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NPK: Will there be enough plant nutrients to feed a world of 9 billion in 2050?

Foresight and Horizon Scanning Series

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Executive Summary

"There is no specific reason to be alarmed about the overall supply of nitrogen, potassium and phosphorus for the world's agriculture but because of changing conditions in production, demand and use, continuous vigilance is called for."

"Will there be enough plant nutrients to feed a world of 9 billion in 2050?" is the central question addressed by this Joint Research Centre (JRC) Foresight Study. N (Nitrogen), P (Phosphorus) and K (Potassium) are three essential nutrients for plant growth. Their availability in the form of fertilizers represents a key factor in the overall question of global food security as we move towards a population of 9 billion. Moreover, over 90% of population growth between 2010 and 2050 will occur in developing economies. Over 90% of the 1 billion poorest people live in these economies where food security is and will remain a serious challenge unless appropriate policy and technical measures are taken to ensure fertilizer security.

Phosphorus (P) (extracted from phosphate rock) can be considered a strategic resource because 1) it is a finite resource; 2) its exploitation has experienced a rapid increase linked to demand; 3) the production comes from a few countries and that it is essential for plant growth.

Nitrogen (N) is ubiquitous (78% by volume in the atmosphere). Its transformation into ammonia is highly demanding both in hydrogen and energy (from natural gas or coal). In a volatile energy market, or changing natural gas availability context, the industrial dimension of its production may become strategic.

Potassium (K) reserves (in the form of potash) are in the hands of a few countries and companies, raising the possibility of cartelisation. Two thirds of the world production is in 3 countries (Canada, Russia and Belarus), while eight companies control 80% of the production.

It is legitimate to assume that in a more rapidly changing geopolitical situation and less stable world, the question of the security of NPK supply could one day become relevant at least in some regional context.

It is now generally accepted that, whatever the existing proven resources, our complete dependence on non-renewable resources such as P and K must be confronted in any long term food security strategy.

Main conclusions

- Based on current demand, usable reserves in P will be reduced by 25% in 2100. These usable reserves will be further reduced if demand for (P) will have more than doubled in the mean time. Furthermore we can assume that i) the quality of P reserves will create soil contamination; ii) excess use of compound fertilizers continues to give rise to water pollution and iii) energy cost for production of N double in the same period. Based on these facts, the questions that need to be addressed are:

1. When (in terms of residual uses of reserves) do we need to start assembling and implementing a global strategy for NPK use (with respect to geographical determinants, efficiencies, requirements, access etc.)?

2. When do we need to have applicable and practical alternatives developed, fully tested and implemented at the required regional/global scale?

- Considering that any global resource or environment policy takes 25-30 years to be developed at international level (e.g. climate change, biodiversity, etc.), any decision possibly made today to tackle NPK potential issues on a global scale can only realistically be put on track in 2040. This is barely a decade before the world population is likely to reach the 9 billion mark. In addition, as the report shows, a significant growth in demand, increase in environmental concerns, cost of energy, geopolitical crises etc. may accelerate the onset of a potential shortage to significantly less than 100 years. Converging courses between the time lag to policy implementation and the onset of potential shortage call for attention. This is the base for the recommendation made here that vigilance is needed with respect to possible developments during the next decade.

- While current concerns are clearly directed to the question of access and rational use of fertilization in a sustainable agriculture, several parameters shaping the global production and demand will evolve; new models to evaluate such evolution of the matching between effective demand and supply will have to:

1. Take into account not only the crop requirements for food production but also the application efficiencies, soil rehabilitation, environmental linkages and socio-economic determinant of access, per crop and per region.

2. Go beyond economics to consider geostrategic elements in a more uncertain global political situation.

- The NPK question is a global issue, access to it is a regional issue and management of crops is a local dimension. The discourse will have to move away from normative approach to sustainability to more practical and geographically adapted solutions in terms of production, access and use of fertilizers, including the development of proper "enabling environments", which integrate the results of research into socio-economic contexts (i.e. transfer of *proven* technology vs. development of *new* technology).

- Finally, this study also underlines the need for considering a global governance system ensuring sustainable management of the three essential plant macronutrients in the context of long-term food (and political) security to the world. The recently proposed FAO Global Soil Partnership is a step in that direction.

Contents

Abbreviations

Common Agricultural Policy (CAP)
Directorate General Agriculture (DG AGRI)
Directorate General for Environment (DG ENV)
Directorates General (DG)
European Union (EU)
Eurostat (DG ESTAT)
Food and Agricultural Organization of the United Nations (FAO)
Food and agricultural Organization of the United Nations Statistical division (FAOSTAT)
Greenhouse gas (GHS)
Gross Domestic Product (GDP)
International Fertilizer Development Center (IFDC)
Joint Research Centre (JRC)
Nitrogen, potassium and phosphor (NPK)
United Nations (UN)
World Trade Organization (WTO)

"There is no specific reason to be alarmed about the overall supply of nitrogen, potassium and phosphorus for the world's agriculture but because of changing conditions in production, demand and use, continuous vigilance is called for."

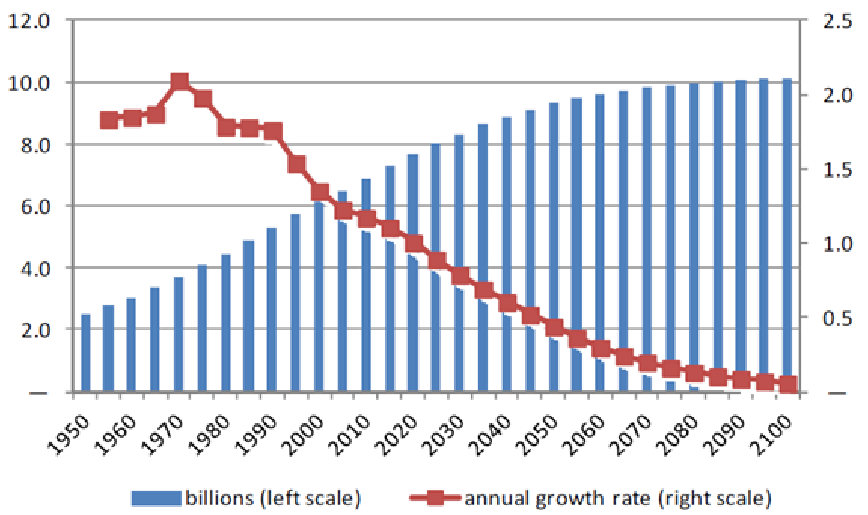
1. Introduction

"Will there be enough plant nutrients to feed a world of 9 billion in 2050?" is the central question addressed by this Joint Research Centre (JRC) Foresight Study. Supporting reviews and analyses were based on a general model of interactions between the components of the agricultural production system as described in the figure in Annex 2. N (Nitrogen), P (Phosphorus) and K (Potassium) are three essential nutrients for plant growth. Their availability in the form of fertilizers represents a key factor in the overall question of global food security as we move towards a population of 9 billion. Moreover, over 90% of population growth between 2010 and 2050 will occur in developing economies. Over 90% of the 1 billion poorest people live in these economies where food security is and will remain a serious challenge unless appropriate policy and technical measures are taken to ensure fertilizer security.

