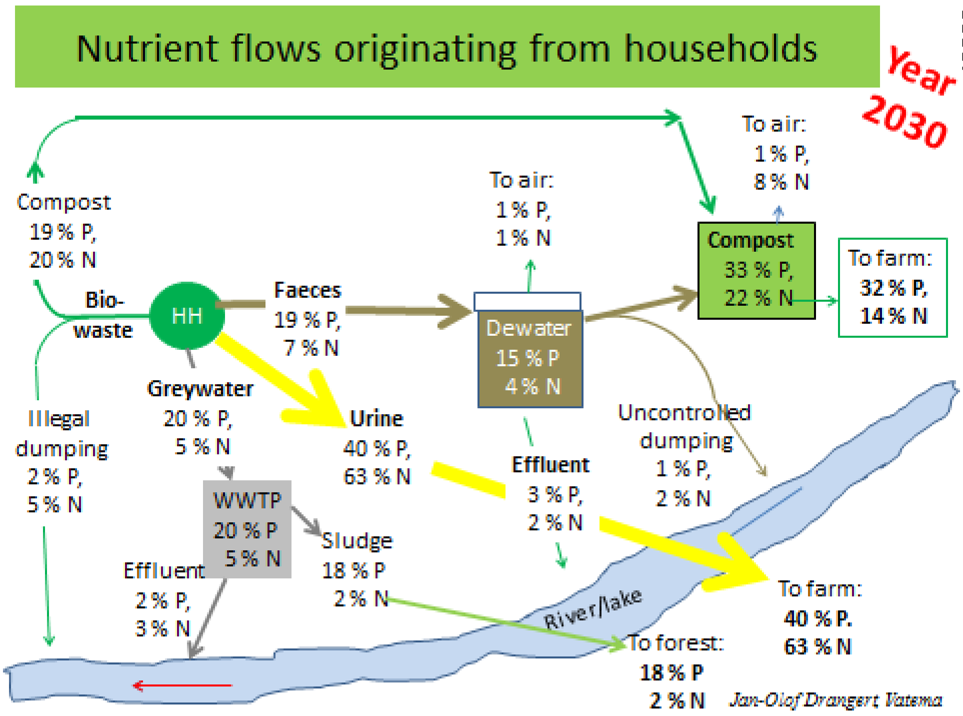
Measures that reduce the environmental impacts from cities and towns include returning organic matter from households to the soil. The picture represents a common situation in today's world where the nutrients are largely discharged to water bodies (red arrow). Flushing away organic matter in sewers will cause eutrophication and algal blooms in receiving water bodies. This may result in less aquatic flora and even dead zones on lake floors and reduced living space for fish.

The picture presents a theoretical calculation of phosphorus (P) and nitrogen (N) flows from households (HH) to the environment. Bio-waste consists of food waste, paper, garden waste etc. It is usually easier to manage solid organic waste than liquid organic waste caught in the sludge after wastewater treatment. So, sweeping away food remains and fat/grease from plates, pan and cutlery into the organic waste bin is preferable as it makes it possible to compost the material and use it as a soil conditioner in the garden or to collect it and use it in agriculture or for making biogas. The alternative is that this fat/oil/grease will eventually clog the sewer pipes, and cause costly repair. The content of P and N as percentage of total P and N leaving the households are given for each flow. Some of the solid waste is illegally dumped while some is composted.

The nutrient-rich excreta are flushed to a septic tank for partial treatment, but much of the nutrients remain in the effluent, while the sludge is collected and brought to the compost. Illegal dumping is commonplace. The co-composted sludge and solid organic waste is available for use in agriculture, but most of the nitrogen has been lost to the atmosphere. A modest one-fifth of the P that households discharge is being gainfully used and only 5 % of the N.

The next slide shows a modified sanitation system with the capacity to improve reuse and recycling considerably.

5.1 - 18

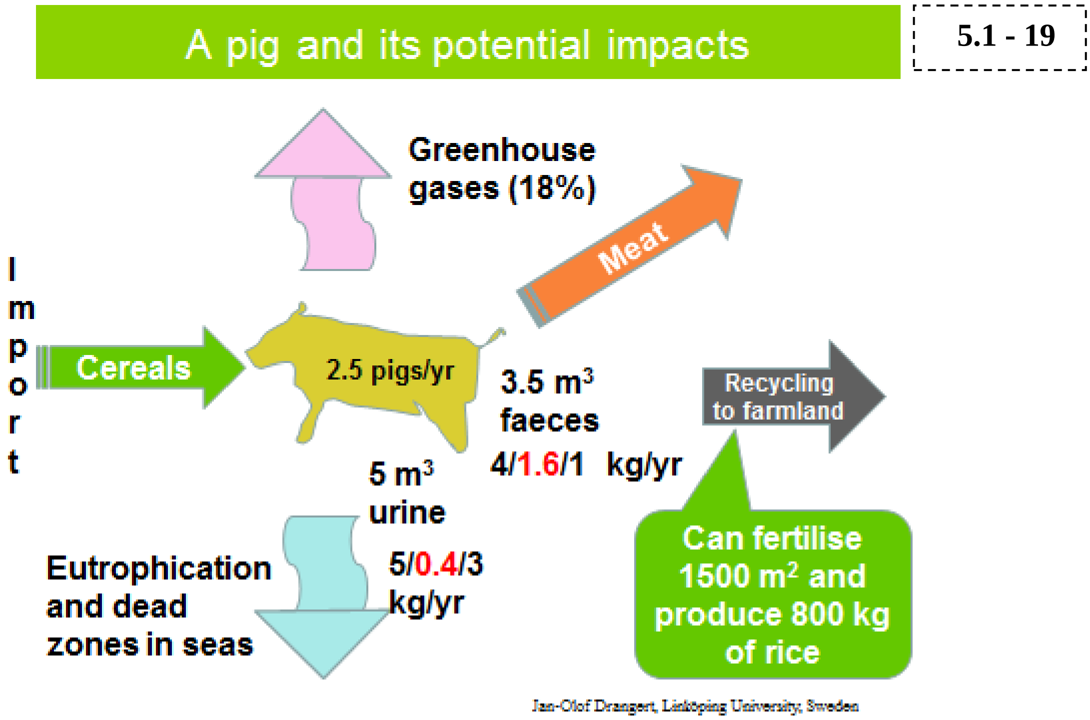


The same city has taken some steps to make it more sustainable. Residents contribute by segregating household solid organic waste and the waste company compost it and this added value reduces illegal dumping. Also, urine-diverting toilets have been installed and urine is collected separatly while faecal matter is dewatered and stored (as recommended by WHO) before being composted. The wastewater treatment plant has improved to 90% P-removal capacity, while the same effect could have been achieved by prohibiting phosphate-based detergents.

