Phosphorus availability in the 21st century Management of a non-renewable resource

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High-grade phosphate ores, particularly those containing few contaminants, are being progressively depleted and production costs are increasing. Ingrid Steen, Group Agronomist, Kemira Agro, in Copenhagen, Denmark, examines the outlook for global phosphate rock supply and management of this non-renewable resource.

Today, the annual global production of phosphate is around some 40 million tonnes of P_2O_5, derived from roughly 140 million tons of rock concentrate. Overall, mineral fertilisers account for approximately 80% of phosphates used worldwide with the balance divided between detergents (12%), animal feeds (5%) and speciality applications (3%), for example, food grade, metal treatment etc.

Considering the dominant role of fertilisers in global phosphate consumption, it is evident that the development of future world phosphate production will be driven by the development of agriculture, which in turn is driven by global population growth and its food requirement. It, therefore, follows that agriculture's share in the use of phosphate will increase in the future.

Estimates of world phosphate reserves and availability of exploitable deposits vary greatly and assessments of how long it will take until these reserves are exhausted also vary considerably. Furthermore, it is commonly recognised that the high quality reserves are being depleted expeditiously and that the prevailing management of phosphate, a finite non-renewable source, is not fully in accord with the principles of sustainability.

Phosphate rock and its characteristics

Phosphorus is the eleventh most abundant element in the lithosphere. Owing to its relative reactivity, it generally is associated with calcium (Ca), sodium (Na), fluorine (F), chloride (Cl), metals such as iron (Fe), aluminium (Al), magnesium (Mg), heavy metals, for example cadmium (Cd), radionucleids like uranium (U) etc. In reality more or less all the elements that can be found in the periodic table are represented in phosphate rock.

There are two main types of phosphate rock deposits, igneous and sedimentary, which have widely differing mineralogical, textural and chemical characteristics.

The most prevalent phosphate minerals in these rocks are species of apatite, i.e. calcium phosphate with quartz, calcite, dolomite, clay and iron oxide as gangue components. Igneous rock is often associated with carbonatites and / or alkalic intrusions and is generally low in grade i.e. low concentration of phosphate. The abundance ratio of igneous versus sedimentary rock is 13 to 87. Some 80% of the world phosphate production is derived from sedimentary phosphate deposits.

More than 75% of the globally commercially exploited phosphate rock is surface mined, which can take many forms from manual methods to the employment of highly mechanised technologies, with the remainder recovered by underground mining.

Phosphate content in currently mined rocks can range from over 40% to below 5%. The mined rock is further processed to remove the bulk of the contained impurities and thus upgrade the rock. Consequently, the rock concentrate contains an increased apatite content of an improved quality. The beneficiation process usually allows a concentration of around 1.5x but higher ratios up to 9x are possible with some rocks. After beneficiation, phosphate rock (concentrate) generally ranges from 26% to about 34% P_2O_5 and up to as much as 42%

Phosphate rock can be beneficiated by many methods, and usually a combination of methods is used. In general, with the lower concentration of phosphate and lower quality deposit, the more waste is generated. Furthermore, more energy and chemicals are required per tonne of useful phosphate produced. Consequently, the cost for recovery and beneficiation of phosphate rock increases significantly in relation to lower grade and lower quality deposit. An analysis of production costs must thus be an integral part in the assessment of the lifetime of phosphate deposits and the likely cost of fertilisers in the future.

Most phosphate rock is further processed, but very small volumes are applied directly to acidic soils as fertiliser.

Global reserves

Phosphate rock deposits are found throughout the world and there are different definitions of the availability of these deposits. Reserves could broadly be defined as deposits that can be extracted profitably under current economics, infrastructure and technical conditions. Resources are defined as reserves (potential reserves) plus all other mineral deposits (geological resources) that may eventually become available. The potential reserves could probably be mined if the necessary investments were to be made, while the geological resources are identified as *in situ* resources.

Many reserve / resource estimates are subjective as they depend on standards and criteria assumed by the data provider in determining the circumstances that might render a deposit economically useful. Hence, it is to be noted that discrepancies exist. For example, the United States Geological Survey (USGS) has defined reserves as those exploitable at a cost below $35 / tonne and the reserve base as deposits that can be processed at a cost below $100 / tonne.

Over 30 countries are currently producing phosphate rock for use in domestic markets and / or international trade. The world's top 12 producing countries account for nearly 95% of the world's total phosphate production. The three major producing countries, i.e. the USA, China and Morocco, currently produce approximately two thirds of global phosphate production.

Of these three major producers, Moroccan reserves account for around 50% of the world total. Morocco is also in the most advantageous situation as its potential reserves and geological *in situ* resources have been estimated to be approximately 60% of total world resources. The USA and China have between them around 20% of global resources. These figures may be an underestimate as they are based on calculations of economic production for the foreseeable future.

Current world phosphate rock production capacity is estimated at around 165-195 million t/a, or approximately 50+ million t/a P_2O_5.