The work reported here is based on an extensive literature review and bilateral meetings with selected industries and European Union (EU) Commission services. A set of background reports[1] were produced summarizing current knowledge related to demand and production of fertilizers and to the research and innovation elements that come into play. An expert workshop was convened by the JRC Foresight team, within the Science Advice to Policy Unit, in Brussels on December 5 and 6 2011. The event was attended by experts from academia, industry, EU policy DGs and the JRC. The workshop examined a broad range of questions related to the adequate provision of fertilizers to support future world agricultural production.

Box 1
The Time Horizon

The time horizon of 2050 was selected for this study as a critical point of maximum demand (*mouths to be fed*) on agricultural production, considering that the population growth rate is expected to be nearing zero around that date. An earlier time horizon does not appear critical in terms of provision of fertilizers for crops (this may not be true, however, with respect to access or impact of their excessive use). Beyond 2050 perspectives are more difficult to assess.



World population predictions to 2100 (source: UN, 2010).

[1] Relevant documents related to the workshop can be consulted at http://eusoils.jrc.ec.europa.eu/projects/NPK/

This exercise focused on three areas of interest: the demand for fertilizers to sustain crop production necessary to feed the world in 2050 (see Box 1), perspectives on the supply of Nitrogen, Phosphorus and Potassium to world agriculture and the role of innovation and technology in improving the match between supply and demand of the fertilizers. The workshop followed the same framework and included a discussion on implications of the findings for current EU and international policies.

In this study we separate the analysis of production aspects by element (N, P and K), since the time and space characteristics of their reserves and availability are different. However, following the long-standing Liebig's law[2], the efficiency of application of one element depends upon the soil nutritional status of the others and – there are good arguments for maintaining attention to the NPK ratio with respect to a balanced fertilization (see Box 2).

Box 2 **Most common fertilizers**		
Nitrogen fertilizers	**Phosphate fertilizers**	**Potash fertilizers**
Urea $CO(NH_2)_2$	Diammonium phosphate (DAP) $(NH_4)_2HPO_4$	Chloride of potash KCl
Ammonium sulphate $(NH_4)_2SO_4$	Single superphosphate $Ca(H_2PO_4)_2 + CaSO_4$	Sulphate of potash K_2SO_4
Ammonium nitrate NH_4NO_3	Triple superphosphate $Ca(H_2PO_4)_2$	Sulphate of potash-magnesia $K_2SO_4 \cdot 2MgSO_4$
Calcium ammonium nitrate $NH_4NO_3+CaCO_3$	Ground rock phosphate (mineral phosphate)	Nitrate of potash KNO_3

Given that phosphorus (extracted from phosphate rock) is a finite resource, that its exploitation has experienced a rapid increase linked to demand (Figure 1), that production comes from a few countries and that it is essential for plant growth, P can be considered a strategic resource.

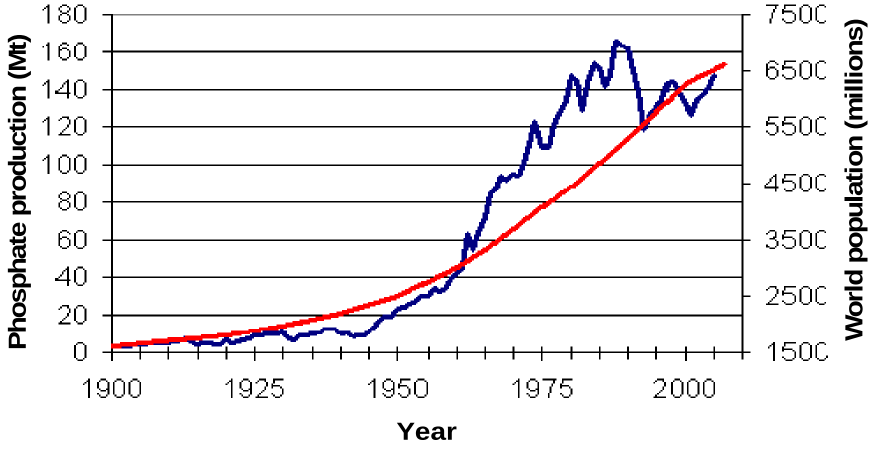
While nitrogen is ubiquitous (78% by volume in the atmosphere), its transformation into ammonia is highly demanding both in hydrogen and energy (from natural gas or coal). In a volatile energy market, or changing natural gas availability context, the industrial dimension of its production may become strategic.

Potassium reserves (in the form of potash) are in the hands of a few countries and companies, raising the possibility of cartelisation. Two thirds of the world production is in 3 countries (Canada, Russia and Belarus), while eight companies control 80% of the production (D'Altorio, 2010).

[2] Liebig's Law of the Minimum, often simply called Liebig's Law or the Law of the Minimum, is a principle developed in agricultural science by Carl Sprengel (1828) and later popularized by Justus von Liebig. It states that growth is controlled not by the total amount of resources available, but by the scarcest resource (limiting factor) (Source: http://en.wikipedia.org/).

