

# ANALYSIS OF PHOSPHORUS DEPENDENCY IN ASIA

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The BACI trade statistics for 2005 were analyzed to determine the dependency of Asian countries on phosphorus, in particular for phosphorus ore, yellow phosphorus, chemicals, and fertilizers. The data revealed a complex set of patterns, with some countries relying heavily on just one or two countries to meet their commodity needs, and others drawing from a wide range of sources. In many cases, a strong dependency was noted on a country which itself was heavily dependent on another source for its commodity needs. Considering the geopolitical issues at hand, it is essential that special attention is paid to maintaining a stable supply of phosphorus to ensure stability in agricultural production as well as in the many industries which use chemicals containing phosphorus.

**Keywords:** *Phosphorus, Dependency ratio, Material Flow Analysis, International trade*

## 1. Introduction

Since phosphorus is essential for cell growth, it is an absolute requirement for all living things. As one of the main components of DNA, RNA, and ATP in animal and plant bodies, there is no substitute for phosphorus in agriculture<sup>1</sup>. The primary source of phosphorus is mined phosphate rock, most of which is processed to produce fertilizer. Of the 18.9 million metric tons of phosphorus produced annually almost 75% is allocated to fertilizer production<sup>2</sup>. Phosphorus is also used in industrial products such as fire retardants, glues, food additives, and surface preparation agents. With phosphorus so closely related to all aspects of our lives, it is reasonable to argue that our modern lives are dependent on the mining, processing and use of phosphate as phosphorus.

Because phosphorus is a scarce and irreplaceable resource and the demand in developed countries is high and rising, the security of phosphorus is an urgent issue<sup>1,3,4</sup>. With high grade phosphate ore deposits rapidly disappearing, it has been suggested that the economically available deposits may be exhausted within 100 years<sup>4,5,6</sup>.

The three largest producers of phosphorus ore are China (37%), the USA (15%), and Morocco (15%), which account for two thirds of all the phosphate rock mined<sup>8</sup>. The next top

five producers are Russia, Tunisia, Jordan, Brazil, and Egypt. It is estimated that Morocco accounts for more than one third of all the phosphate rock reserves in the world. With no phosphate reserves of its own<sup>2</sup>, all of Japan's phosphorus needs must be met by importing. This situation is typical of many Asian countries. Notable among them is India, with its limited phosphate reserves and phosphorus poor soil, which therefore has a heavy dependence on phosphorus imports (85%) to feed its burgeoning population.

The situation of phosphorus is often likened to that of oil. It is unevenly distributed, largely in parts of the world which are not considered stable either geopolitically or economically<sup>3</sup>. The United States no longer exports phosphate ore, and the Chinese government has imposed an export quota on it<sup>4,7</sup>. However, both countries are large exporters of value-added product, in the form of yellow phosphorus, chemicals for phosphate fertilizers, and phosphate fertilizers. The wisdom of long term reliance on exports from these countries has been called into question, with some environmental activists predicting that US supplies may be exhausted by 2030. Indeed, despite its large reserves, some 10% of US phosphorus is reportedly imported from Morocco. As the world's largest agricultural producer, fertilizer consumption in the United States is extremely high. In the case of China, the situation

may be akin to that of rare earth metals, where China may well seek to ensure its phosphate ore is available for domestic consumption rather than export it, or otherwise, impose high tariffs on phosphorus exports. Indeed, a tariff was imposed in 2008, temporarily resulting in a huge price hike in phosphate ore worldwide.

The stocks and flows of phosphorous have been well-summarized from global perspectives<sup>9-11)</sup>. National and regional wide case studies have been done indicating the P-flows in, Japan<sup>12, 13)</sup>, in China<sup>14, 15)</sup>, and other regions<sup>16-18)</sup>, while little analysis on the international network of the P trade has been published.