The amount of phosphate rock reserves and recources in individual countries are rather uncertain as this type of data is often privileged information and documentation concerning many deposits is simply not available. Furthermore, there is generally a lack of information concerning the extent of exploration and criteria used to determine the economics of production or the potential for economic development. Thus, *table 1* is based on a collection of data from different sources that are not always comparable, and most of the data is more than ten years old. To demonstrate the discrepancies in estimates of phosphate reserves, there are differences between sources as much as 100% so a substantial range is evident.

Table 1: Global phosphate reserves

% of total (1996):	Production	Reserves	Potential Reserves	Geologi Resourc
United States	34	4-10	7-13	
China	16	2-25	2-10	
Morocco	16	46-53	63	
Russia	6	3	7-10	
South Africa	2	9-22	3-22	
Tunisia	5	1	1	
Jordan	4	2-3	1-3	
Iraq	–	1	3	
Brazil	3	1-3	1-2	
Peru	–	1	–	
All other countries	14			
Total P_2O_5 (million tonnes)	**38**	**3,600-8,000**	**11,000-22,000**	**30,(**

Source: United States Geological Survey, International Fertilizer Industry Association and British Sulp

Quality depletion and cost implications

There is a limit to the phosphate rock reserves that can profitably be recovered at current market prices. High-grade ores with high P_2O_5 concentration and ores of good quality i.e. containing few contaminants, are being progressively depleted. Consequently, production costs will increase.

It has been widely suggested for many years that, in general, there has been a continuous decrease in world phosphate rock quality as reserves of high-quality rock are being depleted. It might be more appropriate to say that high-grade concentrates from some sources are becoming depleted, principally Florida, and, in general, the quality of phosphate rock that is utilised on a worldwide basis is decreasing. High-grade phosphate rock *is* available from many sources, such as Togo, Senegal and Morocco. However, premium rocks from these sources are not available at costs comparable to those 20 or 30 years ago.

Higher P_2O_5 content equates to lower impurity content, higher yields per tonne of material shipped, handled and processed, increased reaction efficiencies, fewer processing problems and less waste. An industry assessment suggests that the phosphate content of pre-benficiated ore is already decreasing by around 1% per decade.

In the context of declining quality, the levels of certain impurities may pose problems in the processing or in application. The content of heavy metal contaminants are generally higher in sedimentary than igneous rocks. To date, levels have not proved a problem except when producing higher purity phosphoric acid grades. However, certain European countries have applied strict limits to cadmium levels in fertilisers in order to avoid contamination of farmland and crops and cadmium removal could involve further processing costs adding 2-10% to phosphate fertiliser prices.

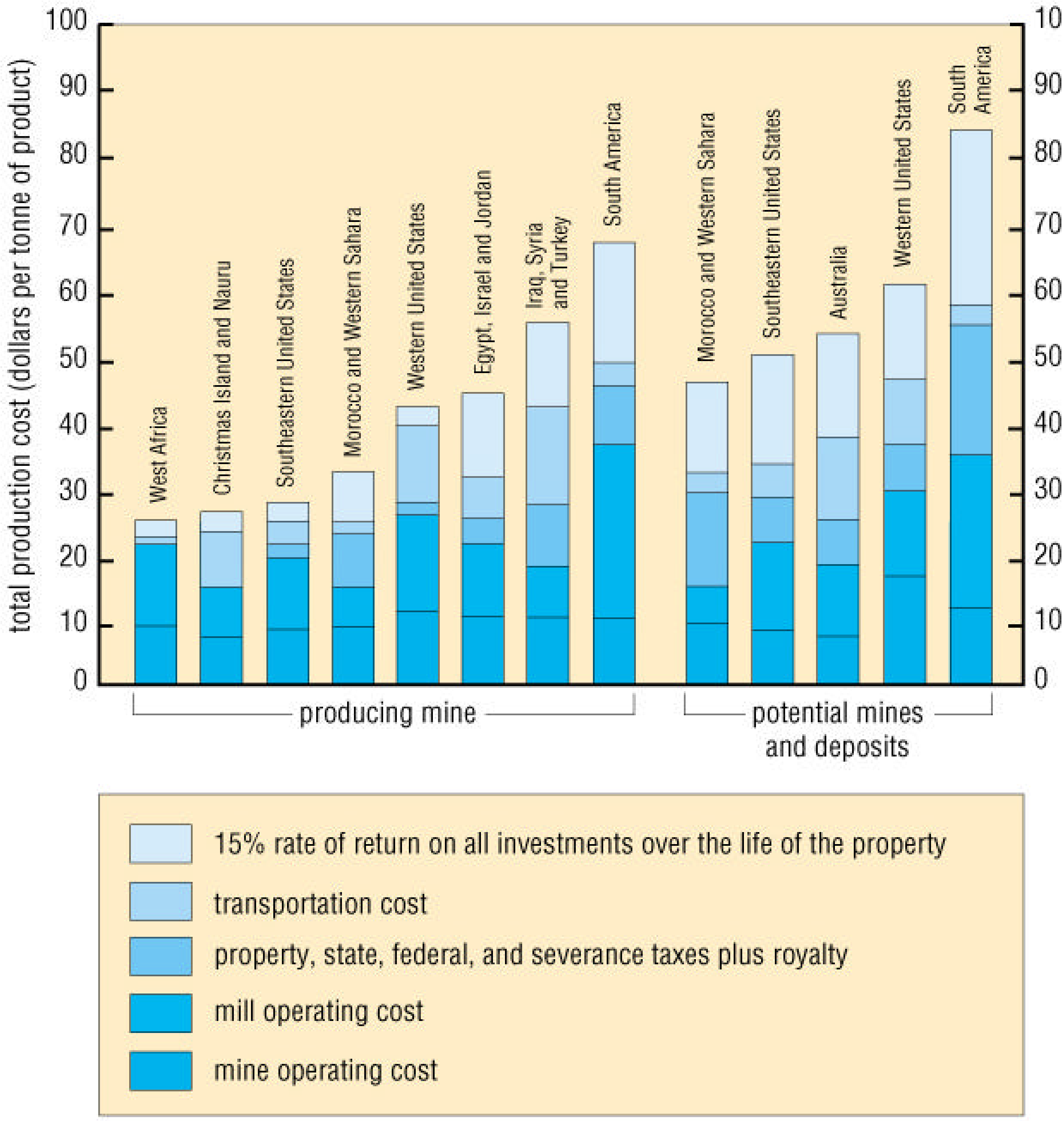
Radionucleids do not interfere with any employed processing technologies. However, they must be considered in the production of high-grade phosphoric acid and because of potential health hazards, not least in connection to stockpiling or depositing phosphogypsum at landfills from processing certain rocks. Phosphogypsum from Florida rock is subject to specific management restrictions by law. It is likely that in the future further environmental pressure will influence mining, processing and waste management at the processing plants and definitely also increase the cost of phosphate production.