This time, the nitrogen-deficient greywater sludge contains polluting compounds that may accumulate in soil, and is therefore only applied on trees. The urine can safely be applied on agricultural soil since it is the least polluted fertilizer available and has an almost perfect composition (Module 4.2). The nutrient loss from well-managed urine is insignificant (Vinnerås *et al*, 2006). Likewise, the quality of the organic compost is likely to be of good quality and possible to apply on soil for food production. The short loop of using urine and composted organic matter in the garden is sustainable, whereas sludge from treated mixed wastewater is more risky and difficult to monitor (see Module 4.5).

Compared to the sanitation system described on the previous slide, there is a significant improvement in reuse/recycling of the nutrients N and P (and surely also all other nutrients). Productive usage of P originating from households increases from 19 % to 90 %, while N increases from 6 % to 79 %. This drastic reduction in wastage also means that water bodies are saved from nutrient pollution and eutrophication.

All these measures reduce production and transportation of fertilizers and thus save energy and reduce air emissions. The required investments in separate urine pipes and composting stations is marginal when new city districts are being build, whereas retrofitting existing houses may be prohibiting expensive (Module 2.1).



One example of recovery of nutrients is the reuse of animal waste practised in all societies. Free-range animals distribute the nutrients in the fields, while stall-fed animals make up hot spots of nutrients. Recycling of animal waste can be analysed in a similar fashion as human waste, keeping in mind that the composition of animal waste differs between different species. For instance, chickens do not pee at all, urine from pigs contains little phosphorus compared to humans, and cow urine contains no phosphorus.

The picture above provides data for pig urine and faeces from an intensive breeding of pigs for meat. A cage in the stable for fattening pigs is used for 2.5 generations of pigs in one year i.e. 2.5 pigs slaughtered per year. The meat may be exported, while feed is often imported from abroad.

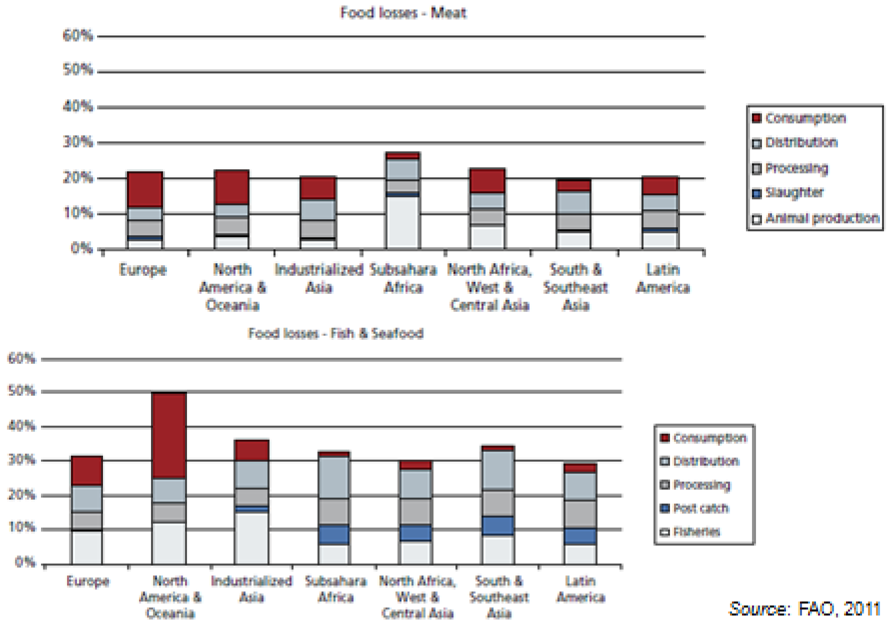
From each cage the farmer collects 1 m^3 of urine and 0.7 m^3 of faeces per year. A sow with her piglets produces 5 m^3 of urine and 3.4 m^3 of faeces. The NPK content is 5/0.4/3 kg in urine and 4/1.6/1 kg in dung, which shows that only 20 per cent of the P is found in the urine and 80 per cent in the faeces (Claesson and Steineck, 1991). It is relatively easy to crudely separate pig urine and faeces and to dewater the manure at the farm. The P in pig manure is to a large extent found in the faeces (80%) as opposed to human excreta where only 33 per cent is in the faeces. This means that the voluminous liquid part can be applied on nearby phosphate-rich soils without adding too much phosphorus. The dewatered faeces are rich in most nutrients and have a high organic content which makes it a good fertilizer and soil amendment. Its small volume is likely to allow for long transport to areas in need of P and carbon-rich soil amendments. The next slide shows the uptake of phosphorus in different plants, and thus how much P farmers may add without over-fertilizing; depending on the crop they plant.

The manure from one sow and her piglets is sufficient to fertilise some 2,000 m^2 from which 800 kg of maize or rice can be harvested. This, in turn, means that the sow and her piglets can get more than 2 kg of maize or rice every day from crops fertilised with their manure - without degrading the soil.

The environmental impact of ruminant livestock is significant, and animals contribute some 18 per cent of the greenhouse gases which cause climate change. Also, if urine and faeces are not managed properly, the high loads of N and P cause eutrophication and dead zones in lakes.

Loss of food in each step of the food chain

5.1 - 20



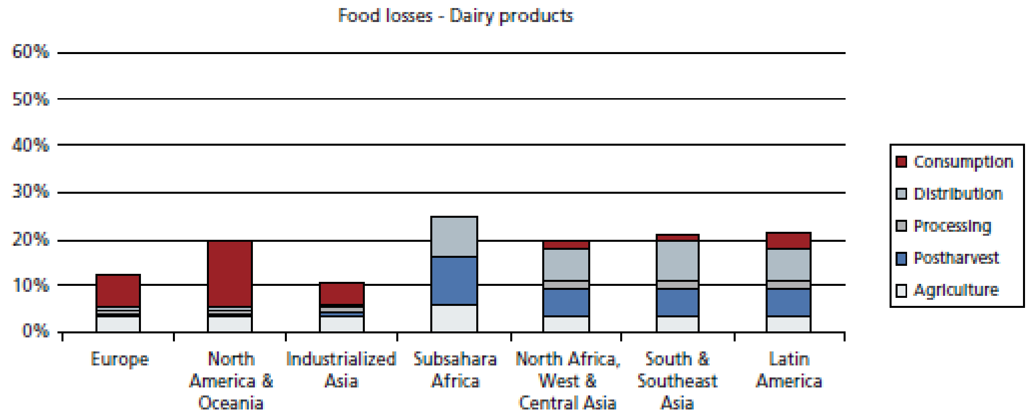
Source: FAO, 2011

FAO (2011) estimated food losses at each step of the food chain for all food categories. They found high losses (45-65 %) for fruit and vegetables, (40-60 %) for roots and tubers, 20-35 % for cereals, and 20-30 % for oil seeds and pulses.