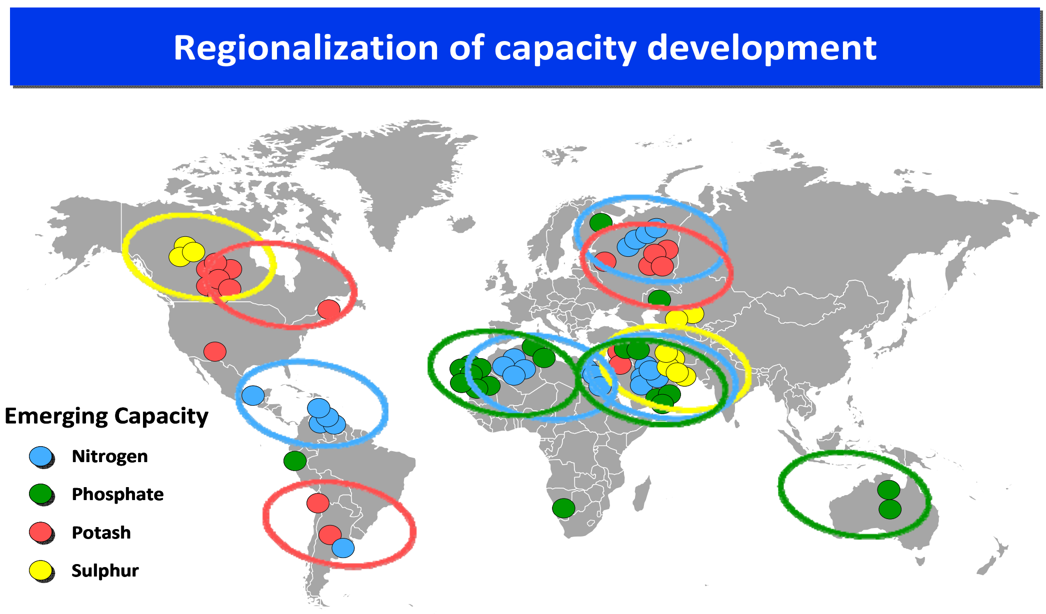
It is legitimate to assume that in a more rapidly changing geopolitical situation and less stable world, the question of the security of NPK supply could one day become relevant at least in some regional context.

Figure 1: Trends in global extraction of phosphate rock (blue line) from 1900 in relation to population growth (red line). In 2005, as the world population neared 7 billion almost 180 Mt of rock were extracted (source: Déry and Andersson, 2007).



The present report underlines that there are numerous uncertainties affecting NPK analyses at global scales; in addition, regional situations are often specific with respect to plant nutrient needs and availability. This mismatch between the geography of supply and demand needs to be further examined in various economic and geopolitical scenarios (Figure 2).

Figure 2: Geography of production (source: Prud'homme, 2011).



The volatility of fertilizer prices has, since the year 2000, closely followed that of crude oil but this feature does not seem to present particular cause for concern in terms of future supply, demand and access of plant mineral nutrients (Huang, 2009). On the other hand, fertilizer prices increased significantly in the first decade of this century; during the food crisis at the end of the decade, they increased more than food prices. The extent to which this has influenced output and farm profits is not clear.
While it is a key input in advanced agriculture, the value of fertilizer is a small fraction of the gross value of production (7% in Western Europe) and influences profit margins in a small way only. In developing agriculture, the high cost of fertilizers is mainly determined by transport and other market constraints (IFDC, 2003; Gregory and Bumb, 2006). In this case, fertilizer price variability does not seem to influence the already low levels of use. The rapid increase in fertilizer prices in 2008 was a result of an increase in energy prices and grain prices, in bio-fuel production, and *panic* buying by large consumers. When buyers were assured of supply in the market, prices dropped drastically in 2009. In developing countries, the impact of higher prices was cushioned by subsidy programmes.

Over the long term, however, further increases in fertilizer costs could worsen conditions of access by individual farmers in developing countries and even put at risk any development programme based on increasing fertilizer inputs.

Overall, our analysis based on the review of existing literature and on discussions in the workshop leads to the conclusion that while the situation is <u>currently not critical</u> with respect to the production and availability of plant nutrients, it is important to <u>remain vigilant</u> <u>in particular given the fact that Europe is not self-sufficient in these nutrients</u> (see Box 3).

Box 3
How self-sufficient is Europe?

Europe is <u>entirely dependent</u> on external countries for phosphates. It is partially self-sufficient for its potassium supply with most of the mines concentrated in Germany and a few in United Kingdom, France and Spain. For nitrogen fertilizers, energy production costs are critical. The largest single user of natural gas in the EU is the nitrogen fertilizer industry. Natural gas contributes to 50-70% of total production costs of nitrogen fertilizers. Although free competition should regulate the supply, Russia, Algeria and Egypt dominate the gas market. Europe is among the region with the highest gas prices in the world with a 230% increase in the last decade. Measures to secure gas supply and regulate prices would therefore also stabilize the price of N fertilizers (source: www.fertilizerseurope.com).

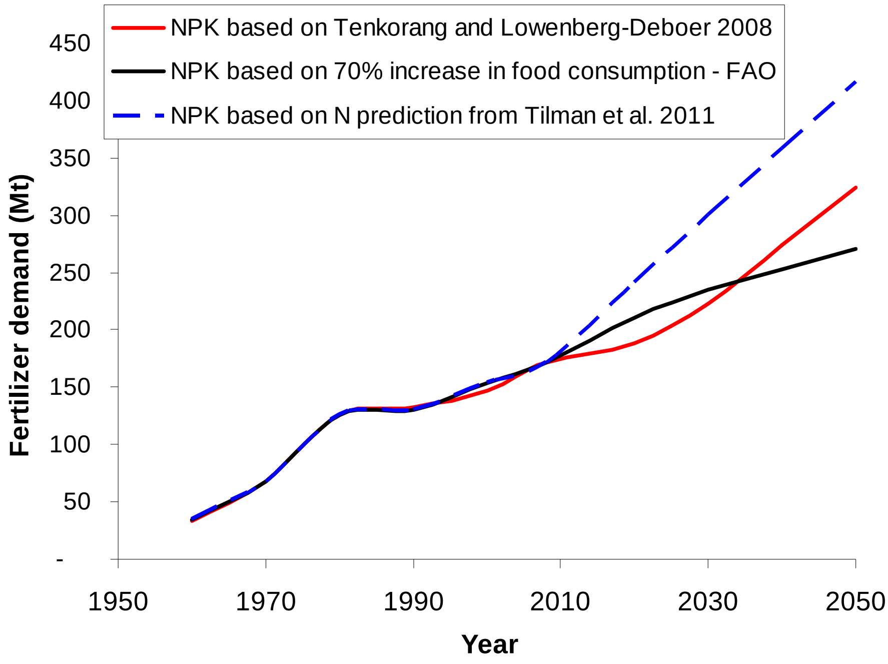
Developments related to reserves (P and K), access (P), changing geopolitical conditions (P and K), economic development, energy costs (mainly for N) and environmental constraints (N and P) could lead to temporary shortfalls and very high prices in some regions of the world. Whether this can lead to crisis situations has to be further examined. The situation of Africa was reviewed with particular attention as production, access and use of fertilizers represent key limiting factors in boosting food production in that continent.

It is now generally accepted that, whatever the existing proven resources, our <u>complete dependence on non-renewable resources</u> such as P and K must be confronted in any long term food security strategy (see Box 3).