Production costs and phosphate availability

A number of analyses on production costs for different producing mines and potential mines and deposits have been made. The most significant factors altering the cost situation for recovery and processing of phosphate rock and thus the profitability would be; accessibility of the ore, degree of beneficiation required, capital investment, operating costs and, availability and cost of other resources.

Some calculations – shown in *figure 1* – are important for the estimates of the amount of commercially exploitable phosphate deposits. There, calculations were made in 1985; nevertheless, the analysis is still relevant.

Fig. 1: **Phosphate rock production costs**



Source: Fantel et al.

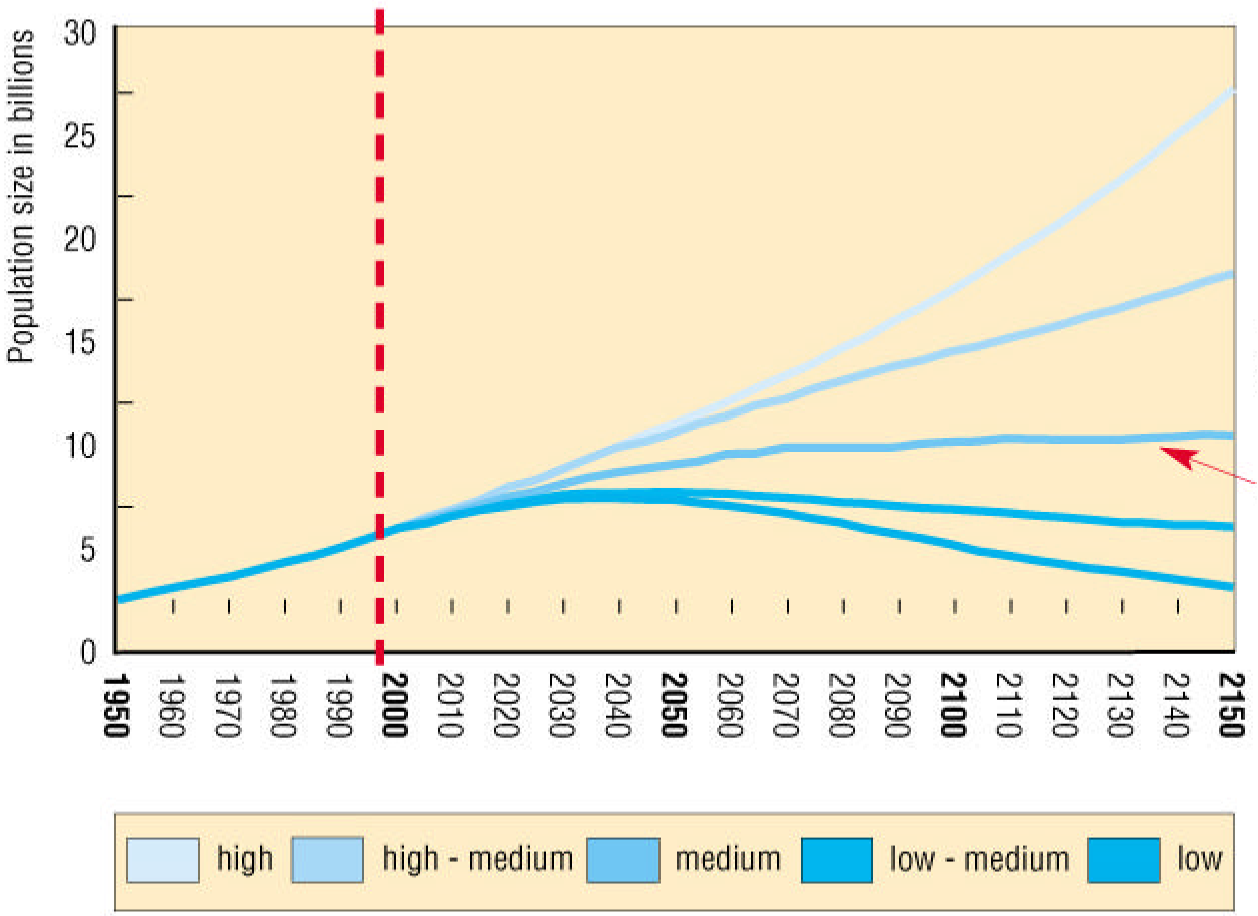
To illustrate the complexity of these assessments, USGS data is used where reserves are defined as those commercially exploitable at a cost of less than $35 / tonne. Supposing a cost of around $60 / tonne, this would more than double the available commercial phosphate deposits in the USA. It is reasonable to assume a similar situation in other phosphate producing countries, using USGS assumptions. Consequently, with an eventual increase in price for phosphate, a reclassification of some resources to reserves would be the outcome.