The picture gives data on losses and waste for meat, fish and sea food. FAO found similar total losses of some 20 per cent for meat over the globe with a slightly higher figure for Subsaharan Africa (27%). Waste and losses at the consumption level is high in Europe and the US and makes up about half of the total loss, while big losses in Subsaharan Africa appear in livestock breeding.

The losses of fish and sea food are higher, about 30% and even 50% for North America and Oceania. The three industrialised regions discard 9-15% of the marine catch, and a large portion of the purchased fish and sea food is wasted.

Dairy products are wasted to a lesser extent than meat and fish. In the industrialised countries the main loss occurs in the households, while wastage in the other regions is dominated by distribution and postharvest losses:



Plant requirement and nutrient removal

5.1 - 21

Crop	Yield, kg/ha	Dry matter	N, kg/ha	P, kg/ha	K, kg/ha
Cereals					
Rice, paddy	4,000	88%	60/45	13/11	25
Wheat straw	4,000	85%	70/16	13/ 2	50
Maize	4,000	88%	200/51	35/ 9	133
Sorghum	4,000	88%	120/56	22/ 9	116
Tubers etc					
Cassava root	20,000	36%	125/32	13/ 1	125
Sweet potatoes	10,000	59%	90/49	19/12	12
Potatoes	25,000	23%	115/83	20/13	166
Others					
Soy bean	1,000	91%	125/54	13/ 5	33
Ground nuts	1,000	94%	50/37	7/ 4	12
Banana fruit	25,000	31%	n.a./67	n.a./ 8	n.a.

Source: Håkan Jönsson. SLU. Sweden

The previous slides present the amounts of nutrients that animals and humans excrete, and what can potentially be brought back to farmland. Crop species vary in their nutrient requirements and in the quantities of nutrients that are removed at harvest (EFMA, 2000b). The table above shows normal yields for ten crops, the dry matter content, and the content of nitrogen (N), phosphorus (P) and potassium (K) contained in the entire plant (black) and their edible part (red). Given that the crop residues are ploughed down in the soil, the red figures indicate the amounts of nutrients that are removed with food and feed. Peels of banana, potatoes and cassava roots are considered edible, whereas peels of groundnuts and soybeans are not.

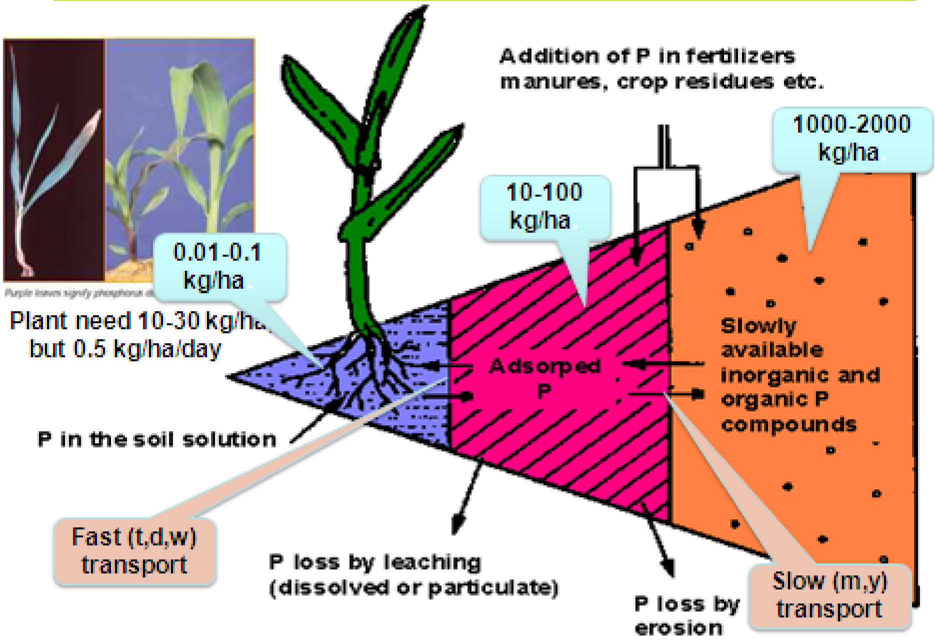
The proportion of P in the edible part as compared to the entire plant varies between 7% and 85%. Conversely, if the non-edible part is left on the field, between 15% and 93% of the P is recycled. The corresponding recycling figure for N varies between 35% and 80%. Such data emphasize the importance of selection of crop given the soil content of nutrients.

The data in the table clearly show that a farmer can benefit from a strategy to select crops which are not requiring so much of a limited soil nutrient as other crops (See also slide 4.1-10). For instance, farming maize and paddy rice yields the same 4 tons per hectare given all nutrients are available to the plants. However, farming maize would require almost three times as much P input as paddy. On the other hand, the return of non-edible parts of maize would provide 26 kg/ha while the non-edible rice plants return only 2 kg per ha. In phosphorus deficient soils in Africa it is vital to plough back the non-edible parts of maize stalks and cobs. This task is difficult and farmers often burn the stalks in the fields (also to avoid pests). But then also much of the nitrogen disappears, and the P in the ashes is not plant available (Schiemenz and Eichler-Löbermann, 2010).

In the long run, all soils will need replacement of the removed nutrients. One source of nutrients is animal manure and another is human excreta. The previous slide shows that a sow with piglets annually provides 9, 2 and 4 kg of nitrogen, phosphorus and potassium respectively. Values in the table shows that this is enough to fertilise 0.2 hectare planted with sweet potatoes or 0.25 ha of groundnuts with a yield of two tonne of potatoes or 250 kg of groundnuts (if all residues are returned). An extended exercise on slide 5.1-23 makes use of data in this table.

Why is it so difficult to apply P?

5.1 - 22



The previous slides may give the impression that it is easy to apply phosphorus and other nutrients to farmland. This is not the case since there are a number of factors influencing what can be achieved. Plants require between 10 – 30 kg/ha and will take up P at different rates during the growing period (slide 5.1-21). A plant may need up to 0.6 kg/ha per day when establishing the roots or setting fruits while much less is needed during other periods (EFMA, 2000b).

All soils contain P (slide 5.1-6) but the concentration may vary much over a field, even over short distances. Also, this P may be easily available to the plants or be adsorbed to soil particles so hard that the roots cannot access the P - usually to iron, aluminium or magnesium in the soil. In acid soils P is fixed to ions or hydrolysed oxides of these metals, while in slightly alkaline soils P is fixed as calcium phosphates. Thus, farmers tend to apply more P than the annual plant/crop takes up in a year.

The top soil (20-30 cm) has a total volume of some 2,500 m^3 or 2,000 tons per ha. It may contain 3-7 tons of P_2O_5, but only a very small fraction of this P is available in the soil solution at any one time (EFMA, 2000b). The P can also disappear from the top soils by being removed by rain and wind erosion. The likelihood of losses of P in this way differs for different soil types, rain regimes, and vegetation cover. The amount may be as much as 0.4 kg/ha annually, and about the same magnitude of P may be deposited on soil from the air (from incineration, soil dust and volcanoes).