2. The demand

Global estimates of fertilizer demand are based on regional analyses of either i) future food consumption (Bruinsma, 2011); ii) Known relationships between crop use and Gross Domestic Product (Tilman et al., 2011) or iii) other relationships between application rates and crop output (Tenkorang and Lowenberg-Deboer, 2008) (Figure 3).

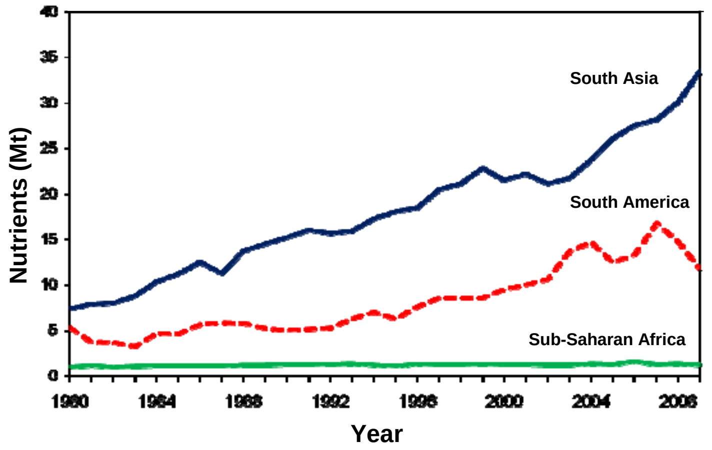
Figure 3: Forecasts of future fertilizer demand based on three different estimates.



Such estimates, however, exhibit high variance since different models, base lines and input data are used. Furthermore, data are not entirely reliable. The three models considered in the current study give a range of 240 to 400 M tons for combined fertilizer demand in 2050 i.e. an increase of 37% to 128% compared to present situation. Wide regional differences exist as illustrated by the case of Sub-Saharan Africa where current fertilizer use is less than 1/10 of the world average (see Box 4).
Changes in diets and food requirements, associated among others with urbanisation, will lead to shifts in crop-food production pathways. Those changes will mainly affect the balance between cereal and meat consumption but their impact on fertilizer demand has not been assessed. Similarly, the impact of the growing demand for biofuels is currently not factored in to fertilizer demand side assessments.

Box 4
Regional differences in fertilizers use

Fertilizer application rates in Sub-Saharan Africa are the lowest in the world, less than one tenth the global average and have remained at less than 10 kg per hectare over the last twenty years (over 200 kg in advanced agriculture). In contrast to other African countries, Sub-Saharan Africa (excluding South Africa) is a net importer of fertilizers. In addition, poor access to credit and lack of adequate market structures give to farmers little security that their investment will be paid back. Morocco the largest supplier of phosphate fertilizers is reported to develop special efforts towards a larger allocation to African countries (Source: FAOSTAT, 2012).



A key issue in pursuing sustainable agriculture is to maintain nutrient balance after harvest and to replenish (rebalance) soils with poor nutrient levels. Many soils, e.g. in Africa, are losing fertility and demand assessments should include the amount of fertilizers that would be needed to bring world agricultural land up to fertility levels adequate for future food production demand (Sanchez, 2002).

This point is not taken into consideration in current food demand based models. Soil depletion/replenishment cycles may represent a large pool in the global NPK equation. Consequently there is a recognised need to complete a detailed inventory of the global soil resources, particularly concerning detailed data on soil fertility and nutrient availability (Sanchez et al., 2009). Addressing global NPK issues raises, therefore, the question of defining an *effective* demand (i.e. a demand figure that would include plant use for food production, soil replenishment, and losses).

Finally, it is often taken for granted that fertilizer demand will closely follow the continuous rise in food production associated with population growth (Bruinsma, 2011). This is based on the fact that future demand will have to be met essentially through increases in yield. Current projected fertilizer increases are based on predicted population growth (summarized in Box 5). However, projections of fertilizer demand are difficult to validate since in many regions of the world a continuous improvement in fertilizer use efficiency is noted (see Figure 5 for N in Europe). In addition to fertilizer uses efficiency, other variables will affect these predictions, including changes in dietary habits, biofuels production and improved plant ability to uptake nutrients.

Box 5 Predicted 2005-2050 relative increase in regional fertilizers demand to meet food requirements (N+P2O5+K2O) (source: Drescher et al. 2011)	
Sub-Saharan Africa	300%
Near East + North Africa	180%
South Asia	88%
East Asia	39%
Latin American & Caribbean	164%
Industrial countries	69%

At this stage, the FAO figure of 70% increase in food production by 2050 is retained for assessing fertilizers demand; yet, new assessments appear to indicate that such reference value may be closer to 60%[3]. The FAO assessment is based on a demand estimation that would obviously be lower if progress was rapidly made towards more sustainable global food consumption.

[3] Provisional estimates of the Global Perspective Studies team in FAO-ESA.

3. The supply

Phosphorus (P) is extracted from phosphate rock, for which the still-controversial reserve estimates vary between 15 B tons and 65 B tons[4] (Cordell and White 2011, Kauwenbergh, 2010). P production has experienced a very rapid increase since the 1950s associated with the growth in global agricultural output; in that sense it has so far kept pace with population growth. Three countries control more than 85% of the known global phosphorus reserves, with Morocco having the largest share. However, more than 70 countries have known deposits of phosphorous ore. In addition to the geographical distribution of P mines, a major concern for the future is associated with extraction costs since most estimates have focused on ore tonnage with limited consideration for ore grade. Quantity is linked to quality in that reserves of phosphate with lower levels of contaminants may be particularly limited.

No independent source of data on reserves exists and there is no global arrangement made (e.g. by the UN) to monitor phosphorus ore mining. There is a critical need for a homogeneous, consistent and informed science-based determination on reserves, and resources.[5]

Discussions on phosphorus supply to agriculture are automatically linked to recycling issues. This point is of importance for Europe in the context of its environmental policy but can be extended to other intensive agriculture areas of the world. By focusing on efficiencies of application, the reform of the EU Common Agricultural Policy (CAP) addresses this point. However, the contribution of current and potential recycling of wastes (manure, sludge, sanitation) to the available global phosphorus is not easy to ascertain. Currently a 20% efficiency of P use along the mine-to-fork pathway is calculated, giving room for improvement along each step of the process (Schroeder et al., 2010). It is worth highlighting, however, that 'recycling of waste' should be first pursued to minimize the adverse impact on the ecosystem; its contribution towards reducing dependence on P imports will not have an effect in the short term.