Population trends and food requirement

The increase in life expectancy, reduced child mortality and improved farming methods, which have led to increased food production, have resulted in a rapid and exponential world population growth over the last 150 years, from 1 billion to an anticipated 6 billion in 1999.

World population is currently growing by approximately 1.5% per year, 80-85 million per year, or 250,000 people every day. This trend will not continue indefinitely. The latest UN World Population Projections to 2150 suggest that a slowing down of population growth may be already occurring with a median projection of 9.4 billion by 2050 (see *figure 2*). The population growth is expected to be concentrated in the developing regions of the world, mainly Africa and Asia, while in the developed countries growth will be very slow.

Fig. 2: **World population size according to the main fertility scenarios, 1950-2150**



Source: UNDP

The expanding population will take pleasure from increasing incomes and more people will profit from economic growth and further improvements in their standard of living. A 50% population increase over the next 50 years would point towards an increase in global food needs by at least a proportionate figure, assuming a roughly constant per capita cereal consumption.

However, the combined effects of rising population and wealth will inevitably increase the demand for higher dietary standards and higher-grade foodstuffs. Consequently, the portion of meat and possibly also of dairy products in the diet will increase. But, even if a higher dietary standard could be afforded it is not likely that there will be a total change to Western-like diets because many communities are likely to retain their traditional cooking to a great extent. Thus it is difficult to assess the time scale and magnitude of this development and consequently the impact on phosphate consumption.

Meat production is inefficient at both energy and nutrient conversion; the cereals to meat conversion ratio in intensive animal husbandry is 3:1 for poultry, 4.5:1 for pork and 6:1 for red meat. This implies that increasing the meat consumption, increases the need for cereals and hence, agricultural phosphate use by a factor related to these ratios. Nevertheless, increased animal production should focus the need for more efficient recycling of the nutrients, especially phosphate in the animal excreta.

Despite all the efforts to feed the world population, approximately 800 million people are still undernourished. On a worldwide basis the dietary energy supply (DES) has grown to an average of 2,720 kcal per person per day, according to data from 1992. This represents an 11% increase over 20 years, despite growth in the world population of almost 40% over the same period. This can be compared with a minimum sustenance level estimated to be not less than 1,700 kcal DES. Furthermore, when current food and population trends are extrapolated, it seems likely that at least 5% of the population in these contries will still be undernourished by 2050.

As demand for food increases, this may result in bringing into agricultural use more land, but certainly will bring a requirement for increased yields, thus increasing fertiliser demand. Hence, agricultural phosphate use may increase faster than world population.

Agricultural demands

Phosphorus is an essential nutrient for all life forms and is a key element in many physiological and biochemical processes. It was the first element to be recognised as an essential nutrient for plants and its functions cannot be performed by any other nutrient.

In the natural environment, phosphorus is supplied through the weathering and dissolution of rocks and minerals with very low solubility. Therefore, phosphorus is usually the critical limiting element for animal and plant production and throughout the history of natural and agricultural production, phosphate has been largely in short supply.

The importance of recycling organic manures to maintain crop production has been recognised by farmers for thousands of years. However, the nutrient recycling loop is broken as increases in production and exports of agricultural produce require external nutrient input to improve and maintain soil fertility.