The tilted triangle in the picture shows top-soil (blue), the layer below (lilac), and the deeper soil (brownish) (Stouman Jensen, 2010). In the topsoil there is always some P in solution and readily available to plants (0.01- 0.1 kg/ha). This amount is soon used up by plants. Fortunately, the transport of P to and from the next layer is fast, usually hours up to days. The P in the lilac layer (10-100 kg/ha) is however adsorbed to charged soil particles such as iron and aluminium. These compounds are too big for the roots to ingest and require some natural biochemical processes to be transferred to the top soil. The deep soils (brown) contain lots of P (1,000-2,000 kg/ha) but this is in a non-soluble form. The transport of P is therefore very slow and would take months or years to become available to plants. This organic P is typically stored for later use.

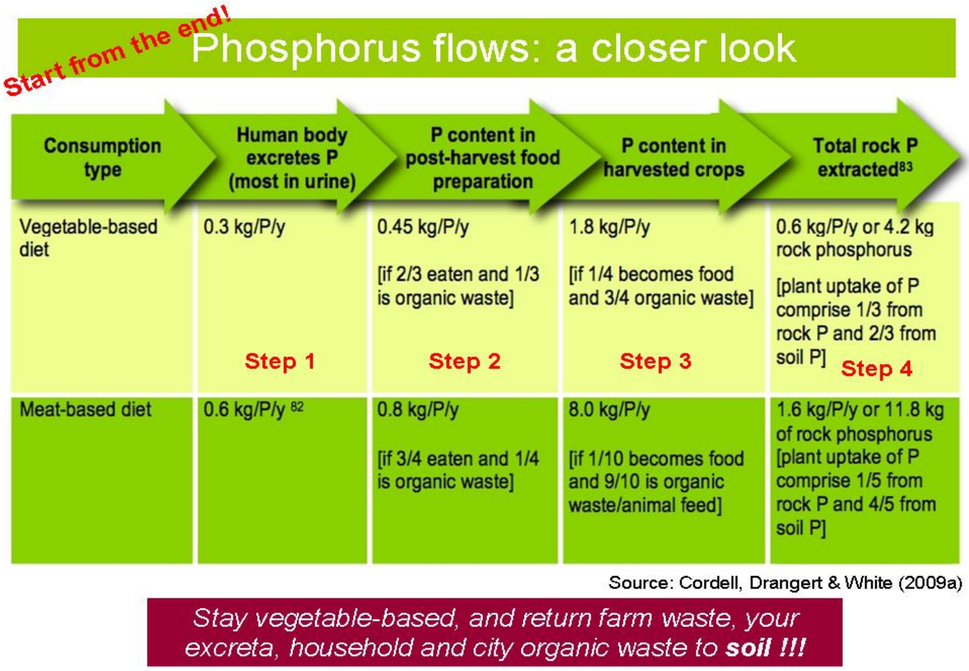
The various conditions described above make it complicated to know the need of P in a certain soil and at a certain time of the growing season. Farmers would need a lot of data and experience to succeed in precision-application of P. Sometimes precision agriculture in the form of band or placement of fertilizer, you can save a lot of P to bridge the vulnerable first plant stages with not enough roots (Smit *et al.*, 2010).

Equally important is to select crops that can reach the different soil levels. For example, lettuce has a shallow root system and can exploit only about 20 cm of the top soil. Others like sugar beet has roots that extend 2 m or more into the soil and benefit from nutrients and water at that level (EFMA, 2006).

In the soil, urea from urine is converted from carbamide nitrogen to ammonium ions (NH4+) by a series of enzyme reactions. Under normal soil conditions, the ammonium ions are adsorbed by the soil (i.e. become attached to the negatively charged soil particles) and the nitrogen becomes available to the plant, either in its ammonium form or as nitrate following microbial oxidation. Urea derived ammonium behaves in exactly the same way as that from other ammonium based nitrogen fertilizers (Code of best agricultural practice at (efma.org) www.fertilizerseurope.com) This breakdown of urea to release ammonium ions normally occurs within a week. Urea should preferably be spread when rain is forecast, or should be washed into the soil by irrigation in the evening and worked into the soil.

In this context it may be quoted from EFMA (2000b) that "soil nitrogen (N) and sulphur (S) exist in the upper soil layer in organic and mineral (inorganic) forms. The total amount in most arable soils ranges between 3,000 to 10,000 kg/ha for N and 500 to 2,000 kg/ha for S, with even greater amounts being found in grassland soils. Usually at least 90-95% of this total soil N and soil S is in the organic form and is unavailable to plants, with about 2% of the organic N being converted each year to mineral forms by microbial action (i.e. being mineralised). From a plant nutrition point of view only mineral N and mineral S are important, because it is only in these forms that the plant root can take up these nutrients. Mineral N occurs in two different forms in the soil: ammonium-N and nitrate-N. Ammonium-N (NH_4^+) is less mobile and can be fixed to clay minerals. However, this ammonium-N is rapidly converted into nitrate-N (NO_3^-) by soil microbes at soil temperatures above 3 to 5°C (nitrification) unless a specific nitrification inhibitor has been added. As a result nitrate-N is normally the predominant mineral N form in soil during the growth period of crops".

5.1 - 23



Phosphorus travels from mine to field to fork – and is finally excreted unless lost on the way. In this exercise students are requested to analyse each step from the end (excreta) and work backwards in order to understand what impact our diet has on phosphorus usage. This exercise requires input of data from several sources found in this training material or – even better – from national data bases. Here we make a few general comments on each of the four steps.

Step 1: The body extracts energy from food, about 2,500 K calories per day, but adult bodies do not accumulate any nutrients only replace some. This means that almost all the phosphorus (98%) consumed with food is excreted in urine and faeces. A vegetarian excretes approximately 0.3 kg P per year, and a meat-eater around 0.6 kg. The reason is that there is more P in meat and milk products and the body does not need all of it (Drangert, 1998).

Step 2: A surprisingly large portion of food is not eaten but ends up as organic waste of leftovers after eating and from food preparation. Other losses occur during transport to shops and from past expiry date. The amount wasted ranges from 10% to 50% in the North (FAO, 2011). In the above picture we conservatively assume that 1/3 of P in vegetarian food is lost in this way and 1/4 of P in meat-based food (slide 5.1-20). Therefore, farmers provide food products that contain 0.45 kg/yr. and 0.8 kg/yr. of P for vegetarians and meat-eaters respectively. Search for country-based data and insert these.