Potassium (K) supply (extracted from potash) is assured without practical time limit; however, reserves are concentrated in certain geographic areas (2/3 of world production in Canada, Russia and Belarus) and in limited industrial groups (80% of production in eight companies). Large scale investments are needed for opening new capacity; securing potash supply (as well as P) is considered critical by some countries (e.g. Brazil) for ensuring food self sufficiency or expanding their share of world food commodity markets. The production of K has been rather stable in the past decade. This is probably due to a limited use of K in soils put under cultivation in recent agriculture expansion (Qiu et al., 2011). In industrialized countries, K is recycled through crop residues so that K use has been increasing slowly.

For P and K the determinants of potential scarcity are, therefore, not related to geology for at least the next 150+ years, given the known world reserves. However changes are possible which may reduce this period; those changes are related to a significant growth in demand for satisfying agriculture development and soil requirements; to the economics of mining, mainly affected by the quality of the remaining ore and to growing environmental impacts (eutrophication, GHG emissions etc.). The cost of energy for transport will become more critical in a situation where there is an obvious mismatch between the geography of supply and the geography of demand.

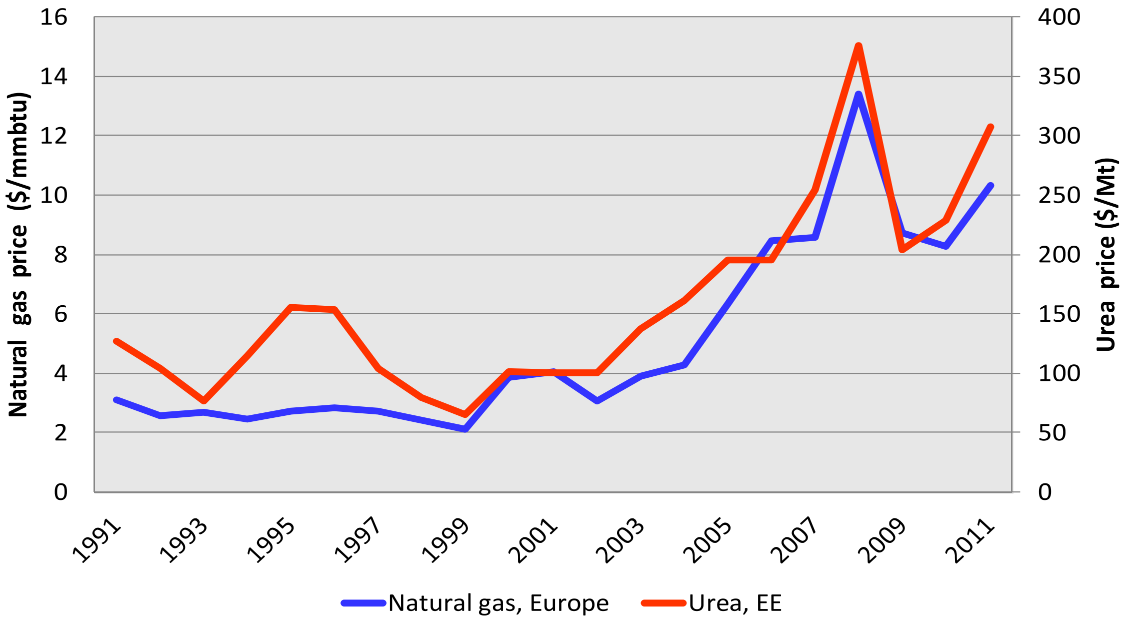
The micro-elements included in K and P minerals are a growing cause for concern (Kratz and Schnug, 2006). In addition to potentially beneficial micro-nutrients (sulphur, magnesium, etc.), small quantities of uranium, cadmium, radium, thorium, cesium and other heavy metals are present in the

[4] The IFA provided the workshop with a new estimate of 88 B tons in Prud'homme 2011.
[5] Reserves: ore that can be economically produced at the time of the determination to make suitable products; Resources: ore of any grade that may be produced at some time in the future, including reserves.

"remaining" 2% of each fertilizer bag .The growth in fertilizer application should therefore be accompanied by a close monitoring of the secondary effects on soil, plant and human health. At the European level systematic soil sampling is now performed to collect data on soil basic properties, soil macronutrients and heavy metals (LUCAS - Land cover and Area Frame Survey - http://eusoils.jrc.ec.europa.eu/projects/Lucas/).

Nitrogen (N) fertilization has contributed to the tripling of global food production over the past 50 years (Stewart et al, 2005) and significant increases in yields are still possible in many parts of the world. The supply of nitrogen is linked to availability of energy for ammonia production in the Haber-Bosch process [ammonia (NH3) is the feedstock for urea and nitrate based fertilizers]. Hence the price of urea and ammonia is closely related to the price of natural gas (Figure 4).

Figure 4: Price of urea and natural gas in Europe (source: Blanco, 2011, derived from World Bank databases; price normalized to 2000; accessed in 2011).



[mmbtu = Million Metric British Thermal Units]

Most production plants are located close to sources of natural gas which closely determines the geography of production. The discovery of new sources of gas will directly determine future production costs (and price) of urea. Efficiencies in ammonia production have improved by 300% since early days of the Haber-Bosch process. Coal gas is however still used by several large scale producers such as China.

GHG emissions associated with ammonia production are related to the consumption of natural gas for the hydrocarbon feedstock and to the energy requirements of the process. These emissions - essentially of CO_2 dominate the emission budget in N fertilizer manufacture. They represent around 6% of the agriculture contribution to GHG emissions (the nitrous oxide emissions from soils representing more than 32 % of such budget Government Office for Science, 2011). It is estimated (Tilman et al., 2011) that for satisfying the global crop demand in 2050 the GHG emissions associated with N use would amount to an additional 225-250 Mt y^{-1} CO_2-C equivalent (compared to 1-3 Gt y^{-1} for land clearing).

Questions are also raised with respect to the capacity of the private sector to invest in industrial N-fertilizer production plants that will be necessary to fulfil future demand (increase of capacity by 100% in 2050; based on the prediction of Tilman et al., 2011). Again, geography matters and the optimisation of supply and demand may have to go beyond economics to consider geostrategic elements in a more uncertain global political situation. Like for energy, questions of security of supply may one day supersede market mechanisms, self-sufficiency not being an option.