External phosphate inputs have become available on a large scale with the mining of phosphate deposits and increased availability of phosphate fertilisers. The success of this development is evident in all developed countries, where serious plant and animal health problems due to phosphate deficiency have been eliminated.

On a global basis, there is a positive balance in phosphate trade. However, phosphate remains in short supply in many countries of the world owing to economic and political constraints.

For more than a century, when modern fertiliser practices have been introduced they have been instrumental in increasing the quantity and quality of agricultural output. The use of mineral fertilisers has made it possible to provide enough food to feed the world’s growing population. Mineral fertiliser use is thus a key aspect of economic development and human health.

The world needs food, fibres and raw material produced by agriculture in an ever-increasing amount. This will have to be achieved with little prospect of further increases in the total agricultural area. The required increase in crop production will have to be derived from both yield increases and more intensive cropping on land currently under cultivation.

Cereals, rice, wheat, maize etc are the main source of nourishment for the world’s population. Cereal production has kept slightly ahead of population. Over the last 25 years the global cereal production has increased by some 65%. The rise in cereal production has been achieved by better yields rather than by the cultivation of new land.

Much of the growth in global cereal production occurred in developing countries. These countries increased their production of cereals by more than 85% between 1970 and 1995 but from a very low base. Taking the population growth into account during this period, the per capita cereal production in developing countries has gone up by 15% to about 260 kilograms per person each year. In the industrial countries the comparable figures are 10% and approximately 600-650 kilograms. However, over the last few years there has been a slowdown in the growth of global per capita cereal production.

Based on current information, around 50% of the nutrients, including phosphate, used in agriculture, are used in cereal production (see *table 2*). Using this assessment, knowing global cereal yields, the global grain to phosphate (P_2O_5) ratio would be 130:1. Crop phosphate content of P_2O_5 varies from 0.5-2% of dry matter and cereals contain 0.75-1%. This also corresponds to the grain to phosphate ratio of 130:1 indicated above.

Table 2: Estimated world fertiliser usage by crop grouping

	Percentage of world usage
Wheat	20
Corn	14
Rice	13
Barley	4
All other cereals	4
Oilseeds	12
Roots and tubers[1]	6
Fruits and vegetables	5
Sugar	4
Fibres	4
Other crops[2]	3
Pasture/hay[3]	11
Total	**100**

[1] Primary potatoes
[2] Includes cocoa, coffee, tea, tobacco and pulses
[3] Includes grassland, fodder, silage, etc

Source: IFA

Annual global cereal production is around 2,000 million tonnes currently. It is produced on half the arable land area, i.e. some 700 million hectares. The average cereal yield is around 2.8 tonnes per hectare; 3.0 in developed countries and 2.6 in developing countries. The annual yield increases over the past few decades have averaged 2-2.5% but have declined recently to around 1.5%. If the growth rate returns to some 2.5% or becomes even higher with the introduction of new varieties and the cereal to phosphate ratio remains at 130:1, increasing crop yields levels will clearly require more nutrients. It can be ssumed that there will be a similar development for other crops.

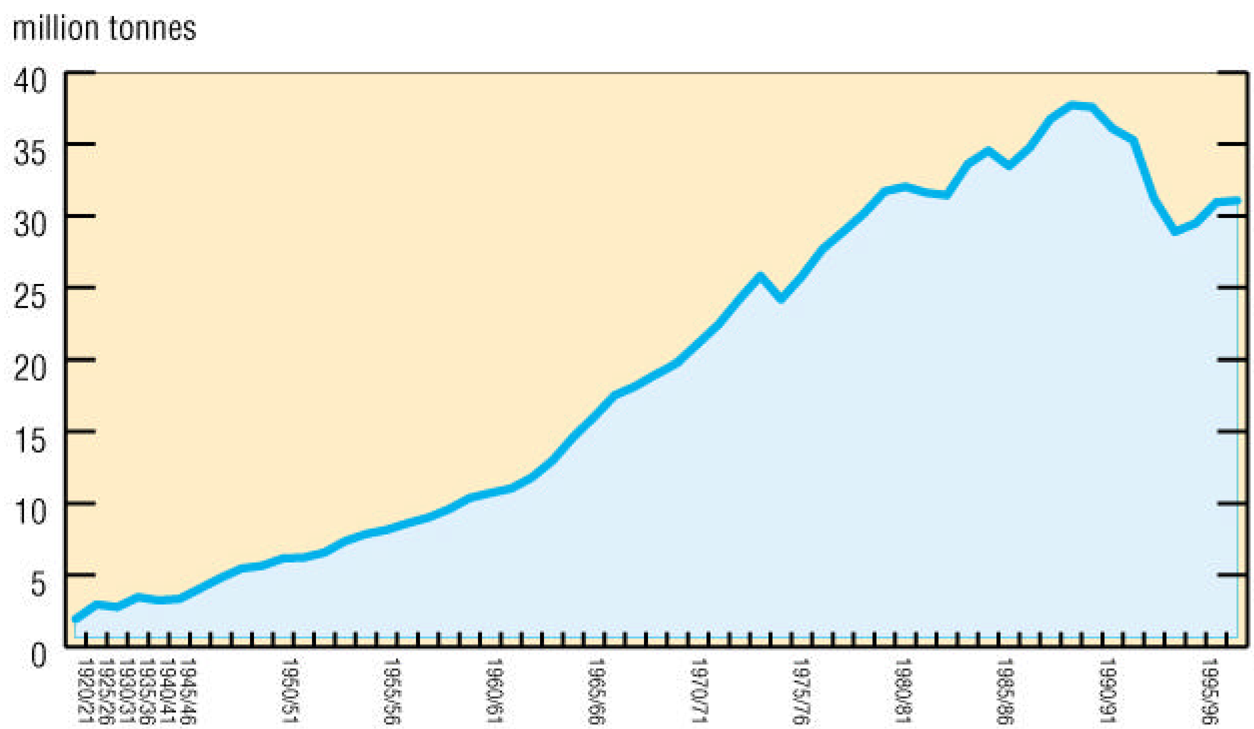
Phosphate efficiency is relatively low in any agricultural system. During the first year after application, only some 15-25% of the phosphate is generally taken up by crops as most of it is fixed in the soil and thus is not available to crops for a long period. Much of the residue remains in the soil to increase phosphate reserves but only a small proportion of each residual increment is available to following crops.