Step 3: The part of the crop that is edible is often small (e.g. the maize on a stem or the banana on a banana tree) and we have assumed ¼ to be the edible part (therefore a total input of 1.8 kg of P), while the rest remains on the farm – if well managed. Producing meat and dairy products involves the production of animal feed and we assume that 10% is converted into food output and 90% is feed and organic waste which remains on the farm. The edible meat therefore would require an input of about 8 kg P. However, accumulation of P in the soil provokes the low efficiency from fertilizer to food (Step 3). Search for country-based data and insert these.

Step 4: Fertilizer application rates differ depending on a number of factors such as soil type, farm practice, economics and crop species. If the phosphorus stock in the soil provides 2/3 of the needed P, 0.6 kg/vegetarian/y needs to be added as fertilizer or 4.2 kg of phosphate rock. Similarly, for meat-eaters some 11.8 kg/p/y of rock P has to be added, if we assume that 1/5 of the P is coming from the fertilizer and 4/5 from the soil phosphorus stock. However, as soil P is gradually depleted, P in residues has to be recycled. Again, search for country-based data.

This simple calculation by hand using guestimates of phosphorus losses should be done with real household, community or country data. It is likely to highlight that a vegetarian diet demands significantly less phosphate fertilizer than a meat-based diet. It also shows that returning biomass from plants and manure from animals to the soil is by far the most important measure to retain soil phosphorus in a meat-based diet. This measure also requires little or no transport. For the vegetarian diet, the recovery of human excreta is the most important measure, but this involves collection and transport of excreta back to the field.

A quick check indicates whether the results are plausible. If we assume that 80 % of the food intake is from plants and 20 % from meat and milk products, an average diet would require 0.8 times 4.2 kg + 0.2 times 11.8 kg = 5.72 kg phosphate rock per person and year. A comparison with info on slide 5.1-3 (7*0.6 kg =4.2 kg) shows that 5.72 kg is on the higher side. For 7 billion people that would add up to some 40 Mt of phosphate rock. This is just a quarter of the global rock production of 160 Mt. The magnitude gives room for losses, but the scenario should be refined by manipulating assumptions and reiterate the calculations.

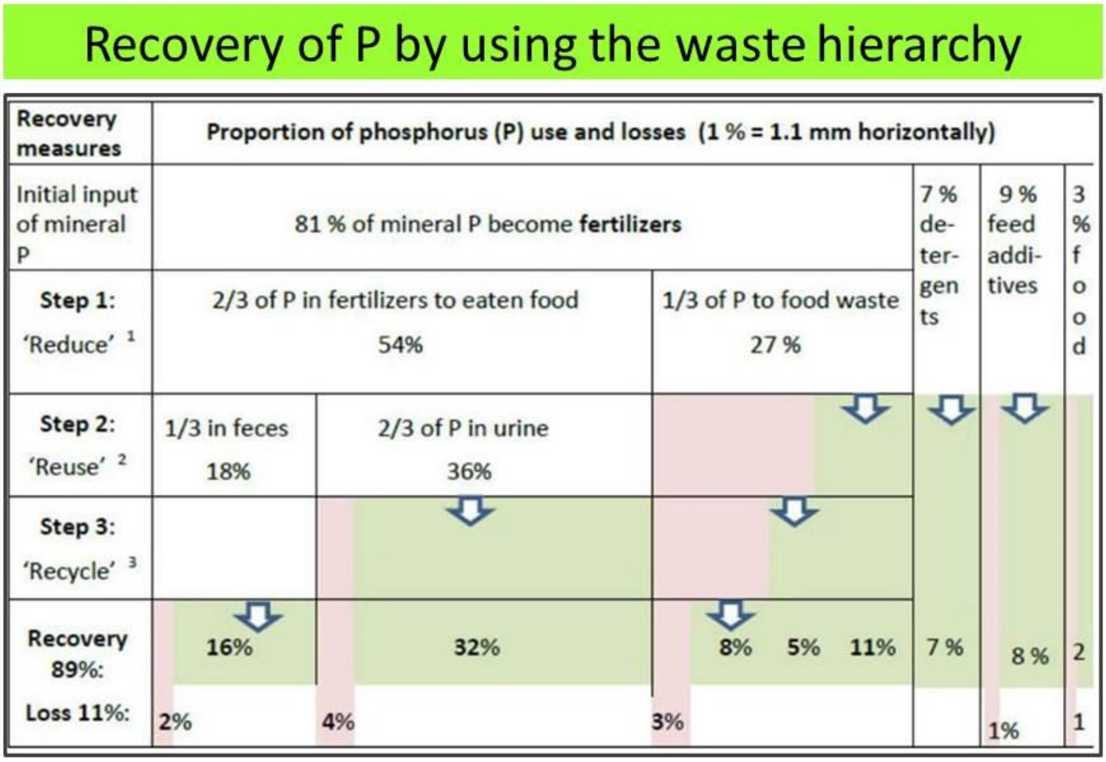
The more data that is available the easier are the above calculations, e.g. country-based data such as the following from China and Hong Kong giving P_2O_5 concentration and per capita consumption for the main food groups for two time-periods. The data shows that the intake of cereals and vegetables go down while those of milk and egg increase over time.

Food group	**P_2O_5 g/ 100 g edible food part**		**g eaten food per capita and day**		**P_2O_5 g eaten per capita and day**		**Hong Kong g/cap/day a**
	1985-92	**1993-06**	**1985-92**	**1993-06**	**1985-92**	**1993-06**	**1997**
Cereals	0.48	0.33	432	356	2.07	1.18	303.8
Potato/tubers	0.08	0.14	56	30	0.04	0.04	n.a.
Vegetables	0.22	0.10	310	259	0.68	0.26	206.3
Fruits	0.05	0.05	74	73	0.04	0.04	292.9
Animal meat	0.47	0.40	61	61	0.29	0.25	352.3
Poultry meat	0.37	0.35	20	23	0.08	0.08	
Milk product	0.55	0.82	23	73	0.13	0.60	231.8
Poultry eggs	0.47	0.41	22	192	0.11	0.79	n.a.
Fish products	0.74	0.59	33	36	0.24	0.21	160.0
Sum					3.68	3.45	

Source: Li et al., 2011 and a) Warren-Rhodes et al., 2001. n .a. = not available

We may also consider an extreme case where all food is produced locally and all organic waste including excreta is returned to the soil. No extra P would be necessary. A small household with a garden of a few hundred square meters could be almost self-sufficient in food (slide 5.1-15). The nutrients in sanitised human urine and composted faecal and other organic matter would return as input for the next crop of maize, tomatoes, etc. These fertilizers only have to be transported a few metres and the work required to prepare them for the garden (storage) is easy. The household could also raise a few chickens and possibly a pig if culturally feasible. Almost all nutrient losses can be avoided. Precision farming will reduce emissions of greenhouse gases. See also slide 1.3 - 13 on the proportions of recycled P over time in a Swedish town.