Ultimately, the importance of phosphorus as a resource is expected to grow over time. The two and a half fold increase in the commodity price of P-ore (phosphate ore) from 1995 to 2010 reflects the increased demand and diminished supply of P-ore by earthquake in southwest China in 2008<sup>8)</sup>. Added to the problems that are associated with ever higher demand and costs, geopolitics will play a significant role in the availability of phosphorus to meet local demand in most countries. In order to assess the phosphorus dependency of Asian countries, and the top 5 Asian economies in particular (China, India, Japan, South Korea and Indonesia), trade statistics have been analyzed and their dependency assessed by the HS code with a particular focus on phosphorus ore, yellow phosphorus, phosphate chemicals used in fertilizer production and on phosphate fertilizers. The 2005 statistics were chosen because 2005 is the most recent year for which both a set of full trade data and a Japanese Input Output Table is available. In the light of the findings regarding dependency, the geopolitical risks and ideas to reduce dependency are discussed.

## 2. Data and Settings

### 2.1. Data

Firstly, material flow of phosphorus for each commodity and country is estimated. 231 countries are set in BACI (Base pour l'Analyse du Commerce International) and 286 commodities are extracted from the HS code<sup>19)</sup>. All data used in this study are from 2005. Commodities used in this study are separated into three categories (Table 1), based on phosphorus flow from overseas to Japan, as estimated by Matsubae et al.<sup>13)</sup>

The 2005 BACI estimates indicate that a total of 5million tons of P-ore was traded, 222.5 kilotons of yellow phosphorus was traded, 3.1 million tons of phosphorus in chemical product was traded, and another 6.2 million tons of phosphorus was traded in agricultural fertilizer. The key players in this trade

varied from commodity to commodity. The 2005 BACI statistics were analyzed to ascertain which countries were key players, with particular focus on the Asian region. Since China and India are the two biggest economies in Asia, the trade statistics relevant to these countries were analyzed closely. Japan, South Korea, and Indonesia, as the three next largest economies, were also given special attention.

Table 1 Commodities and its phosphorus contents

| Commodities                 | HS Code   | P contents         |
|-----------------------------|---|--------------------|
| Phosphate ore               |   |                    |
|                             | 251010  | 13.46%             |
|                             | 251020  |                    |
| Yellow phosphorus           |   |                    |
|                             | 280470  | 100%               |
| Phosphorus compounds        | 1. Diphosphorus pentoxide                                   | 280910, 1. 42.33%  |
|                             | 2. Phosphoric acid and polyphosphoric acids                 | 280920, 2. 26.87%  |
|                             | 3. Sulphides of non-metals except carbon disulphide         | 281390, 3. 56.34%  |
|                             | 4. Phosphinates and phosphonates                            | 283510, 4. 21.78%  |
|                             | 5. Mono- or di-sodium phosphates                            | 283522, 5. 23.81%  |
|                             | 6. Trisodium phosphate                                      | 283523, 6. 18.89%  |
|                             | 7. Potassium phosphates                                     | 283524, 7. 14.59%  |
|                             | 8. Calcium hydrogen-orthophosphate                          | 283525, 8. 22.76%  |
|                             | 9. Calcium phosphates except hydrogen-orthophosphate        | 283526, 9. 24.38%  |
|                             | 10. Phosphates of metals nes                                | 283529, 10. 21.04% |
|                             | 11. Sodium triphosphate                                     | 283531, 11. 25.25% |
|                             | 12. Polyphosphates of metals except sodium triphosphate     | 283539, 12. 20.74% |
|                             | 13. Phosphides, whether/not                                 | 284800, 13. 30.45% |
|                             | 14. Phosphoric esters, their salts and derivatives          | 291900, 14. 10.00% |
|                             | 15. Thiophosphoric esters(phosphorothioates), salts, derivs | 292010, 15. 19.88% |
|                             | 16. Lecithins and other phosphoaminoalipids                 | 292320, 16. 4.23%  |
| Fertilizer products         | 1. Animal or vegetable fertilizers, in packs >10 kg         | 310100, 1. 11.35%  |
|                             | 2. Superphosphates, in packs >10 kg                         | 310310, 2. 7.42%   |
|                             | 3. Phosphatic fertilizers, mixes, nes, pack >10kg           | 310390, 3. 11.38%  |
|                             | 4. Fertilizer mixes in tablets etc or in packs <10 kg       | 310510, 4. 12.90%  |
|                             | 5. Nitrogen-phosphorus-potassium fertilizers, pack >10kg    | 310520, 5. 2.73%   |
|                             | 6. Diammonium phosphate, in packs >10 kg                    | 310530, 6. 22.29%  |
|                             | 7. Monoammonium phosphate & mix with diammonium, <=10 kg    | 310540, 7. 25.59%  |
|                             |   | 310551, 8. 19.75%  |
|                             | 8. Fertilizers with nitrates and phosphates, nes, <=10kg    | 310559, 9. 12.90%  |
|                             | 9. Fertilizers with nitrogen and phosphorus nes, <=10kg     | 310560, 10. 2.73%  |
|                             | 10. Fertilizers containing phosphorus & potassium, <=10kg   | 310590, 11. 12.90% |
| 11. Fertilizers, mixes, nes |   |                    |