In many Western countries the soil fertility has been improved over the years by repeated application of phosphate fertilisers, increasing soil phosphorus levels, so that it is now possible to harvest some of the phosphate that has been accumulated in the soils. In these areas, depending on climate and soil conditions such as soil structure, soil type, pH, other soil constituents, etc., an appropriate policy for fertiliser application which enables crop yields to be sustained, might be to only replace the phosphate taken off in the harvested crop and thus maintain or permit a slow decline of the present soil phosphate status. In developing countries, on the other hand there is a need to develop soil fertility and phosphate levels are often the limiting factor for crop yields.

Phosphate use in agriculture

World fertiliser consumption has increased tenfold since 1930 and almost sixfold from approximately 5 million tonnes of phosphates in 1950 to 30 million tonnes in 1995. This gives an average annual growth rate of some 4% (see *figure 3*). However, the global fertiliser consumption growth rate has levelled out, the peak year being 1988 with a total consumption of 37.7 million tonnes P_2O_5.

Fig. 3: **Phosphate consumption**



Source: International Fertilizer Industry Association

There is a clear contrast between phosphate consumption development in developed and developing countries. Over the last 25 years, farmers in developing countries have increased their overall fertiliser use more than five times and the phosphate use has increased sixfold to the present level of 18 million tonnes. In developed countries phosphate fertiliser use is now what it was 30 years ago. During the 1980s, the P_2O_5 consumption was levelling at around 22-23 million tonnes and has since declined by almost 50% to the current level of some 12 million t/a P_2O_5 (see *table 3*).

Table 3: **Phosphate use in different parts of the world in 1995**

	% of total	Million tonnes	Kg/ha of arable land[1]	Range of application rates to cereals kg/ha	Avera kg/cap
Global	100	31	23 (0-250)	0-100	[illegible]
West Europe	12	3.5	25 (10-165)	10-40	[illegible]
CEE + FSU	7	2	7.5 (0-130)	0-60	[illegible]
USA	13	4	21.5 (5-120)	5-65	1[illegible]
Developed countries	39	12	18	–	[illegible]
Developing countries	61	19	27	–	[illegible]

[1] Assumption: All phosphate fertilisers being used in arable land i.e. permanent crops, excluded

In some regions of Europe and locally in the USA and Central and Eastern Europe, there is an oversupply of phosphate to agriculture due to the large combined input of phosphate in the form of fertilisers and organic manures derived from feed and feed supplements. In large parts of the developing countries, on the other hand, there is an insufficient supply of phosphate both in terms of total application and imbalance in the N to P to K ratio. If many of the areas being farmed today were to receive sufficient phosphate to prevent mining of soil reserves, this in itself would substantially increase world demand.

An assessment for West Europe shows that the amount of phosphate excreted by livestock in this region could be some 50% more than the amount currently applied as mineral phosphate fertiliser. However, all of it is and cannot be efficiently used as many animals are grazing in fields and not kept in stables. Thus, all the manure is not collectable for spreading. Nevertheless, a limited quantity – perhaps up to around 40% – of the phosphate contained in manure could be more effectively spread onto agricultural land. The amount of phosphate is equal to a maximum of 1.5 to 2 million tonnes P_2O_5, which could replace an equivalent quantity of P_2O_5 as mineral fertiliser. In general, it is difficult to assess the amount of mineral fertiliser phosphate that could be replaced by a more efficient use of animal excreta since much data is not available. A rough world estimate would be that some 4-5 million tonnes of mineral fertiliser phosphate could be replaced by a more efficient use of manure, mainly in regions of Europe and the USA.