Global trade - Given the existing and future imbalance between the geography of fertilizer production and the geography of fertilizer demand, trade in fertilizers has played and will continue to play an important role in ensuring fertilizer security in almost all regions of the world. Over 80% of potash requirements and nearly 30%-40% of N and P requirements are met through trade. Therefore it is essential that both exporting and importing countries follow fair trade practices embodied in the WTO agreements. Restrictions on fertilizer trade by some countries contributed to the rise of fertilizer prices of 2008 (as well of 1974) and created unnecessary perception of scarcity in the market, which led to *panic* buying by some large countries. Monitoring of trade and tariff regimes of key countries will be necessary to ensure free and fair trade in fertilizer products. Given the strategic role of fertilizers in promoting global food security, and given an ever increasing role of trade in supplying N, P, and K requirements, fertilizers should be considered as a strategic commodity and be treated as such in future international negotiations.

4. Research and innovation

Current research related to NPK issues relates to i) the available resources, mining and production processes on the supply side, ii) the current nutrient balance in soils and iii) to plant uptake, field application practices and farm economics on the demand side.

On resource estimation:

There is strong agreement that a defendable methodology to evaluate the existing and exploitable P and K resources is urgently needed. Indeed, it is difficult to meaningfully address the question of supply if the stock is not known. Exploration geology and ore characterisation including microelements is to be further developed for phosphate resources and - to a lesser extent - for potash.

On soil nutrient balance:

A more in-depth understanding of the cycling of nutrients in soils is needed, starting from a detailed and updated inventory of soil resources and their current NPK balance. A global scale inventory is on-going with the participation of the major soil survey agencies in the framework of the GlobalSoilMap.net consortium (Sanchez et al., 2009; http://www.globalsoilmap.net/). An inventory of the current fertility levels of European soils has been completed (Guicharnaud et al., 2011). Because of very high retention potential in some soil types, detailed data are needed to correctly address phosphorus deficiencies (Batjes, 2011).

On production:

New technologies are required to catch-up with low-grade P extraction. Considering that there is a 35% loss from the mine to finished fertilizers and an additional 45% loss until human ingestion, there are large margins for improving the efficiency in the mine-to-fork pipeline. Phosphate fertilizers were generally developed for use in temperate climates, and their efficiency is lessened in sub-tropical and tropical climates. The FAO and the IFDC are seeking methods to apply phosphate rock to crops directly or with minimal processing (FAO, 2004). This would increase the amount of phosphate available to crops, while decreasing the amount of phosphate rock lost in processing and the amount of nutrients lost to the environment. This process could be even more efficient if plants ability to extract P at root level is advanced via biotechnology (see later in this section).

Specific quantification of minor minerals (including heavy metals) and technology improvement for their recovery should be considered in the overall economy of the mining process.

Increasing the energy efficiency of ammonia production has been a major goal for industry - The most energy efficient technology available is the auto-thermal reforming process, which combines partial oxidation and steam reforming technology. This compares with close to 120 Gj/t when the Haber-Bosch process was introduced in the mid-1930s. In 2007, the world's average energy intensity of ammonia production was 41GJ/t NH3, with a range between 33 and 49 Gj/t (IEA, 2007; UNIDO, 2010). Switching to gas-based processes has reduced emission of CO_2 and improved energy efficiency (IEA, 2007).

On application:

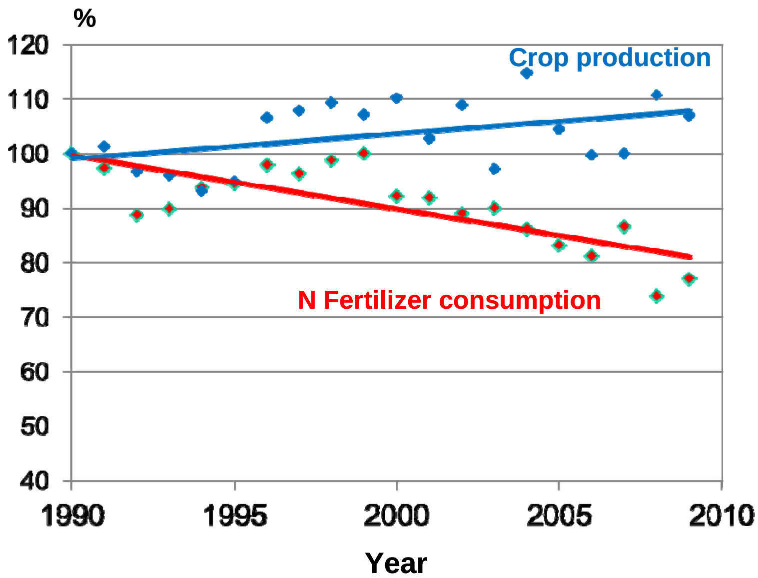
Most research currently focuses on the Precision Nutrient Management approach which can significantly improve fertilizer use efficiency (from 15 to 20% to a potential of 90%). The method requires the acquisition of adequate data on the soil/water/plant complex system (observations and modelling). The use of soil maps and of derived soil properties needs to be further developed in such context. Maintaining the balance between nutrient input and output in Europe must be based on data on current soil nutrient stocks and their plant availability; such data are collected in the context of the LUCAS - Land Use/Land Cover Area frame survey (http://eusoils.jrc.ec.europa.eu/projects/Lucas/).

The second challenge is a more mechanical one as it relates to the placement of the fertilizers at the right time and in the right place to satisfy the plant requirement. Here new machinery and the use of global positioning system are increasingly adopted. Linking water and fertilizer management may provide further efficiency improvement, including further developments of "fertigation" (e.g. combined implementation of fertilization and irrigation) to a larger number of field crops.

In the face of potential limitations in terms of fertilizer availability and use, pressure is mounting to develop plants that demand less macronutrient. Adaptive response by plants to soil nutrient status includes a more active exploration by roots of the surrounding soil and an increase in the root surface area for absorption (Calderon-Vazquez et al., 2011). Genotypes are identified with the required adaptive changes and some low Phosphorus tolerance traits have been revealed (Gaxiola et al., 2010). There is also some room for improvement in the symbiotic relationship between roots and mycorrhizae leading to attempts to transgenically introduce nitrogen fixation into cereals with exploitable results only a few years away (Curatti et al., 2007; Madsen et al., 2010). Inducing the production of nodules with presence of the necessary bacteria has also been carried out. There is agreement that there is substantial research potential to reduce fertiliser requirements of plants. Significant results can be expected within 5 years for nitrogen fixation and in the next decade for phosphorus.

What is clear is that, for a given crop, the relationship between application of fertilizers and yields will not remain stable in the future (see also N /production relationships of the past 20 years in Figure 5).

Figure 5. Nitrogen Use Efficiency has increased during the last 20 years (source: www.fertilizerseurope.com).