5.1 - 24



[1] Food waste reduced to 20%, detergents down to nil, use of additives reduced to 2%

[2] Reuse 90% of all urine; reuse 30% of bio-waste.

[3] Recycle 90% of fecal matter and 70% of bio-waste (compost/biogas)
(Jan-Olof Drangert, Linköping University)

A 'waste hierarchy' (5.1-14) and life-cycle thinking serves the dual purpose to grasp the importance of recycling nutrient resources for improved global food security. Data presented in this module are brought together in a comprehensive format in the figure to assist stakeholders to identify wasteful handling of nutrients in urban waste and to suggest measures to better manage those nutrients. Since excreta contain most P and nitrogen in urban waste flows it is included in the calculations to show the possibilities to realize the P recovery potential.

P in biodegradable paper, board and wood waste is not included in the Figure since these flows are already recycled to a large extent for non-agricultural purposes. Garden waste is also not considered due to a lack of reliable data, but it can easily be composted and recycled.

The Figure shows the fate of P through the three fist steps of the 'waste hierarchy'. The mined phosphate rock is mainly used to manufacture fertilizers (81%), feed additives (9%), detergents (7%) and food additives (3%). Reducing P content (Step 1a) is possible for additives and detergents. However, no reduction of mineral P fertilizer use is suggested since this is an issue for the agricultural sector, *i.e.* to improve the fertilizer use efficiency, and not part of efforts to recover urban nutrients. Nor is a shift back to more vegetarian diets suggested, although it could reduce P demand considerably.

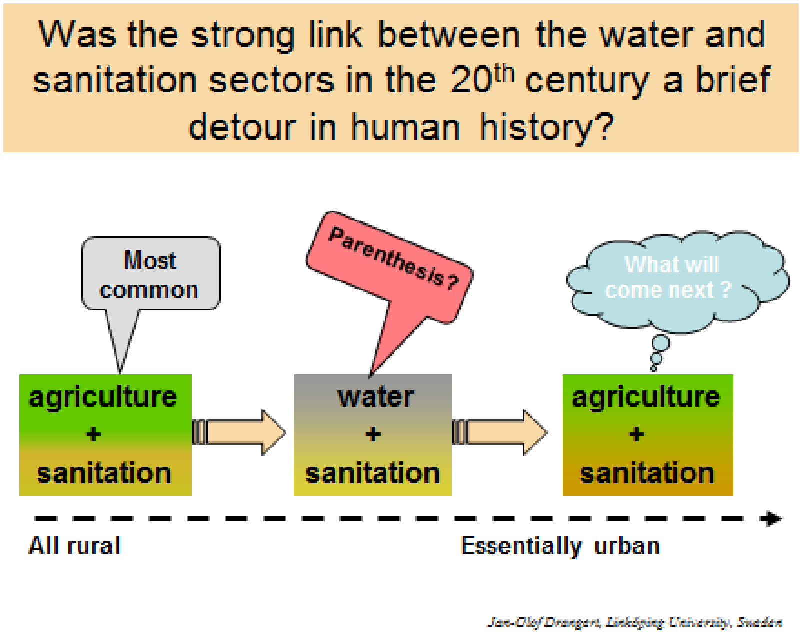
In our chemical societies, the long-term affordable solution to securing good-quality sludge and urine/faeces/blackwater is to design systems that avoid mixing flows (Step 1b). Just like polluting industries today have to collect their sewage in separate sewers and treat it separately, households should also dispose of its polluted greywater (often containing more varied chemical composition than industrial wastewater) in a separate sewer and treat it separately.

Eaten food contains 54% of total P that is subsequently excreted and ends up in sludge. The sludge is presently partly landfilled due to harmful substances in mixed wastewaters and to associated negative perceptions on excreta recycling. With a well-designed city infrastructure it is realistic to recover 90% of P in urine and faecal matter (or from blackwater). Some 30% of food waste can be reused directly (Step 2), and 70% of the remaining food waste can be recycled. Anaerobic digestion and composting (Step 3) allow the nutrient-rich digestants and compost to be used as a fertilizer in agriculture.

The proposed measures increase P recovery from a few percentage points to 89%. 28% of the P can be saved by shifting to using other substances (17%) and to decrease food losses (11%). Another 31 % can be saved by reusing/recycling food P and human excreta. We have assumed that half of the mined P is still lost in the food chain up to the consumption stage, and no change in the role of soil P in agricultural soils. With those assumptions, the time-span with food security is more than doubled and the transgression of planetary P resource boundary is delayed by hundreds of years. In addition, sustainable levels are achieved regarding harmful emissions from food production, consumption and nutrient waste management.

The necessary changes in infrastructure to achieve the above result will continue to the end of this century. EU has shown that this is practically and economically feasible. Now is a window of unprecedented opportunity to design urban infrastructure since houses and infrastructure for an addition 5.5 billion new urban residents in the 21st century have not yet been planned. A win-win situation is imminent, providing both food security and reduced harmful emissions to air, water and soil.

5.1 - 25



Feeding humanity is a serious global challenge both today and for the future. Today, an unprecedented 1 billion people are hungry – one sixth of all humanity. Global food security is now considered a global priority (UN, 2000). The UN's Food and Agriculture Organization (FAO) states that food security "exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs for an active and healthy life" (FAO, 2005). This definition does not address the emerging health hazard of eating too much. Obesity will soon become as common as malnourishment. Obesity also increases the environmental burden since a fat person is responsible for about one tonne more of carbon dioxide emission than a thin person (Edwards and Roberts, 2009). Lastly, the EU estimates that every citizen accounts for 11 tons of greenhouse gas emissions a year.

A century ago, most people lived on farms and produced their own food nearby with the help of easily recycled organic matter. Today, the conditions are totally different. More than half the world's population lives in urban areas, and there will be another two billion new urban mouths to feed before 2050. Future food security can only be achieved by addressing a number of interlinked social, economic and environmental issues. Innovative ways are needed to meet the food requirements of undernourished urban populations, not least those living in peri-urban areas of mega-cities. Existing decentralised urban food production could be developed further by sustainable communities which recycle nutrients and water (slide 2.1-19). We will have to stop the wasteful linear one-way flow of nutrients from farms to lake sediment.

The kind of food we eat on a daily basis has a dramatic impact on the environment. An illustration is the strong link between diet and land use. The production of meat-based food occupies almost a third of the world's land surface. This consists mostly of permanent pasture but also the third of the world's arable land that is cultivated to provide livestock feed (McMichael et al., 2007). A meat-based diet requires a much larger area of land than a diet of cereals and vegetables. A serious challenge is to keep crop-based diets and not to switch to meat-based diets for status reasons.

Averting future phosphorus and food crises is possible, but it will require substantial changes to our behavior, and to our society's physical infrastructure and institutional frameworks. Sanitation systems of the future, for example, will need to ensure that close to all phosphorus in excreta is recovered for re-use in fertilizers. Hence the sanitation sector will play a vital role in achieving phosphorus security and food security, in addition to enhancing environmental protection and public health.