Phosphate consumption scenarios

The traditional approach to forecasting phosphate fertiliser demand has been to use a linear model. However, most forecasters often restrict their assumptions to the next five to ten years and this provides little help for calculating the approximate lifetime of phosphate reserves. The most conservative and simplistic approach for assessing the lifetime of phosphate reserves is to calculate how long the reserves will last based on present consumption. This provides a basis for simple comparisons but does not say very much about anticipations of future development. The reason for these approaches is the difficulty in predicting demand that depends largely on the development of market economy and political circumstances.

The current fertiliser industry forecast on the development of global phosphate consumption suggests an annual increase of approximately 3% until the first years of the next century. Some fertiliser manufacturers have extended their forecast into the early part of next century, 2010-2015, suggesting an increase in phosphate fertiliser consumption of 2.8% per year before it begins to level off.

The view that crop yields might increase by some 2-2.5% per year matches the long-term historical cereal yield trends. With this view, it is assumed that agricultural production will continue to keep pace with, or slightly exceed, the global population growth and hence the world per capita crop production would remain stable or slightly increase.

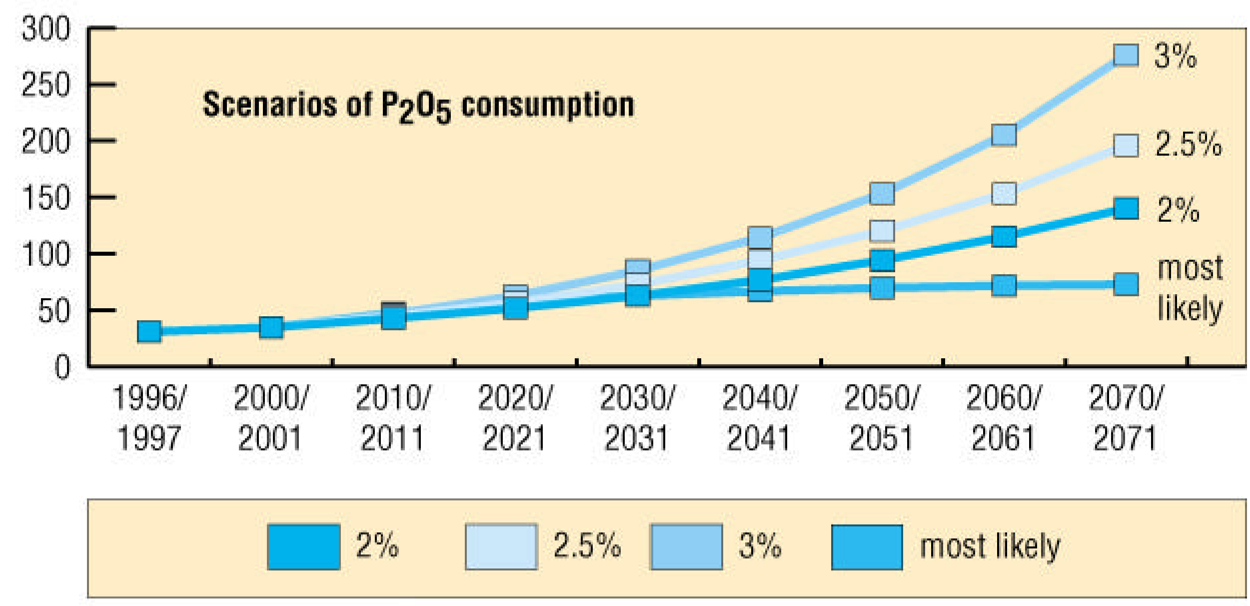
This would lead to a first estimate of a 2.5% annual growth in phosphate consumption over the long term. This would, in turn imply an additional consumption of 10 million tonnes of P_2O_5 between the years 2000 to 2010, an additional 13 million tonnes between 2011-2020, and close to 20+ million tonnes between 2021-2030. In total, this would amount to an annual consumption of around 100 million tonnes of P_2O_5 in 2050. This is more than three times the current consumption in global agriculture and would equal an average supply of some 70 kg P_2O_5 per hectare, which certainly would be regarded as an oversupply of phosphate.

A workable assumption is that Western agriculture, i.e. in the developed world, would not need to supply more phosphate than that removed by the harvested crop. In approximately 50% of the remaining agriculture it would be feasible to improve the soil phosphate status, and in the other 50% slightly more than replacement would be a relevant policy. Furthermore, it could be assumed that the crop uptake efficiency of phosphate fertilisers could improve in the future due to improved farming technologies, nutrient management and plant breeding.

Using these assumptions, the phosphate fertiliser consumption in developed agriculture could stabilise at its present level of around 20-25 kg phosphates per hectare as an average with a possible slow increase starting some 20 years from now. Further, recycling of nutrients will improve in the developed world, somewhat reducing the need to add mineral phosphates. In those developing countries where it is necessary to improve soil fertility, it could be necessary to supply some 30-50% more phosphate than crop requirements for a period of perhaps 30-50 years. After this, it would be necessary to maintain the phosphate status of the soil as in countries where this is done currently. In other countries, where the soil phosphate status should be maintained, it may be necessary to add 10-30% more phosphate than is removed by the harvested crop. This scenario gives a second more realistic estimate for annual P_2O_5 consumption in 2050 of around 70 millions tonnes.