### 2.2. Settings

Equation (1) is used to estimate phosphorus flow following commodities.

$$P_{ij} = T_{ij} * (1 - W_{ij}) * Cont_{ij} \quad (1)$$

Note that  $P_{ij}$ ,  $T_{ij}$ ,  $W_{ij}$ , and  $Cont_{ij}$  refer to, respectively, the amount of phosphorus flowing to country  $j$  (or from country  $j$ ) following commodity  $i$ , the amount of commodity  $i$  flowing (import volume or export volume of country  $j$ , referring to BACI data), the water content of commodity  $i$ , and the phosphorus content of commodity  $i$  ( $W_{ij}$  and  $Cont_{ij}$  are estimated with reference to existing databases<sup>20-22)</sup>). The phosphorus containing commodities analyzed in this study and their P contents are listed in Table 1.

### 2.3. Dependency ratio

In order to determine the dependency of import countries for their phosphate ore, yellow phosphorus, phosphorus in chemicals and their phosphorus in fertilizers, the dependency ratio,  $S_{ij}$  was calculated using the following equation,

$$S_{ij}^k = X_{ij}^k / X_j^k \quad (2)$$

$$\sum_{i=1}^N S_{ij}^k = 1 \quad (3)$$

where  $S_{ij}^k$  is the share of the k commodity imported from i country in j country.  $X_{ij}^k$  and  $X_j^k$  are the import amounts of the k commodity from i country and the total import amount of the k commodity in j country. This defines the market shares in a range from 0 to 1.0, moving from a huge number of very small shareholders to a single monopolistic market.

### 3. Results

#### 3.1. Whole flows

Fig.1 shows the phosphorus flows associated with the international trade of yellow phosphorus, phosphorus compounds and P-ore. According to the estimated results, of the 5 million tons of phosphorus as P-ore that was traded in 2005, approximately 1.3 million tons was imported by Asian countries, accounting for about one third of all the P-ore traded. The Asian trade in yellow phosphorus, however, constituted more than half of the global commercial activity for this commodity, with 50.8% of the 308.5 tons of phosphorus as yellow phosphorus traded in 2005 imported by Asian countries. Almost two thirds of the nearly 300,000 tons of phosphorous compounds traded in 2005 was destined for Asian countries. The global trade in phosphorus in agricultural fertilizers was almost equivalent to the sum of the total trade in P-ore, yellow phosphorus and phosphorus in chemicals. Of the 6.2 million tons of phosphorus traded in agricultural fertilizers, approximately 40% was imported by Asian countries.

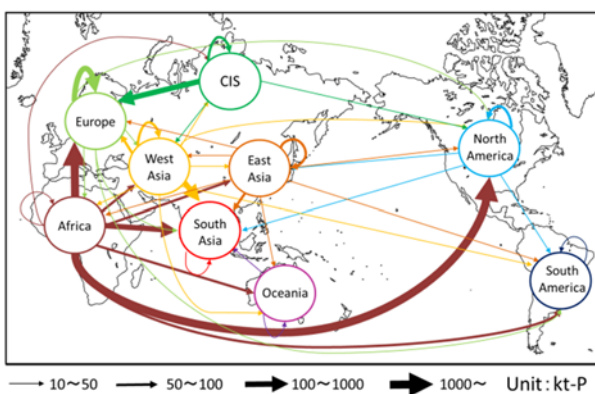


Fig. 1 Global flows of phosphorus

#### 3.2. P-Ore

While the 2005 trade figures indicate that some countries imported P-ore from a variety of countries in 2005, other countries were strongly dependent on just one or two exporters. Just ten countries exported more than 95% of all the P-ore

traded worldwide in 2005, with the top five exporters accounting for 83% of all the trade. Among them, Morocco traded a massive 43% of the global total, and the next four largest traders in P-ore fall way behind, with Jordan, Russia, Syria and China exporting 13%, 12%, 8% and 6% of the total amount traded in 2005.

Accounting for just over 31% of global P-ore imports in 2005, a total of 16 countries exported P-ore in quantities of 500 tons or more to Asia, from places as diverse as the Bahamas, New Caledonia, New Zealand, Togo, Israel and South Africa as well as the major exporters. Of the almost 1.6 million tons imported by Asian countries, five countries accounted for more than 96% of all imports: Jordan accounted for 30% of all the P-ore imported in Asia, and Morocco, China, Egypt and Togo accounted for 30%, 27%, 17%, 11% and 11%, respectively. While Russia, Tunisia and Algeria were major exporters in the global market, they did not play a significant role in Asia.

While some Asian countries depended heavily on one or two countries for their P-ore, other countries imported from a wide variety of sources, as shown in Fig. 2. India was the world's largest importer of P-ore, importing more than 727,000 tons of phosphorus in P-ore, or twice that of any other country. India depended on just three sources: It depended on Jordan to provide approximately half of its phosphorus as P-ore, and another 21% and 15% came from Morocco and Togo, respectively. It should be noted here that only 3% of India's requirements came from China. Japan imported about half of its phosphorus as P-ore from China, about 30% from Morocco, and 20% from Jordan. In the case of South Korea, however, 70% of its P-ore came from China, and 22% originated from Morocco. Indonesia, the other of the top five economies, imported more than 75% from just two sources: Morocco and Egypt. China played the role of exporter and imported negligible quantities of phosphorus as P-ore in 2005 (41tons) compared to its huge output of 308,905 tons, 86% of which was destined for the Asian market.

Many of the large importers of P-ore varied their sources, as shown in Fig. 2. Pakistan imported just 10% less phosphorus as P-ore than India, it chose to import more than two thirds of its needs from Morocco, and about 20% from Jordan. Notably, no Chinese ore was imported by Pakistan in 2005. As can be seen from Fig. 2, many countries were non-importers of P-ore in 2005.

While China imported negligible quantities, its exports of phosphorus as P-ore accounted for approximately 6% of the global total in 2005. Approximately 52% of Chinese P-ore was imported by South Korea, and Japan was the next largest market at 18.6%, followed by India, the Philippines, and then

Australia and New Zealand, at 13.5%, 9.0%, 7.7% and 5.8% respectively. The remainder of the Chinese ore was imported by Bangladesh, Malaysia and Hong Kong.

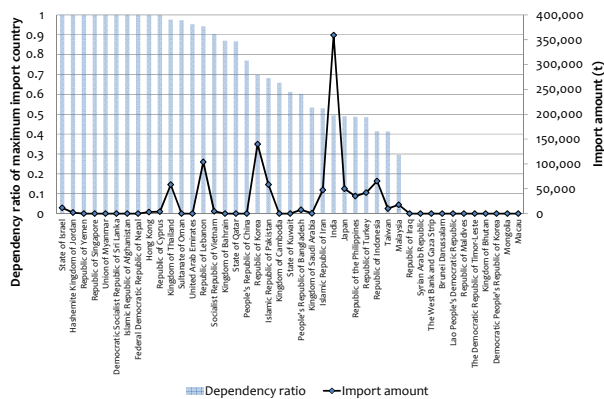


Fig. 2 Dependency ratio of import market of phosphorus ore

### 3.3. Yellow Phosphorus

With regard to the 2005 trade in yellow phosphorus, exports from China account for approximately half the global trade. Yellow phosphorus is used extensively in industry in the production of cars, in paints and in electronics. It is produced from P-ore by a limited number of countries, notably China and Vietnam. Japan was the biggest importer, importing a total of 30.9 million tons of phosphorus as yellow phosphorus, or 30% of all the yellow phosphorus traded by China. South Korea also imported significant quantities of yellow phosphorus, comprising 6% of China's yellow phosphorus export market in 2005. Together Japan and South Korea imported approximately 44% of Chinese yellow phosphorus exports. Chinese exports accounted for 97.5% of Japan's yellow phosphorus imports, and 87.5% of South Korean imports.

The amounts of phosphorus in yellow phosphorus imported by various countries are plotted with the dependency for those countries indicated in Fig. 3. Japan stands out as a large importer with a heavy dependence on one country. India was also a large consumer of yellow phosphorus in 2005 with a heavy dependence. In fact, Japan and India accounted for approximately 20% of all the Chinese exported yellow phosphorus in 2005. The combination of Japan, India and South Korea, which also showed a heavy reliance on China, were equivalent to approximately 25% of the global market that year. Though Indonesia imported very little yellow phosphorus, approximately half of its requirements came from the United Kingdom, and less than 10% came from China. Countries which imported very small quantities of yellow phosphorus typically showed a high dependence on one source.

It should be noted that while Europe relied heavily on CIS states to meet its yellow phosphorus needs, CIS yellow phosphorus was not traded in Asia at all in 2005.

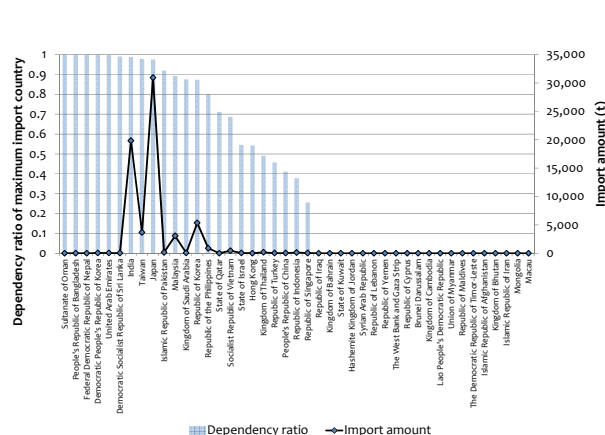


Fig. 3 Dependency ratio of import market of yellow phosphorus

### 3.4. Chemical compounds containing phosphorus

A total of 3,264,491 tons of phosphorus was traded in the form of phosphorus-containing chemicals in 2005, according to the BACI statistics. Approximately 360,000 tons, or about 11%, was exported from Asia, with China accounting for 83% of the Asian export market and 9% of the global export market. China was the world's fourth largest exporter of phosphorus in chemical compounds in 2005, ranking behind Morocco, which had almost double the exports of its nearest competitor, Tunisia (667,500 tons compared to 365,000 tons), and South African exports were only slightly ahead of China's 299,000 tons.

Approximately two thirds of the Chinese produced phosphorus-containing chemicals were exported to Asian countries. South Korea, Japan and Taiwan were its biggest importers at 12%, 9.2% and 8.8% of the Asian market. Almost every country in Asia imported phosphorus in chemicals from China. The import quantities and dependencies of various countries are shown in Fig. 4. India imported significantly more than other Asian countries, but did not show a particularly strong dependency on one importer. While most countries imported their phosphorus in chemicals from a variety of sources, as indicated by the relatively low dependency value, many countries in Asia depended on China for a considerable portion of their phosphorus in chemicals. Chinese chemicals accounted for 90% of all Thai imports, 71% of the South Korean imports, 46% of Indonesian imports, and 41% of Iranian imports. While both Japan and the Philippines imported about one third of their needs from China in 2005, the remaining two thirds of Japan's imports came almost exclusively from South Africa, and the Philippines imported from the United States and a variety of other Asian states. In the

case of Indonesia, almost equal imports from Morocco, Tunisia and the US made up another 30% of its imports, and the remaining 24% was imported from within Asia. A high dependency was noted for countries with small imports.

Despite being the biggest importer of phosphorus in chemicals in Asia, with its imports totaling twice those of the rest of Asia combined, India imported less than 1% of its requirements from China in 2005. India imported its supplies from a wide range of sources, with Morocco and South Africa both accounting for more than a quarter of its imports, and Tunisia and Senegal providing India with 13.5% and 14.5% of its needs. India also imported phosphorus-containing chemicals from the US, Australia and from Jordan, and smaller quantities from Panama, Lebanon and Russia.

Chemicals containing phosphorus were traded quite extensively within Asia from countries other than China. South Korea, which depended on China for 70% of its P-ore and has no phosphate mines of its own, supplied the world with approximately 23,000 tons of phosphorus in chemicals, trading 21,000 tons in Asia in 2005. Almost all of the Asian countries which imported phosphorus-containing chemicals imported some from South Korea. Japan, Thailand and Malaysia also exported phosphorus chemicals widely throughout Asia.

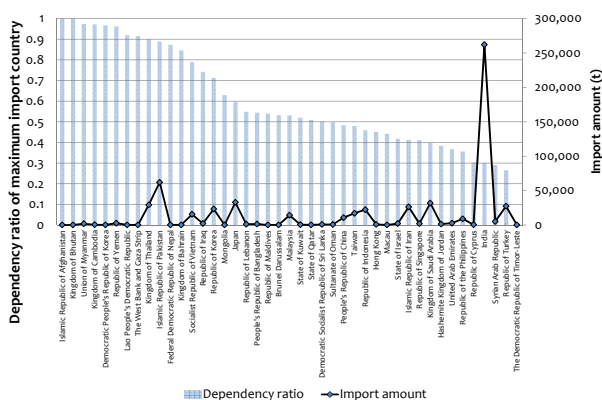


Fig. 4 Dependency ratio of import market of chemical compounds

### 3.5. Phosphorus in agricultural fertilizers

According to the BACI data for 2005, the amount of phosphorus traded in agricultural fertilizers exceeded that of the P-ore, yellow phosphorus and chemicals containing phosphorus combined. A total of 6,160,270 tons of phosphorus in agricultural fertilizers was traded that year, with Asia accounting for 34.5% of the imports, and 8.6% of the global exports. South Korea and Thailand stand out among all the other Asian countries as being the only net exporters of phosphorus in agricultural chemicals in Asia. While a total of 20 Asian countries exported phosphate fertilizers in 2005, their

imports way exceeded their exports, typically by a factor of 1:10, but South Korea exported more than three times what it imported (60,000 and 18,670 tons, respectively), and Thailand exported about half as much again as it imported (17,000 tons and 12,600 tons, respectively).

Just ten countries controlled 75% of the market in phosphate fertilizers in 2005, with the United States commanding more than one third of the global market. With its 2 million tons and Russia's 1 million tons of phosphorus in phosphate fertilizers, together they accounted for half of all trade in the global phosphate fertilizer trade. The third largest exporter was Morocco, exporting less than one third of Russia's exports. China ranked as the world's fourth largest exporter of phosphorus in agricultural fertilizer in 2005, exporting a total of 342,917 tons of phosphorus as phosphate fertilizer, 61% of which was destined for the Asian market. While a total of 13 Asian countries imported phosphate fertilizer from China, Vietnam, Bangladesh and Indonesia accounted for more than 90% of Chinese export market, at 52%, 28% and 12%, respectively.

While China was the largest exporter of phosphate in agricultural fertilizers in Asia, its imports exceeded its exports. Indeed China was the world's largest importer of phosphorus containing fertilizers in 2005, importing more than 550,000 tons of phosphorus in fertilizers that year, more than 200,000 tons more than it exported. Over 60% of China's imported phosphorus as fertilizers came from the United States, with the remaining 40% coming from a number of other countries.

The amounts of phosphorus in fertilizers imported by various countries and their dependencies are shown in Fig. 5. The second and third largest importers of phosphorus in fertilizer were also Asian countries in 2005. China and India and Pakistan accounted for more than 20% of the global market in fertilizers. Like China, India relied on the United States for more than half of its phosphate fertilizer requirement, but imported from another 8 countries, Russia being the only major contributor among them (accounting for 17% of India's import volume). Pakistan, on the other hand, did not have a strong dependency on the United States for its phosphate fertilizer needs. Just 4% of its requirements were met by the United States. Rather, Pakistan imported phosphate fertilizer from a wide variety of sources.

Both Japan and Indonesia demonstrated a strong reliance on the United States to meet the local demand for phosphate fertilizers in 2005. Added to the 65% supplied by the United States to Japan, Jordan and China contributed another 13% each. The United States provided 59% of the domestic demand in Indonesia, followed by China, which provided another 28%



of its requirements. That is, Japan and Indonesia relied on just three and two countries, respectively, to meet 90% of their domestic demand in 2005.

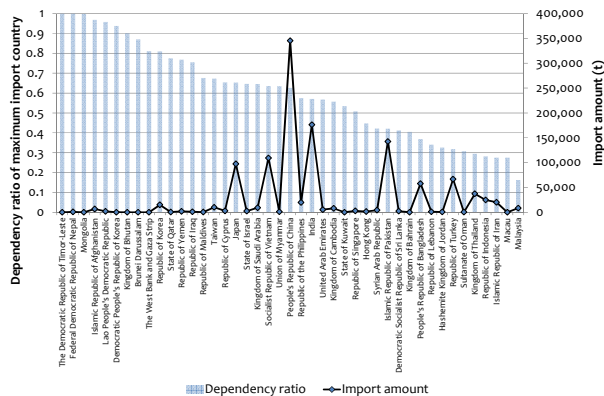


Fig. 5 Dependency ratio of import market of fertilizer

#### 4. Discussions

##### 4.1. General tendencies affecting P-ore imports

In this study, the supply of phosphorus has been clarified, with a focus on Asia. Large quantities of phosphorus are imported into Asia in the form of P-ore, yellow phosphorus and chemicals for use in the fertilizer industry as well as actual phosphate fertilizers. The uneven distribution of raw phosphorus resources and the technology to produce yellow phosphorus has resulted in a tendency for countries to have a strong dependency on just one country or a few of the countries which export phosphorus in one form or another. Among the five largest economies in Asia the following trends were noted.

In 2005, China was a large exporter of P-ore, yellow phosphorus, chemicals containing phosphorus and fertilizers containing phosphorus. Despite the huge output of P-ore in China, China's imports of phosphate fertilizer eclipsed its exports, suggesting that as China's economy and population grow, China will adopt phosphorus conservation strategies to ensure its domestic demand for phosphate fertilizer is met. This will inevitably mean that countries that import from China will be forced to find other suppliers.

India was a massive importer of P-ore, yellow phosphorus and phosphorus in chemicals and in agricultural fertilizers in 2005. In order to meet its domestic needs, India depended on just three countries, Jordan (50%), Morocco (21%) and Togo (15%), for 70% for its P-ore, and on the United States to provide more than 50% of its phosphate fertilizer. While India also demonstrated a high dependency for yellow phosphorus, dependency was low for imports of phosphorus containing

chemicals.

Japan depended on just four countries to meet its P-ore requirements and three countries to meet phosphate fertilizer requirements in 2005. China supplied half of all the P- ore imported, with Jordan, South Africa, and Morocco making up the balance, while the United States provided 65% of the phosphate fertilizer, with Jordan and China equally splitting the balance. Two thirds of the phosphorus containing chemicals was imported from South Africa, and Japan was almost entirely reliant on China for yellow phosphorus.

South Korea imported more than two thirds of its P-ore from China, and was a net exporter of fertilizer in 2005. In fact a number of other Asian countries showed a strong reliance on South Korea to meet their demand for phosphate based fertilizer. Like Japan, South Korea imported almost all of its yellow phosphorus from China, but was a major supplier of phosphorus containing chemicals in the Asian region, particularly.

Indonesia, the fifth largest economy in Asia, imported large quantities of P-ore from a number of sources in 2005, but showed quite a strong dependency on Morocco to meet its phosphate fertilizer needs, at over 40%. Indonesia showed a strong dependency on the United States to meet its local demand for phosphate fertilizer, at 59% in 2005.

The top six countries by export volume of P-ore to Asia were Jordan (30%), Morocco (27%), China (17%), Egypt (11%) and Togo (11%), representing 97% of all the P-ore imported by Asia in 2005. It should be noted that about 60% of all the phosphorus exported globally was supplied by just six countries. Although P-ore is produced in Russia, South Africa and the USA, these countries choose to process the phosphorus before exporting it as a value-added product, mostly as fertilizer, since the profit margin is considerably larger. Recent trends suggest that other countries with large P-ore resources will follow suit and that less P-ore will be available as an import commodity over time. This will inevitably mean that the phosphorus requirements of importing countries will be met at a higher cost.

Moreover, the influence of the strategy in some countries to conserve phosphorus resources is evident in our results. Both the USA and China import large volumes of phosphorus despite having extensive phosphate reserves, and exported less than Morocco in 2005, indicating that domestic consumption is higher than the local supply. As the economies in heavily populated countries improve, their phosphorus needs will increase as the diets become more globalized. It follows that the agriculture sector will require increasing amounts of phosphate fertilizer over time to provide for the increasing

population. This increase in demand will come as the costs of extracting ever-lower concentrations of  $P_2O_5$  from P-ore mined from existing sources inevitably rise over time.

#### 4.2. Geopolitical issues

Besides the risk that countries which export P-ore and phosphorus product will adopt conservation strategies or choose to supply value-added product rather than P-ore, there are significant geopolitical risks associated with the global flow of phosphorus. Instability in the MENA countries in the wake of the Arab Spring has been shown to have an impact on the flow of phosphorus. It should be noted that more than two thirds of the P-ore imported by Asia in 2005 was supplied by just three countries in the MENA region, Jordan (30%), Morocco (27%) and Egypt (11%). There are issues of sovereignty, labor disputes, political grievances, civil strife and even civil war threatening the flow of P-ore and phosphorus products for use in industry and agriculture from these countries<sup>23,24</sup>. Strife in South Africa or in South Korea, both of which are major suppliers of phosphate fertilizers and phosphorus containing chemicals for use in industry, would also have the potential of disrupting the phosphorus flow to the extent that other countries would be unable to meet their domestic demand. It should be noted that it is beyond the scope of this paper to quantify the potential for social and economic damage which could result from the local demand for phosphorus not being met.

#### 4.3 Options to decrease outside phosphorus dependency

##### 4.3.1 Appropriate phosphorus use in agricultural production process

The more efficient use of phosphate fertilizers would reduce the amount of phosphorus “lost” in the water systems due to run-off or in the soils as phosphorus bonds with iron and aluminum ions. Recent studies have indicated that phosphate fertilizer tends to be used liberally on soils which are already P-rich<sup>25,26</sup>. In developed countries, farmers tend to go about business as usual in order to ensure a bumper crop, inevitably over-using fertilizer. On the other hand, the use of phosphate fertilizers as well as sewage sludge and manure in developing countries also results in “lost” phosphorus<sup>27</sup>. With more education and the development of simple tool-kits to test the phosphorus levels in soils, it would be possible to ensure that phosphorus would be used more appropriately. By compiling a comprehensive database of soils and their phosphorus history and amounts would serve as a guideline for appropriate phosphorus use.

##### 4.3.2 Recovery and recycling of phosphorus from waste streams

The utilization of secondary phosphorus resources has the potential to improve the phosphorus dependency since the domestic demand for natural ore declines with better recycling and recovery. It is therefore important to chart the phosphorus flow in the economic activities of each country and to consider the availability of phosphorus resources that remain untapped at present. In order to promote recycling and recovery, there are some significant bottlenecks which need to be overcome. Developing countries lack environmental regulations and the necessary infrastructure to collect waste containing phosphorus, including waste water, sewage sludge, and incineration ash. In developed countries, the market itself poses a problem: consumer preference is considered a difficult barrier to overcome in the marketing of recovered phosphorus. Better public awareness of the importance phosphorus would most likely remove this obstacle.

Besides improving dependency, the reduced demand for P-ore would benefit the ore-mining countries. As with the production of any ore, the mining of P-ore causes large amounts of mining waste. The nutrient enrichment caused by the waste water and the emission of naturally occurring radioactive materials (NORM) are two serious problems associated specifically with P-ore mining which would be reduced by the adoption of natural phosphorus resource conservation methods.

#### 5. Conclusions

A close analysis of the 2005 BACI trade data revealed that many countries in Asia have a strong dependency on just one or two countries to meet their phosphorus requirements. Given the geopolitical risks associated with the P-ore producing nations, close attention needs to be paid to prevent shortfalls in phosphorus requirements. Besides the threat of disrupted supplies from the phosphorus exporters, a clear tendency for P-ore producing countries to export value-added product at a higher cost rather than export ore is clear in the 2005 data. To prepare for the day when phosphate ore is inevitably in short supply, and to ensure a stable supply of phosphorus, efforts need to be made to ensure that phosphorus is recycled efficiently in all societies, and to improve the use of phosphate fertilizers in agriculture. The impact of change in the phosphorus supply on agriculture and therefore on food and food prices need more careful attention.

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