5.1 -26

Today we are faced with numerous interlinked global sustainability challenges, from climate change, peak oil, water scarcity and poor sanitation to food security. Global phosphorus scarcity presents yet another such globally significant challenge. The good news is that opportunities exist to integrate innovative responses to this new challenge with responses to other challenges in order to create a sustainable, safe and food-secure future. Countries with no phosphate rock reserves can, through recycling strategies from farm to toilet, reduce the demand for rock phosphate to a minimum. Poor countries can prevent price shocks and limit high costs for fertilizer subsidies by subsidising recycling measures instead.

Given the dire consequences of phosphorus scarcity for food production, it is surprising that the role of future phosphorus scarcity is not yet well recognised in the food security debate. For example, the director of FAO, as recently as World Food Day on November 2009, said that food security can be achieved if the rich countries provide subsidies to poor countries so that they can buy chemical fertilizers. The missing debate could be due to a 'lack of fit' between the natural phosphorus cycle and existing institutions and social arrangements. For example, while almost all phosphorus flows from consumed food to excreta in the natural phosphorus cycle, there is little institutional connection between the food sector and the sanitation sector. Phosphorus is perceived quite differently by different sectors. For example, it is perceived as an 'environmental pollutant' by freshwater ecologists, or an 'agricultural commodity' by resource economists, and so on. Up to now, phosphorus scarcity has been a priority to none. It has essentially slipped through the institutional cracks. It is clear that the market alone cannot manage the wider system in a sustainable, equitable and timely manner.

Increasing political awareness about the future of oil in recent decades has resulted in a massive restructuring of investments to reduce oil dependency. The phosphorus sector can learn from such experiences to redirect investments to plant nutrient recycling. This will at the same time reduce energy demand and greenhouse gas emissions.

The Green Revolution saved millions from starvation through the use of irrigation, fertilizers and new crop varieties. The next revolution is a rethink that will require new infrastructure, partnerships and social change to recycle nutrients back to agriculture.

The International Fertilizer Industry Association (IFA) indicates it is committed to a sustainable fertilizer industry and the European Fertilizer Manufacturers Association states: “Two major opportunities for increasing the life expectancy of the world’s phosphorus resources lie in recycling by recovery from municipal and other waste products and in the efficient use in agriculture of both phosphatic mineral fertilizer and animal manure” (EFMA, 2000a).

EFMA in 2009 formulated a policy for the industry when developing new products. It reads: “Being committed to Responsible Care, all fertilizer producers should identify the potential impacts of their new products on people, property and the environment. They should satisfy themselves that all reasonable steps have been taken to minimize these impacts and that any residual risk can be managed satisfactorily - taking into account the supply and manufacturing, the distribution, intermediate storage and handling from the factory to the farm, and the farmers' handling and application of the product.” (EFMA Product Stewardship for fertilizers, 2009)

The European fertilizer industry has its own regulations for life-cycle analysis of phosphorus in addition to the EU framework (see Module. 4.1.9 in the Product Stewardship for fertilizers). It includes waste minimisation and disposal.

While dependence on mined phosphate rock increased dramatically over the second half of the 20th century, reliance on non-renewable phosphate will need to decrease over the 21st century (due to the phosphorus peak). A sustainable phosphorus future will include a reduced reliance on phosphate rock and efficient recycling measures in all spheres of P usage.

References

Claesson, S. and Steineck, S. 1991. Växtnäring hushållning – miljö (Plant Nutrient management – Environment). In Swedish. Sveriges Lantbruksuniversitet. Speciella skrifter 41, Uppsala.

Cordell, D., Drangert, J.-O. & White, S. 2009a. The story of phosphorus: global food security and food for thought. *Global Environmental Change*, 19, May 2009, pp.292-305.

Cordell, D., Neset, T. S., White, S., & Drangert, J.-O. 2009b. Preferred future phosphorus scenarios: a framework for meeting long-term phosphorus needs for global food demand, International Conference on Nutrient Recovery from Wastewater Streams Vancouver, 2009., Edited by Don Mavinic, Ken Ashley and Fred Koch. ISBN: 9781843392323. IWA Publishing, London, UK.

Dery P. and B. Anderson 2007. Peak phosphorus. *Energy Bulletin*, 08/13/2007.Available: energybulltin.net/node/33164.

Drangert, J.-O. 1998. Fighting the urine blindness to provide more sanitation options. *Water SA,* 24, (2) 157-64.

Drangert, J-O., Tonderski, K., McConville, J., Tidåker, P., Rauch, S., Schmid Neset, T., and D. Mara 2013. Managing local organic waste for global food security: Functional criteria to guide nutrient-effective urban sanitation. (in preparation).

Edwards, P. and I. Roberts, 2009. Population and adiposity and climate change. *Int. J. Epidemiol*., 38(4):1137-1140; doi:10.1093/ije/dyp172.

EFMA 2000a. *Production of Phosphoric Acid*, Booklet #4 (2000). European Fertilizer Manufacturers Association. *www.fertilizerseurope.com/*

EFMA 2000b. *Understanding phosphorus and its use in agriculture*. European Fertilizer Manufacturers Association, Brussels *www.fertilizerseurope.com/*

EFMA 2000c. Code of best agricultural practice. Urea. European Fertilizer Manufacturers Association. Brussels.

EFMA 2006. *Sustaining fertile soil and productive agriculture*. European Fertilizer Manufacturers Association. Brussels. www.fertilizerseurope.com

EC 2008. Waste Framework Directive 2008/98/EC. Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0098:EN:NOT

FAO 2005. *The Special Program for Food Security*, Food and Agriculture Organization of the United Nations, Available: http://www.fao.org

FAO 2006. Plant nutrition for food security: A guide for integrated nutrient management, *FAO Fertilizer and Plant Nutrition Bulletin 16*, Food and Agriculture Organization of the United Nations, Rome.

FAO 2008. Efficiency of soil and fertilizer phosphorus use: Reconciling changing concepts of soils phosphorus behavior with agronomic information, *FAO Fertilizer and Plant Nutrition Bulletin 18*, Food and Agriculture Organization of the United Nations, Rome.

FAO 2011. Global Food Losses and Food Waste. Study conducted for the International Congress Save Food! At Interpack 2011 in Dusseldorf, Germany. Food and Agricultural Org. Rome.

FAO 2013. Think, Eat, Save. The FAO, UNEP and partners launch of a global campaign on food waste. http://www.fao.org/news/story/en/item/168515/icode/

Fertilizer Week 2008. Industry ponders the impact of China's trade policy, in *Thursday Markets Report*, 24th April 2008, British Sulphur Consultants, CRU.