The development of world agricultural phosphate consumption until 2050, according to the above scenarios, is summarised in *figure 4*.

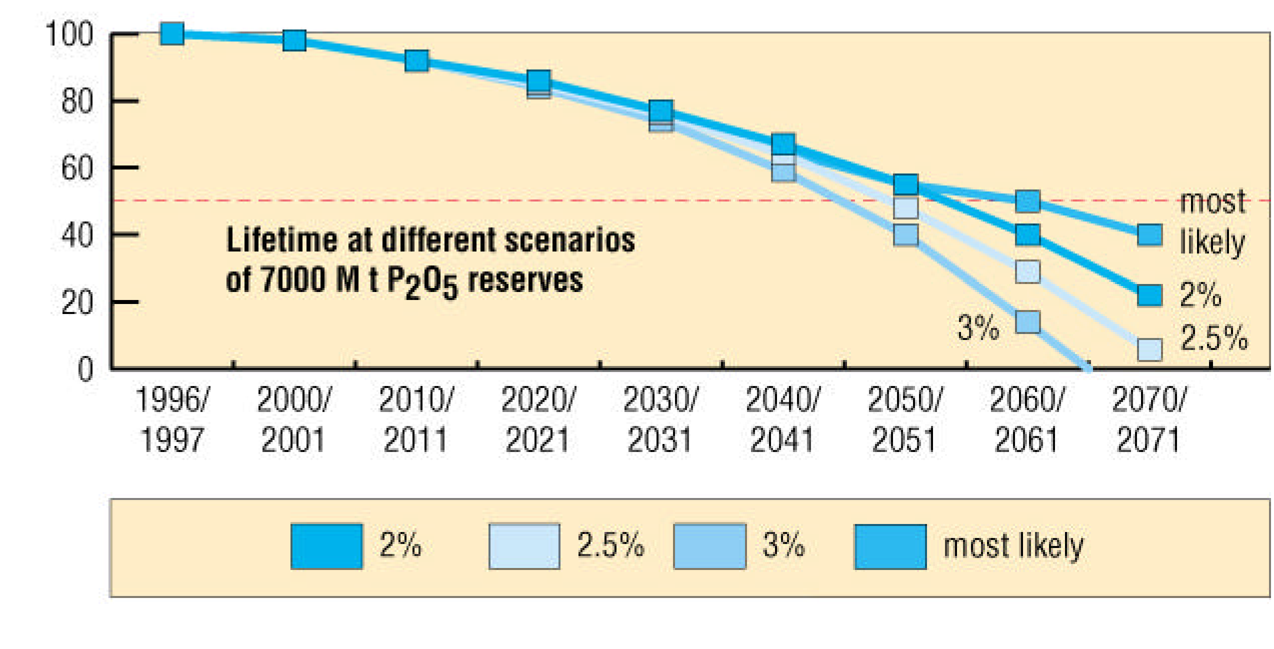
Fig. 4: **Scenarios of P_2O_5 consumption**



Lifetime of global reserves

By applying the phosphate consumption growth rates estimated in the *Phosphate use in agriculture* section, world fertiliser use would reach 60-70 million t/a of phosphates by 2050. It is concluded that global phosphate resources extend, for all intents and purposes, well into the future, but that depletion of current economically exploitable reserves can be estimated at somewhere from 60 to 130 years. In essence, using the median reserves estimates and under reasonable predictions, it appears that phosphate reserves would last for at least 100+ years (see *figure 5*).

Fig. 5: Lifetime of reserves



The data presented here, based on reasonable assumptions, suggests that within a time horizon of some 60-70 years about half the world's currently economic phosphate resources will have been used up. Furthermore, current global phosphate capacity will be utilised at its maximum production level in 10 years. This may lead to a progressive increase in prices, both as extraction cots rise, as countries holding deposits become conscious of their depletion and scarcity value, and maybe above all because of increases in processing costs. The phosphate content of pre-beneficiated ore will continue to drop, leading to proportionately increasing quantities of waste and costs for disposal. Also, the degree of impurities will progressively increase as the better quality reserves are used up and this will increase processing costs. n

The information used in the article was gathered from a large number of sources of which the following are the most significant:

l EFMA, 1997, *Fertiliser forecast* and other documents

l FAOSTAT *database*, 1998, and other documents.

l IFA,1998, Statistics, and other documents.

l IFDC, 1998, *Fertiliser Manual.*

l United Nations, 1992, 1995, 1998, *World Population Projections.*

l *Fertiliser Society Proceedings*, 1993-1997.

CAPTIONS

Surface mining of phosphate rock can take many forms from manual methods (left) to the employment of highly mechanised technologies (right).