Minimizing losses from agro ecosystems and recovering and re-use of NPK from all waste streams is also a key area of research. Ongoing EU funded research is addressing the question of how to reduce mineral fertilisers and chemicals in agriculture and optimize use of energy and nutrients.

Research will also need to address the possible impact of large scale urbanisation with respect to phosphates and nitrates leakages in the effluents. Sustainable cities of the future, will however, minimize waste streams and unwanted accumulation of N and P in the ecosystem and they will also improve the cost-benefit of recycling. Feeding a mostly urban world of 2050 with large scale industrial farming vs. food supply from smallholdings will also have an impact on production patterns and nutrient management.

Fertilization also affects food safety (e.g. mycotoxins in maize grain) and quality (e.g. industrial cereals; baking quality of wheat flour) (Blandino et al., 2008) and this requires to be further examined in a sustainable management context (e.g. more fertilization for better quality food?). Increased use of N in developing countries, especially in Africa, improves protein content of grains with consequent positive health benefits.

The role of innovation:

The effect of innovation on the global NPK balance and future availability is difficult to evaluate. Indeed, at a global level, significant progress on the rational use of fertilizers will first come from the application of known agronomic and field practices at farm level. In large parts of the world, the adaptation and implementation of such background knowledge to specific farm types and soils/regions of the world represent a logical priority. This calls for integrating the results of research in a socio-economic context that stimulates their adoption. The so-called "enabling environment" is therefore a logical object of further research (as well as target for policies). In more advanced agriculture areas, innovation will play its role as in precision farming and recycling of wastes.

Other points of interest for innovation are related to mid-term advance research on plants that will exhibit high levels of nutrient use efficiency. Combined with technological advances in fertilizer precision management (placement, release, dosage, etc.) biotechnology may provide useful contribution to the fertilizer global balance.

Research related to mass recycling of nutrients escaping in effluents and waste streams will continue; this area calls for more rigorous scientific approach than in the past as it has to deal with more complex cocktails of inorganic and organic compounds.

5. Policy implications

Fertilizers are at the core of the agriculture sustainability challenge which aims at reconciling a growing demand for food products, respect for the environment and improved economic livelihood at farm level. A range of EU policies are directly concerned by those questions. Future increase in agriculture production will have to come for a good part from yield increase to which fertilizers could contribute up to 40-60%. Access to fertilizers will be a key to the development of agriculture in regions which are currently producing way below their potential. A rapid growth in global fertilizer market will - more than in the past - be affected by unexpected events linked to food and energy crises (as in 2008), possible political unrest and other types of disruptions. A closer monitoring will be in order.

Fertilizer production and use are not without negative impacts; the accumulation of nutrients in effluents and soils leads to eutrophication of surface waters and pollution of underground aquifers. Heavy metals might be naturally present in some phosphate fertilisers. The ingestion of some of them via the diet is a source of concern for human health in the longer term.

The following summarizes a few key points associated with fertilizer availability and use in a set of relevant EU policy areas.

Agriculture

CAP instruments and fostering innovation in European agriculture are geared to:

- Reducing mineral fertilizer consumption and optimize their use; good agricultural practices vary widely across the EU.
- Maintaining or increasing the current level of production (yields are highly dependent on fertilizer use).
- At EU level, technology transfer from West to East on better nutrient management efficiency is needed.
- Fertilization related policies in the EU should be considered in a global context with respect to competitiveness and trade.
- Farm Advisory Systems could play an important role in promoting efficient fertiliser use in compliance with good agro-environmental practices.

Environment

An issue for long term global food security is the sustainable supply of phosphorus, a key resource for soil fertilisation that cannot be substituted.

- Further research is needed in order to identify how improvements in fertiliser use, food production and bio-waste issues could reduce our dependence on mined phosphate.
- The EU Green Paper on sustainable phosphorus will propose a "resource efficiency" approach, looking at environmental impacts across the life cycle.
- Leakages related to import of foodstuff produced in non sustainable systems is to be avoided and calls for traceability tools.
- Improving understanding of the soil/plant/water cycles in nutrients is crucial for developing appropriate recycling practices.

Development

Fertilizer access and management issues are not specifically addressed in agriculture and food security related policies where they are usually included in "good" soil management practices. They should receive a more explicit treatment. Fertilizer use has remained low and stagnant in various parts of Sub Saharan Africa where appropriate organic and mineral fertilisation is a key component to increase productivity, food security and restore soil fertility.

- Limited access to finance for small holder and dealers: need to promote insurance schemes, which reduce risks by covering inputs (fertiliser and seeds) costs.
- Supply system is not efficient; transport costs are high in the chain.
- Infrastructural investments; joint ventures for multi-country markets could be supported - subsidy/non subsidy arguments are not always clear cut.
- Farm level extension services are needed for sustainable use of fertilizers (re: Maputo declaration calling for significant budget increase in this area).
- Global inequity in access to fertiliser at reasonable cost must be redressed.
- The question of subsidies should be addressed through proper measures to prevent market distortions.

Legal framework

- A revision of the EU framework for placing fertilizers in the EU Market is currently underway; it will open the scope to the regulation to organic fertilizers and other soil improvers.
- Maximum limits of contaminants such as heavy metals and organic compounds in commercial fertilizers will be set. To ensure that appropriate information is provided to the farmers and hence allow a better management of these commodities, the revision of the legislation will propose to streamline existing provisions concerning labelling and to extent them to all types of fertilising materials.

Statistics and data collection

- Coherent statistics on the production, trade and use of fertilisers are lacking in Europe.
- In production and trade almost all data are confidential because of the small number of actors.
- Available data on fertilizers are not comprehensive for all EU countries and there is a need to agree on terms and methodologies.
- New fertiliser surveys should cover both mineral and organic fertilisers, as well as their use and application techniques. Ideally, data should be collected at farm level.
- Detailed and policy relevant soil data from traditional soil surveys as well as from modern soil monitoring tools need to be collected at regular time intervals at European and Global scales in order to fully assess the nutrient balance and soil fertility status of agricultural soils.

6. Conclusions

Fertilizer use may have to double to provide sustainable food security for over 9 billion people in 2050; this raises a host of issues that goes beyond mere questions of fertilizer use.

To guide any future *foresight* study on this topic it is useful to run the following thought experiment. Based on current demand, usable reserves in P will be reduced by 25% in 2100. These usable reserves will be further reduced if demand for (P) will have more than doubled in the mean time (Tenkorang et al., 2009). Furthermore we can assume that the quality of P reserves will create soil contamination, that excess use of compound fertilizers continues to give rise to water pollution and that energy cost for production of N double in the same period. The questions that need to be addressed are:

1. When (in terms of residual uses of reserves) do we need to start assembling and implementing a global strategy for NPK use (re: geographical determinants, efficiencies, requirements, access etc. as described in the present report)?

2. When do we need to have applicable and practical alternatives developed, fully tested and implemented at the required regional/global scale?

Considering that any global resource or environment policy takes 25-30 years to be developed at international level (e.g. climate change, biodiversity, etc.), any decision possibly made today to tackle NPK potential issues on a global scale can only realistically be put on track in 2040. This is barely a decade before the world population is likely to reach the 9 billion mark. This is the base for the recommendation made here that vigilance is needed with respect to possible developments during the next decade.

While current concerns are clearly directed to the question of access and rational use of fertilization in a sustainable agriculture, several parameters shaping the global production and demand will evolve; new models to evaluate such evolution of the matching between effective demand and supply will have to take into account not only the crop requirements for food production but also the application efficiencies, soil rehabilitation, environmental linkages and socio-economic determinant of access, per crop and per region.

The NPK question is a global issue, access to it is a regional issue and management of crops is a local dimension. The discourse will have to move away from normative approach to sustainability to more practical and geographically adapted solutions in terms of production, access and use of fertilizers.

Finally, this study also underlines the need for considering a global governance system ensuring sustainable management of the three essential plant macronutrients in the context of long-term food (and political) security to the world. The recently proposed FAO Global Soil Partnership is a step in that direction.

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8. Annex

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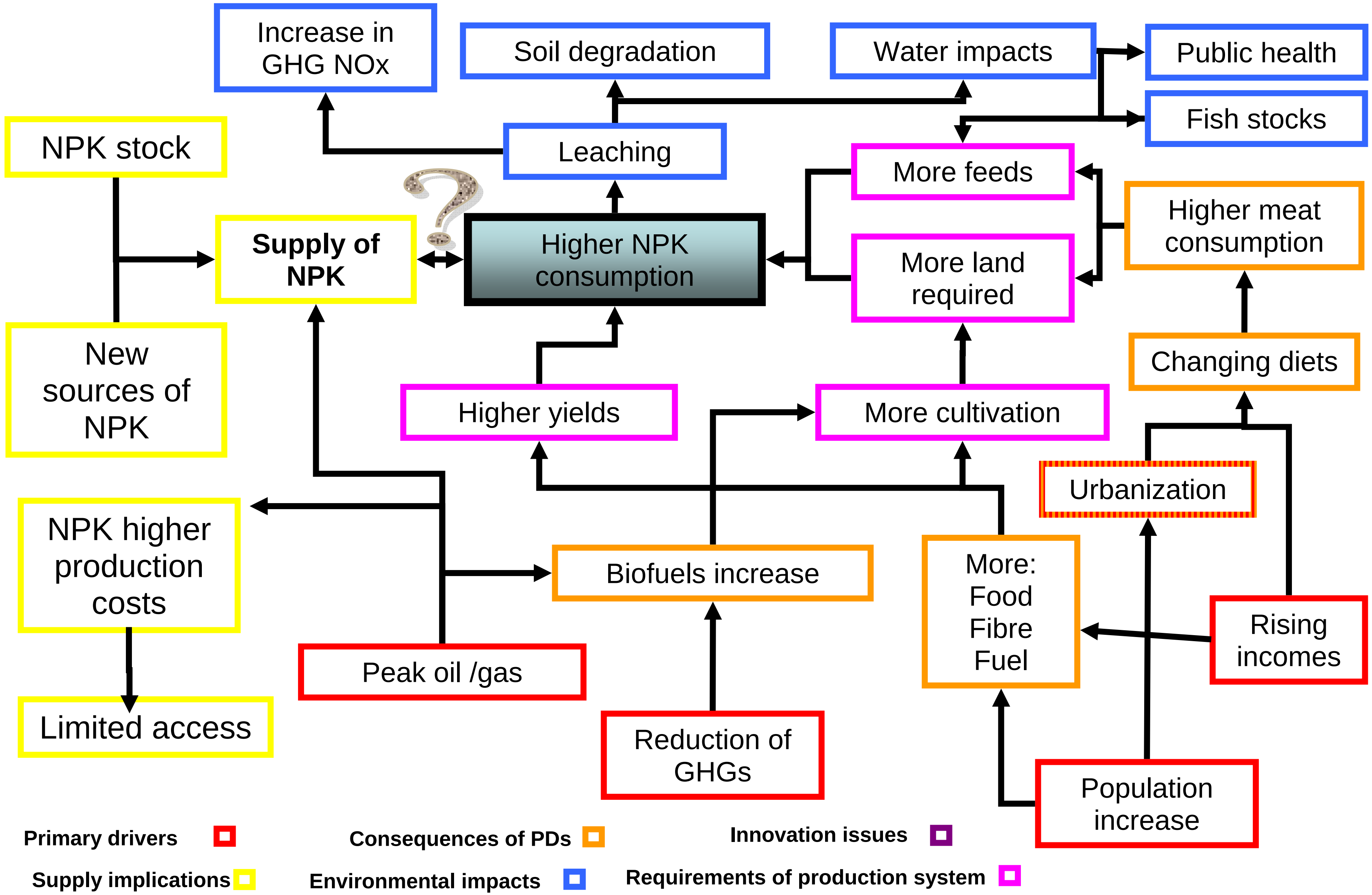
8.2 Lines of consequence from drivers to impacts NPK



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Abstract

Will there be enough plant nutrients to feed a world of 9 billion in 2050? is the central question addressed by a JRC study. This exercise was based on consultations with experts and a thematic workshop focused on three areas of interest: 1) the demand for fertilizers to sustain crop production necessary to feed the world in 2050; 2) perspectives on the supply of Nitrogen (N), Phosphorus (P) and Potassium (K) to world agriculture and 3) the role of innovation and technology in changing the match between demand and supply of fertilizers. Implications of the main findings for current EU and international policies were addressed.

Overall, analysis of existing literature and discussions with major experts and stakeholders led to the conclusion that while the situation is currently not critical with respect to the production and availability of plant nutrients, it is important to remain vigilant. The question of reserves (P and K), access, changing geopolitical conditions, economic development, energy costs (mainly for N) and environmental constraints (N and P) could lead to shortfalls and possibly crisis situations in some regions of the world. The situation of Africa deserves particular attention as production, access and use of fertilizers represent key limiting factors in boosting food production in that continent.

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