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Gerber, J S, Johnston, M, Mueller, N D, O'Connell, C, Ray, D K, West, P C, Balzer, C, Bennett, E M, Carpenter, S R, Hill, J, Monfreda, C, Polasky, S, Rockström, J, Sheehan, J, Siebert, S, Tilman, D, Zaks, D M. Solutions for a cultivated planet. *Nature* 2011; 478:337-42.

Gilbert, N. 2009. The disappearing nutrient. *Nature*, Vol.461-8 October, 2009.

Hagen, E. 2008. The role of natural resources in the Western Sahara conflict, and the interests involved, International conference on multilateralism and international law, with Western Sahara as a case study, 4-5 December 2008, Pretoria, South Africa.

Heffer, P. and Prud'homme, M. 2009. *Fertilizer Outlook 2009-2013*, 77th IFA Annual Conference International Fertilizer Industry Association (IFA) Shanghai (China P.R.), 25-27 May 2009.

Hubbert, M. K. 1949. Energy from fossil fuels. *Science,* 109, 2823, 103.)

IFA 2006. Production and International Trade Statistics. International Fertilizer Industry Association. Paris. Available: www.fertilizer.org/ifa/statistics/pit_public_statistics.asp (accessed 20 August, 2007).

IFA 2008. *Feeding the Earth: Fertilizers and Global Food Security, Market Drivers and Fertilizer Economics* International Fertilizer Industry Association Paris.

IFDC, 2010. *World phosphorus rock resources and reserves*. September, 2010. International Fertilizer Development Center.

IFPRI 2002. *Reaching sustainable food security for all by 2020: getting the priorities and responsibilities right*, International Food Policy Research Institute, Washington.

Jönsson, H., Stintzing, A. R., Vinnerås, B. & Salomon, E. 2004. *Guidelines on the use of urine and faeces in crop production*, EcoSanRes, Stockholm Environment Institute, Stockholm.

Jönsson, H., Hallin, S., Bishop, K., Gren, I-M., Jensen, E.S., Rockström, J., Vinnerås, B., Bergkvist, G., Strid, I. Kvarnström, E. 2012. Många skäl att återvinna mer fosfor (Several reasons to recover more phosphorus). *Dagens Nyheter* 2012-08-03.

Li, G. et al., 2011. Urban phosphorus metabolism through food consumption: The case of China. *Journal of Industrial Ecology* (accepted).

Livsmedelsverket 2008. *Towards eating recommendations based on environmental concerns* (På väg mot miljöanpassade kostråd). Report 9-2008, Swedish National Food Administration, Uppsala, Sweden. (In Swedish.).

Malingreau, J-P., Hugh Eva, Albino Maggio 2012. *NPK: Will there be enough plant nutrients to feed a world of 9 billion in 2050? Foresight and Horizon Scanning Series*. JRC Science and Policy Report. European Commission, Joint Research Centre. Brussels.

McMichael, A.J., Powles, J.W., Butler, C.D., Uauy, R. 2007. Food, livestock production, energy, climate change, and health. *The Lancet*, Vol. 370, October, 2007.

OCP, 2009. Annual Report 2009. Office Cherifien des Phosphates (OCP Group). Casablanca.

Parfitt, J., Barthel, M., and S. McNaughton, 2010. Food waste within food supply chains: quantification and potential for change to 2050. *Phil. Trans. R. Soc.* B (2010) 365:3065-81.

Prud'homme, M. 2010. *Peak phosphorus: an issue to be addressed*, Fertilizers & Agriculture, International Fertilizer Industry Association, February 2010.

Quested T, Johnson H. Household Food and Drink Waste in the UK. Waste and Resources Action Programme WRAP, Banbury UK; 2009.

Reuters News Agency, Nov 26, 2010.

Rognlien, A. 2010. Nok fosfor i 2000 år (Enough phosphorus for 2000 years). Aftenposten 28 Oct. 2010. Norway.

Schiemenz, K. and B. Eichler-Löbermann (2010). Biomass ashes and their phosphorus fertilizing effect on different crops. Nutrient Cycling in Agro ecosystems: 1-12.

SIWI-IWMI 2004. *Water – more nutrition per drop, towards sustainable food production and consumption patterns in a rapidly changing world*. Stockholm International Water Institute, Stockholm.

Smil, V. 2000a. *Feeding the world: a challenge for the 21st century,* MIT Press, Cambridge.

Smil, V. 2000b. Phosphorus in the environment: natural flows and human interferences *Annual Review of Energy and the Environment,* 25, 53-88.

Smit, A.L., A.A. Pronk and P. De Willigen (2010). Placement of phosphate leads to a more efficient use of a finite resource. Acta Horticulturae 852: 189-194.

SPI, 2010. Sustainable Phosphorus Initiative. Viewed at sustainablep@asu.edu 2011.

Stoumann Jensen, L. 2010. P in Danish fertilizer- and waste streams – needs, potentials and requirements. Presentation at MLS P Partnerskaber Workshop, Copenhagen, 16 Nov. 2010.

UN 2000. Millennium Development Goals, Millennium Assembly.

UNDP 1996. *Urban Agriculture: Food, jobs and sustainable cities*. UNDP Publication Series for Habitat II. Volume One. New York.

USGS 2008. *Phosphate rock, mineral commodity summaries*, U.S. Geological Survey Jasinski, S. M., March, 2010. http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock

Vaccari, D. 2009. Phosphorus: a looming crisis. *Scientific American*. June 2009. Vol. 300 No. 6.

Villalba, G., Y. Liu, H. Schroder and R.U. Ayres (2008). Global Phosphorus Flows in the Industrial Economy from a Production Perspective. Journal of Industrial Ecology 12(4): 557-569.

White, J. 2000. *Introduction to Biogeochemical Cycles (Ch.4)*, Department of Geological Sciences, University of Colorado, Boulder.

Wijkman, A. and J. Rockström. 2012. Bankrupting Nature. Denying our planetary boundaries. A report to the Club of Rome. New York. Routledge

Williams, H., Wikström, F., Otterbring, T., Löfgren, M., and A. Gustafsson. 2012. Reasons for household food waste with special attention to packaging. J Clean Prod 2012; 24:141-8.

Vinnerås, B. Palmquist, H. Balmer, P. & Jönsson, H. 2006. The characteristics of household wastewater and biodegradable solid waste-A proposal for new Swedish design values. Urban Water, 3(1): 3-11.

Wissa, A.E.Z. 2003. *Phosphogypsum disposal and the environment* Ardaman & Associates Inc., Florida. Available: www.fipr.state.fl.us/pondwatercd/phosphogypsum_disposal.htm

World Bank 2011. *Commodity price data (pink sheet), prospects for the global economy*, World Bank, Available: http://go.worldbank.org/5AT3JHWYU0.

WWF 2004. *Living planet report*, World Wide Fund for Nature, Cambridge. Available: