The IMPHOS Strategic Plan of Action 2001-2010 calls for resumption of the traditional series of conferences on "phosphorus compounds", organized in Rabat (October, 1977), Boston (April, 1980), and Brussels (October, 1983).

In application of this plan, IMPHOS co-organized an international workshop on "Phosphates: New Uses and New Technologies" in Jena, Germany, 10-13 July, 2002. Several companies producing phosphate for industrial use joined efforts. The workshop was an opportunity for IMPHOS to collect useful data and information and to establish several contacts, particularly with the Japanese Association of Inorganic Phosphorus Chemistry (JAIPC). This Association is known to organize regularly international symposia on inorganic phosphate materials.

As a follow-up to Jena discussions, IMPHOS and JAIPC decided to co-organize a meeting in Japan in 2005. This joint International Workshop on Phosphorus and Phosphate Compounds (IWPPC) was held along with the 5th International Symposium on Inorganic Phosphate Materials (ISIPM-5). Both events took place in Chubu University in Kasugai in Japan, 6-8 September, 2005. This second ISIPM attracted about 140 participants from 16 countries. The scientific program of the symposium provided for the presentation of 16 lectures to be given by invited speakers, 25 papers pre-selected on the basis of submitted abstracts, and 85 posters.

IMPHOS paper informed the audience of the internal organization of the Institute and its operating mode as well as its var-
ious technical and agronomic undertakings in the recent years. The paper also illustrated the technical, scientific and financial efforts made by the Institute for the sake of enhancement of use of phosphates in all forms. The Institute was praised for its efforts to provide the scientific backing and explain the new technologies to the phosphate industry; and to encourage promising research relevant to phosphates and their derivatives. The IMPHOS oral presentations to the scientific community in this workshop covered phosphate mining and chemical processing activities as well as the important role of this nonrenewable natural resource to both increase and sustain agricultural production and meet the food requirements of the world population. Furthermore, the environmental concerns prompted by mining and industrial activities brought IMPHOS to examine the environmental issues arising from the use of phosphates both in agriculture and industry. Several papers at the conference dealt with the latest developments in fundamental phosphate-related research on glasses and glass-ceramics, apatite and biomaterials based on phosphates, optical phosphate materials, ionic and electronic conducting phosphate materials, phosphorus and nitrogen containing materials and environmental science and technology of phosphates, not to speak of polyphosphates as flame-retardants, etc.

The company Chemische Fabrick Budenheim reviewed new grades of Ammonium Polyphosphates with improved stability, water resistance and polymer compatibility. Different types of coatings were applied and their performance in different turnescent fire retardant systems were investigated. Because of improved properties, Ammonium Polyphosphate was understood to gain new applications in coatings, thermostoastics, thermosetting resin and textile treatment.

This workshop discussed the use of a wide range of new products derived from phosphates other than the well-known fertilizers.

The applications of these new phosphorus compounds are promising, particularly in the following areas: Data processing, energy, health, food preservation and environment protection. Among potential application with very high added value, environmental science and technology of phosphates, not to speak of polyphosphates as flame-retardants, etc.

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The applications of these new phosphorus compounds are promising, particularly in the following areas: Data processing, energy, health, food preservation and environment protection. Among potential application with very high added value, the followings were cited:

- **New Titanium Oxy phosphate Material for Lithium Batteries.** Application: Mobile phones, laptops.
- **Composite Membranes of Bacterial cellulose and sodium polyphosphate.** Applications: medical applications, dietary fibres, headphone membranes,

special paper, protective layer in the construction of enzyme-based glucose sensors, fuel cells, etc.

- **CdS and WO3 (tungsten oxide) nanoparticles in Eu3+ doped polyphosphate glasses.** Application: Semiconductor doped glasses.
- **Development of Phosphate Crystalline Materials for Radioactive Wastes Solidification Towards Increasing the Ecological Safety of their Storage and Disposal.** Application: The wide isomorphism of cation, including those which might be presented in various combinations and quantitative ratios in wastes of the nuclear fuel cycles.
- **Effective Cellular Responses on Polarized hydroxyapatites Vector Ceramics in Body Fluid.** Application: Medical application, the Hydroxyapatites (Ca10(PO4)6(OH)2,HA) has an excellent biocompatibility and valuable electric properties.
- **Pd2P2O7 and AuPO4 - New Anhydrous phosphates of Noble Metals.** Application: Anhydrous Phosphorus can play the role of noble metal collectors, as: Gold, palladium and platinum.

### Table 1: Phosphorus compounds used as food additives

<table>
<thead>
<tr>
<th>Food additive</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphoric acid</td>
<td>Colas, cooked meats, sauces, ham, cheese</td>
</tr>
<tr>
<td>Sodium Phosphate</td>
<td>Cheese cake mix, lemon-pie filling</td>
</tr>
<tr>
<td>Disodium phosphate</td>
<td>Spreads, cooked meats, sausages, instant desserts, cheese slices</td>
</tr>
<tr>
<td>Trisodium phosphate</td>
<td>Cooked meats, ham, sausages, cheese spread</td>
</tr>
<tr>
<td>Potassium phosphate</td>
<td>Cup soups, trifle mix, dessert topping</td>
</tr>
<tr>
<td>Dipotassium phosphate</td>
<td>Non-dairy powdered coffee creamers</td>
</tr>
<tr>
<td>Calcium phosphate</td>
<td>Cheeses and crisps</td>
</tr>
<tr>
<td>Ionsine 5'-disodium phosphate</td>
<td>Rice-based snacks and gravy granules</td>
</tr>
<tr>
<td>Sodium aluminum phosphate</td>
<td>Packet cake mixes</td>
</tr>
<tr>
<td>Calcium diphosphate*</td>
<td>Short pastry mix and baking powder</td>
</tr>
<tr>
<td>Tricalcium diphosphate*</td>
<td>Cake mixes</td>
</tr>
<tr>
<td>Sodium diphosphate*</td>
<td>Bread, catering-grade whipping cream, cheese, condensed milk, dried milk product</td>
</tr>
<tr>
<td>Sodium tripolyphosphate</td>
<td>Cheese, packed soups, condensed milk</td>
</tr>
<tr>
<td>Potassium tripolyphosphate</td>
<td>Canned hot-dog sausages</td>
</tr>
<tr>
<td>Sodium/potassium Polyphosphates</td>
<td>Poultry, ham, bacon, canned costar, reduced-sugar jam, cheese, frozen fish fingers</td>
</tr>
<tr>
<td>Calcium polyphosphates</td>
<td>Cheese</td>
</tr>
<tr>
<td>Ammonium polyphosphates</td>
<td>Cheese</td>
</tr>
</tbody>
</table>

*Diphosphate is also known as pyrophosphate*

Alkaline Polyphosphates. Application: Food preservation.

Hard Polymer Compounds of Polyorganophosphazenes. Application: Substitute of silicone for medical application, Polymers used at high temperature for industrial application. Several other phosphorus compounds are used as additives in rubbers and stabilizing agent in plastics and porcelain.

Table 1 illustrates phosphorus compounds used as food additives. Phosphate compounds have many other industrial applications including their use in steel, as water softener, for preventing corrosion, additives for safety matches and fireworks...etc. In this connection, the main current applications are the following:

Fire starter:
Since phosphorus catches fire readily, it is used in all matches. Earlier white phosphorus was used, but today, red phosphorus is used as "safety matches" because it is safer, less volatile and does not involve any risk of accidental fire as it does not catch fire readily.

Fire stopper:
Phosphorus compounds are among the best flame-retardants for many flammable materials; many are used as plasticizers and flame-retardants as two-in-one. Since more and more materials are made of synthetic polymers (which are easily flammable), the use of fire-resistant materials is badly needed and very common.

In synthetic polymers, paints and protective coatings for wood, plasticizer/flame-retardant (and fire-resistant), phosphorus compounds play a key role. They are used as additives and can be presented in small molecules or as polymer themselves.

Lubricants:
Several phosphate compounds are used to make high temperature lubricants with good lubrication and thermal stability and fire-resistance properties.

Metal treatment:
Phosphate coatings provide an inert and insoluble coating to many metals such as manganese, iron and zinc. The process is called phosphatizing. In addition, phosphoric acid is used in metal surface cleaning (for electroplating or painting).

### Table 2: The main phosphate compounds manufactured by Taihei company

<table>
<thead>
<tr>
<th>Sodium Phosphates</th>
<th>Typical analysis</th>
<th>Major uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mono-sodium phosphate NaH₂P₂O₇, Technical grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 98.0 min, Heavy metal (%): 0.004 max, Arsenic (%): 0.0004 max</td>
<td>Water conditioning, Boiler water treatment, Emulsifier in process cheese, pH control, Metal cleaning</td>
</tr>
<tr>
<td><strong>Disodium phosphate Na₂HPO₄, Technical grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 98.0 min, Heavy metal (%): 0.004 max, Arsenic (%): 0.0004 max</td>
<td>Water treatment, Emulsifier in process cheese, Boiler water treatment, Metal cleaning, Wool scouring, pH control, Stabilization of casein in the production of condensed milk</td>
</tr>
<tr>
<td><strong>Tri-sodium phosphate Na₃PO₄, Technical grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 97.0 ~ 104, Heavy metal (%): 0.004 max, Arsenic (%): 0.0004 max</td>
<td>Water conditioning, Soap and detergents, Boiler water treatment, Metal cleaning, Wool scouring, Alkali agent for Chinese noodle</td>
</tr>
<tr>
<td><strong>Tetra sodium pyrophosphate Na₄P₂O₇.H₂O, Edible grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 97.0 min, Arsenic (%): 0.0004 max</td>
<td>Conditioning oil drilling wells, Metal cleaning, Boiler water treatment, Curing of ham and sausage, Alkaline agent for Chinese noodle, Prevention of tooth-scale</td>
</tr>
<tr>
<td><strong>Sodium acid phosphate Na₃H₂P₂O₇, Technical grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 95.0 ~ 100, Heavy metal (%): 0.002 max, Arsenic (%): 0.0004 max</td>
<td>Conditioning oil drilling wells, Metal cleaning, Boiler water treatment, Curing of ham and sausage, Alkaline agent for Chinese noodle, Prevention of tooth-scale</td>
</tr>
<tr>
<td><strong>Sodium tripolyphosphate Na₅P₃O₁₀, Edible grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 54.0 ~ 60, PH: 9.0 ~ 10.0, Heavy metal (%): 0.004 max, Arsenic (%): 0.0002 max</td>
<td>Soap builder, Detergent and water softener, Conditioning oil drilling mud, Curing of ham and sausage, Alkaline agent for Chinese noodle</td>
</tr>
<tr>
<td><strong>Sodium hexametaphosphate Na₆P₃O₁₀, Technical grade</strong></td>
<td>Appearance: white powder, Assay (%): 65.0 ~ 71, Heavy metal (%): 0.004 max, Arsenic (%): 0.0002 max</td>
<td>Water softener, Boiler water treatment, Dishwashing composition and detergent, Textile and food processing, Dispersion, Curing agent, Binder for unshaped refractory</td>
</tr>
<tr>
<td><strong>Potassium phosphate</strong></td>
<td>Appearance: crystal, Assay (%): 98.0 min, Heavy metal (%): 0.002 max, Arsenic (%): 0.0002 max</td>
<td>Control pH of culture media in penicillin manufacture and glutamic acid fermentation, Special medicinal purposes, Soluble fertilizers, Bio-science</td>
</tr>
<tr>
<td><strong>Dipotassium phosphate K₂HPO₄, Technical grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 98.0 min, Heavy metal (%): 0.004 max, Arsenic (%): 0.0004 max</td>
<td>Control pH of culture media in penicillin manufacture and glutamic acid fermentation, Bio-science</td>
</tr>
<tr>
<td><strong>Tri-potassium phosphate K₃PO₄, Technical grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 97.0 ~ 103.0, Heavy metal (%): 0.004 max, Arsenic (%): 0.0004 max</td>
<td>In synthetic rubber manufacturing, Alkaline agent for Chinese noodle, Boiler water</td>
</tr>
<tr>
<td><strong>Tetra potassium pyrophosphate K₄P₂O₇, Technical grade</strong></td>
<td>Appearance: white powder or crystal, Assay (%): 98.0 min, Heavy metal (%): 0.004 max, Arsenic (%): 0.0001 max</td>
<td>In textile oils and soaps to increase emulsifying values, For copper plating, To improve cleaning action of soaps, Liquid detergent, Alkaline agent for Chinese noodle</td>
</tr>
<tr>
<td><strong>Potassium poly-metaphosphate (KPO₄) Edible grade</strong></td>
<td>Appearance: white powder, Assay (P₂O₅): 53 ~ 80, Heavy metal (%): 0.002 max, Arsenic (%): 0.0004 max</td>
<td>Curing agent for ham and sausage, Stabilizer for ice-cream</td>
</tr>
</tbody>
</table>
In electroplating, white phosphorus hypophosphate is used as a reducing agent to deposit the desired metal on any surface, including non-conducting polymer objects.

In electroplating copper or zinc, their pyrophosphate can be used as electrolyte (along with potassium hypophosphate).

Water treatment:
Many soluble phosphates are used to remove unwanted metal salts from water for various purposes including conversion of hard water to soft water by removing the metal ions as insoluble metal phosphates. For much better performance some organophosphates are used, especially that they are no more costly than normal inorganic phosphates.

A visit to the Taihei Chemical Industrial Company, LTD. was organized at the end of the conference. The Company is a manufacturer of general chemicals which has established a solid record and earned a good reputation in Japan and overseas.

The company boasts major market shares in several products such as phosphate compounds and activated carbon which are essential to chemical substance production. At the company headquarters, a variety of products were mass produced using up-to-date technology.

The company is now vigorously developing its business in dentistry, medical products, and a number of new fields including new ceramics, high technology and biotechnology. The main phosphate compounds included in their business are shown in table 2.

In conclusion, the conference generated a lot of interest among the attending scientific and industrial community. Furthermore, it has enabled IMPHOS to collect useful data and diversify contacts with partners who may be helpful later when IMPHOS plans future events on phosphorus compounds.

The numerous and important aspects of phosphorus applications in everyday life, as discussed at the conference, should contribute to improving the public perception of phosphorus as such applications become widely known to the public. Meanwhile, the current public’s knowledge of phosphorus remains often limited to its use in fertilizers or detergents.


### Table 2: Phosphate Compounds

<table>
<thead>
<tr>
<th>Calcium phosphate Compound</th>
<th>Typical analysis</th>
<th>Major uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-calcium phosphate CaH2PO4·2H2O</td>
<td>Appearance: scaly crystal, Assay (%): 95 ~ 105, Heavy metal (%): 0.002 max, Arsenic (%): 0.0004 max, Loss on drying %: 17.0 max</td>
<td>Fermentation agent, Baking powder, A nutrient salts for yeasts, Purification of brown sugar</td>
</tr>
<tr>
<td>Dicalcium phosphate CaHPO4·2H2O</td>
<td>Appearance: fine crystal, Assay (%): 98 ~ 101, Heavy metal (%): 0.0031 max, Arsenic (%): 0.0002 max, Loss on drying %: 19.5 ~ 22</td>
<td>Calcium, and phosphorus supplement for food and cereal, A polishing medium in toothpastes, Medicinal, Chinese wine</td>
</tr>
<tr>
<td>Tri calcium phosphate Ca3(PO4)2</td>
<td>Appearance: white powder, Assay (%): 90.0 ~ 105.5, Heavy metal (%): 0.002 max, Arsenic (%): 0.0004 max, Loss on ignition %: 10.0 max</td>
<td>Mineral supplement, Lubricant for casting, A flow auxiliary for powder-type food ingredients and pharmaceutical products, A suspension stabilizer in dispersion polymerization</td>
</tr>
</tbody>
</table>

### Table 3: Ammonium Phosphates

<table>
<thead>
<tr>
<th>Ammonium phosphates Compound</th>
<th>Typical analysis</th>
<th>Major uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-ammonium phosphate NH4H2PO4</td>
<td>Appearance: crystal, Assay (%): 96.0 min, Heavy metal (%): 0.002 max, Arsenic (%): 0.0004 max</td>
<td>A component of flame proofing for paper, plywood and textiles, Glazing, pH control, Manufacture of yeast, Flame retardant, Bio-science</td>
</tr>
<tr>
<td>Di-ammonium phosphate (NH4)2HPO4</td>
<td>Appearance: crystal, Assay (%): 95.0 min, Heavy metal (%): 0.002 max, Arsenic (%): 0.0004 max</td>
<td>Mineral supplement for livestock, Yeast food by yeast producers, Dyeing agent, Flame retardant, Produce for glutamate, Bio-science</td>
</tr>
</tbody>
</table>

### Table 4: Magnesium phosphate

<table>
<thead>
<tr>
<th>Magnesium phosphate Compound</th>
<th>Typical analysis</th>
<th>Major uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tri magnesium phosphate Mg3(PO4)2</td>
<td>Appearance: white powder, Assay (MgO) (%): 29 ~ 31.5, (P2O5) (%): 32.5 ~ 35.5, Heavy metal (%): 0.003 max, Arsenic (%): 0.0005 max, Loss on ignition %: 34 ~ 37, Mesh: 200 mesh/all pass (%): 99.5 min</td>
<td>Stabilizer in toothpastes</td>
</tr>
</tbody>
</table>

### The water treatment

<table>
<thead>
<tr>
<th>NMC-4 It's a polyphosphate</th>
<th>Typical analysis</th>
<th>Major uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance: white powder, Assay (P2O5) (%): 53 ~ 80, Heavy metal (%): 0.002 max, Arsenic (%): 0.0004 max</td>
<td>For the prevention of scale deposition and corrosion in water systems</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5: Calcium and Sodium Hyrophosphate

<table>
<thead>
<tr>
<th>Calcium and Sodium Hyrophosphate Compound</th>
<th>Typical analysis</th>
<th>Major uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium hypophosphate CaH2PO4</td>
<td>Appearance: white crystal, Assay (%): 98.0 ~ 101.0, Acidity (mL): 0.5 max, Insoluble water (%): 0.5 max, Barium: limited, Arsenic (ppm): 4 max, Lead (ppm): 10 max, Loss on drying (%): 1.0 max</td>
<td>For medicine</td>
</tr>
<tr>
<td>Sodium hypophosphate NaH2PO4·H2O</td>
<td>Appearance: crystal, Assay (%): 98.0 min, Heavy metal (%): 0.0002 max, Arsenic (%): 0.0001 max</td>
<td>For electro less nickel plating, Plastic &amp; engineering plastic industry, Motorcar industry, Electronics, Office machine</td>
</tr>
</tbody>
</table>

### Table 6: Phosphorus Acid

<table>
<thead>
<tr>
<th>Phosphorus acid Compound</th>
<th>Typical analysis</th>
<th>Major uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance: crystal, Assay (%): 97.0 min, Heavy metal (%): 0.003 max, Sulphate (%): 0.0006 max</td>
<td>Reducing agent, Catalyst, Raw material of PVC stabilizer [Pb3(PO4)2]</td>
<td></td>
</tr>
</tbody>
</table>
MPHOS attended the first British Sulphur Phosphates Conference and Exhibition held in Paris on 2-5 April 2005. The Conference covered the future direction of phosphate market and the key issues and developments that will affect it. It consisted of three sessions in addition to the exhibition, as illustrated in box.

After enduring several years of industry-wide downturn, the phosphate industry began to pick up in 2003. Sustained demand for fertilizers drove prices upward at the international market. The international phosphate industry is currently enjoying an upbeat period.

There nevertheless remain significant challenges, most notably at the sources of supply of phosphate rock. It is predicted that the global phosphate rock market will tighten during the next five years as demand outpaces supply. Currently, the U.S., China, Morocco and Russia account for nearly 70% of total world output. While U.S. rock output is the largest in the world, it is in decline as the reserves that can be mined economically are gradually depleted. For Russia, there is little short-term prospect for any significant increase in phosphate rock production.

There is one project, however, which could change the global balance in phosphate rock demand and supply: the Al-Jalamid reserves in Saudi Arabia. The capital costs of the full-scale development are enormous; however, the project envisages over the next decade the mining and beneficiation of around 4.5 million tonnes a year of phosphate rock at 32% P₂O₅ content.

On the fertilizer side, the industry does not seem to envisage many heavy long-term investments, considered too risky. Instead, it is more committed to specific and limited short-term investments to reduce production costs, in the way of rehabilitating fertilizer plants, de-bottlenecking, and improving existing facilities.

The industry is equally more interested in quality control of finished products in order to comply with environmental regulations in effect. Understandably, research and development efforts continue to focus on gypsum as a byproduct of the phosphate industry. Attempts are made to add value to this byproduct through recycling, instead of piling it up in stacks. The latter practice has brought about the shutdown of many phosphoric acid plants.

Demand for phosphates other than fertilizers is increasing. For example, feed products (DCP/MCP/DFP) are more demanded than fishmeal and other meals of animal origin, because these are suspected to cause the mad cow disease (bovine spongiform encephalitis-BSE).

Phosphate-based detergents witnessed equally a strong recovery after the significant setback in the use of synthetic ‘Zeolite’ in detergent manufacturing. From experience, Zeolites proved to be costly and ineffective.

It is worth mentioning here, in conclusion, that the recovery of the phosphate industry has been instrumental in boosting the activities of certain sideline sectors such as transportation, processing and associated services.

### Phosphate Conference Sessions

<table>
<thead>
<tr>
<th>1. Fertilizer Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Important issues facing the phosphate fertilizer industry</td>
</tr>
<tr>
<td>- Current phosphate situation and world outlook</td>
</tr>
<tr>
<td>- Saudi Arabia: A project with a global impact (Al-Jalamid)</td>
</tr>
<tr>
<td>- Potential applications for phosphogypsum</td>
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<tr>
<td>- The outlook for phosphates in:</td>
</tr>
<tr>
<td>- USA</td>
</tr>
<tr>
<td>- China</td>
</tr>
<tr>
<td>- Russia</td>
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<tr>
<td>- Environmental regulations</td>
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<tr>
<td>- Cadmium regulations and other issues in the EU</td>
</tr>
<tr>
<td>- Regulations on gypsum stacks</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Animal Feed Session</th>
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</thead>
<tbody>
<tr>
<td>- The production and consumption of inorganic feed phosphates</td>
</tr>
<tr>
<td>- New DCP technology</td>
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<table>
<thead>
<tr>
<th>3. Industrial Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Overview of Industrial Phosphates</td>
</tr>
<tr>
<td>- Current status and future of detergent phosphates</td>
</tr>
<tr>
<td>- Phosphate builders and industrial phosphates</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Exhibition Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>- New equipments:</td>
</tr>
<tr>
<td>- Rock crushers</td>
</tr>
<tr>
<td>- Instantaneous coolers of fertilizers at the dryers outlet</td>
</tr>
<tr>
<td>- Laboratory equipments adapted to the analysis of phosphate fertilizers, especially in relation to trace elements.</td>
</tr>
<tr>
<td>- Chemical reactants for new flotation techniques.</td>
</tr>
<tr>
<td>- Fertilizer anti-caking products.</td>
</tr>
</tbody>
</table>
MPHOS has been involved in a long-term project in Pakistan for the past 15 years, in an effort to promote balanced fertilizer use for sustainable agriculture. The results presented below concern the third and final phase of the project.

Background

The level of fertilizer use in the country is about 130 kg per ha but the N:P2O5 ratio is wider than the recommended ratio, with the result that applied nutrients have low efficiency. The situation clearly required investigation of fertilizer management practices and dissemination of the results to farmers. A collaborative three-year program on phosphate use development in Pakistan was jointly sponsored by World Phosphate Institute (IMPHOS), and the Food and Agriculture Organization (FAO) and implemented starting from 2003 by National Fertilizer Development Centre (NFDC) in collaboration with provincial organizations.

It was agreed that the program should address the following issues:

1. Quantification of material and economic gains from balanced use of fertilizers and dissemination of the findings;
2. Improving efficiency of phosphate application through new technologies;
3. Assessing phosphorus requirement based on accumulated soil P reserves and P budgeting;
4. Studying phosphorus requirement of certain crops (legumes and pulses) highly responsive to phosphorus;
5. Monitoring the residual effect of previous phosphorus applications.

Methodology

Resource-poor farmers with smallholdings and limited knowledge of fertilizers were if possible selected. Fertilizer trials and demonstrations have been laid out throughout the country, but mostly under irrigated conditions. Few demonstrations were conducted in rainfed areas as well. Fertility status of selected sites varied from place to place, but none had serious salinity or water logging problems. Half N full P and K rates were applied as basal dose and remaining half N as topdressing under irrigated conditions, while full dose of fertilizer was applied as basal in rainfed plots. Recommended seed rate of approved varieties was used. To the extent possible, plots were kept free from weed.

Effect of efficient and balanced use of fertilizers

At the experimental area of Agricultural Research Institute, Tandojam, Sindh, an experiment on wheat was conducted in wheat-cotton cropping system. Treatments were randomised within each replication. Average of four replications showed a yield increase of 91.5 percent in response to the application of 100 kg/ha of phosphate (Table 1).

Table 1: Effect of efficient and balanced use of fertilizers on wheat in Tandojam

<table>
<thead>
<tr>
<th>Fertilizer application rate</th>
<th>Wheat yield (kg/ha)</th>
<th>Yield increase over N alone (kg/ha)</th>
<th>Increase over N alone (%)</th>
<th>Gross return (Rs)</th>
<th>Net return (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer’s practice</td>
<td>2 622</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150-0-0</td>
<td>2049</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150-100-0</td>
<td>3924</td>
<td>1875</td>
<td>91.5</td>
<td>16406</td>
<td>11056</td>
</tr>
<tr>
<td>150-100-60</td>
<td>4236</td>
<td>2187</td>
<td>106.7</td>
<td>19136</td>
<td>11896</td>
</tr>
<tr>
<td>75-50-0</td>
<td>2378</td>
<td>329</td>
<td>16.0</td>
<td>2879</td>
<td>204</td>
</tr>
</tbody>
</table>

Table 2: Effect of various methods of P application in Tandojam

<table>
<thead>
<tr>
<th>Fertilizer application rate</th>
<th>Treatment</th>
<th>Wheat grain yield (kg/ha)</th>
<th>Increase over N alone (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150-0-0</td>
<td>N alone</td>
<td>2698</td>
<td>-</td>
</tr>
<tr>
<td>150-100-0</td>
<td>N+P (100% P broadcast)</td>
<td>3394</td>
<td>25.8</td>
</tr>
<tr>
<td>150-75-0</td>
<td>N+P (75% through drilling)</td>
<td>3333</td>
<td>23.5</td>
</tr>
<tr>
<td>150-75-0</td>
<td>N+P (75 mixed with cow dung)</td>
<td>3735</td>
<td>38.4</td>
</tr>
<tr>
<td>150-75-0</td>
<td>N+P (75% as fertigation)</td>
<td>3296</td>
<td>22.1</td>
</tr>
</tbody>
</table>

Table 3: Effect of various methods of P application at D.G. Khan and Sukkur

<table>
<thead>
<tr>
<th>Fertilizer application rate</th>
<th>Treatment</th>
<th>Wheat grain yield (kg/ha)</th>
<th>Increase over N alone (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120-0-0</td>
<td>N alone</td>
<td>2444</td>
<td>-</td>
</tr>
<tr>
<td>120-90-60</td>
<td>N+P (100% P broadcast)</td>
<td>3234</td>
<td>32.3</td>
</tr>
<tr>
<td>120-67.5-60</td>
<td>N+P (75% through drilling)</td>
<td>3463</td>
<td>41.7</td>
</tr>
<tr>
<td>120-67.5-60</td>
<td>N+P (75 mixed with cow dung)</td>
<td>3185</td>
<td>30.3</td>
</tr>
<tr>
<td>120-67.5-60</td>
<td>N+P (75% as fertigation)</td>
<td>3606</td>
<td>47.5</td>
</tr>
</tbody>
</table>

Note: 1 kg N costs 18.1 kg P2O5 costs 26.50, and 1 kg K20 costs Rs. 31.50. Wheat is sold at Rs. 8.75 per kg. (US$ 1 = Rs. 50)
increasing further to Rs.11,896 with the addition of potash, which means a positive response to K application, though limited in magnitude.

**Effect of various methods of P applications**

To assess the effect of various P application methods, four (4) trials were conducted and response to different treatments were measured, as shown in Table 2.

The data indicate the best performance was realized with the application of 75 percent P mixed with cow dung in 1:2 ratio, resulting in 38.4 percent gain over application of N alone. The second best ranking treatment was the broadcast application of 100 percent P.

Similarly, trials conducted at D.G. Khan and Sukkur compared the effect of different methods of P application on wheat. Table 3 indicates the performance of different treatments on the basis of average yield from two experiments.

The average yield from the two experiments shows that broadcast application of 90 kg P, had better performance with 32.3% gain over N alone treatment, but 75% P applied in fertigation proved to be the best treatment followed by the P drilling treatment. On the basis of individual experimental sites, the yield level at D.G. Khan was higher than that achieved in all other experiments.

### Table 4: P Residual effect on succeeding crop in Tandojam

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Wheat grain yield (kg/ha)</th>
<th>Yield increase over FP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>109-57-0 Farmers Practice (FP)</td>
<td>1587</td>
<td>-</td>
</tr>
<tr>
<td>170-85-62 Recommended NPK</td>
<td>2137</td>
<td>34.6</td>
</tr>
</tbody>
</table>

An experiment on the residual effect of P application on succeeding crop was conducted in four replicates at the Agricultural Research Institute Station, Tandojam. Comparison of yield is given in Table 4.

Farmer’s practice (FP) calls for application of 109-57-0 kg/ha compared to the recommended rate of 170-85-62 kg/ha. Average of four replicates indicates 34.6 per cent yield increase over FP in response to recommended application.

A brochure with all findings from the project was published in the national Urdu language to the benefit of researchers, extension workers, NGO’s and farmers.

As this phase of the project comes close to an end, a synthesis report of all three phases is under preparation. Here are the main features of this report:

**Review and consolidation of data from IMPHOS/FAO/NFDC activities over three phases of the project**

There is general agreement that phosphate research and development work conducted over a period of more than 10 years under IMPHOS/FAO/NFDC project should be compiled through collection, analysis, synthesis and interpretation of data. International and local consultants have been identified and started working on:

1. Collection of data from NFDC-extended phase II and interaction with collaborating institutions in the provinces.
2. Analysis, synthesis and collation of data.
3. Collection and incorporation in the report of similar data available from Research Institutes in crop production regions.
4. Integration of the data from extended phase III, phase I and II, for the purpose of producing one single document on project activities.
5. Extrapolation of data on the possible total growth in crop production if the practice of balanced fertilizer application were to be adopted by farmers in similar zones, the implications of such yield growth for fertilizer demand and farm-gate prices of agricultural produce.
6. Analysis, assessment and in-depth review of the impact of all 3 phases of this project on phosphate fertilizer use and trend nationwide in Pakistan.
7. Any other relevant activity to strengthen the project output.

Final report including all the above items will be issued early 2006 and will be given wide publicity and distribution in Pakistan.
Testing Various Fertilizer recommendations: The Hungarian Fertilizer Advisory Systems

Peter Csathó *, Tamás Árendás and Tamás Németh
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The World Phosphate Institute (IMPHOS), the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences (RISSAC), Budapest, and the Agricultural Research Institute of the Hungarian Academy of Sciences (RIA), Martonvásár, started in Autumn 2003 a three-year program of field trials in areas characteristic of Hungary. Winter wheat, maize (corn) and spring barley were selected as test crops in the program for the first, second and third year, respectively. The aim of these trials is to field test the three recommendation systems of the RISSAC-RIA: 1) The cost-saving, environment friendly system, 2) the intensive MEM NAK system 3) other systems applicable to Hungarian agriculture. The preliminary results from the first year of trials on winter wheat, a crop with strong demand for N and P, but less for K, are evaluated in the article.

EXPERIMENTAL SITES AND FIELD TREATMENTS

Sites
IMPHOS-1: Balatonszentgyörgy, brown forest soil, slightly acidic sandy loam, medium to good P supply.
IMPHOS-2: Mezőkövesd, meadow soil, strongly acidic clay loam, poor to medium P supply.
IMPHOS-3: Nagyhörcsök-Sarhatvan, chernozem soil, calcareous loam, poor to medium P supply.

Treatments
The three new field trials on the three sites consisted of the following treatments:

Treatments 1-8: P1 dose refers to annual application rate of 50 kg ha⁻¹ P₂O₅, while P2 dose refers to 100 kg ha⁻¹ P₂O₅ annually. N dose is the annual application rate of 150 kg ha⁻¹ N, and K dose corresponds to 50 kg ha⁻¹ K₂O. Treatments 1-8 were designed to check the capacity of the soil to supply N, P and K according to criteria applied by the RISSAC-RIA under the environment friendly fertilizer recommendation system.

Treatments 9-14: RISSAC-RIA minimum application rates, environment friendly, nutrient balanced and integrated recommendations. Talajerö recommendation and MÉM NAK intensive recommendation were calculated according to soil test values, expected yield levels and adjustment factors.

These 14 treatments in 3 replications were set up in randomised block design. In 2003/2004, the weather was extremely wet compared with the average weather conditions in Hungary. Winter wheat showed differentiated development in all of the three sites depending on the treatments.

RESULTS

IMPHOS-1 trial at Balatonszentgyörgy
Fertilizer doses of N-P₂O₅-K₂O applied in the treatments, and resulting winter wheat grain yields are shown in Table 1.

<table>
<thead>
<tr>
<th>Code</th>
<th>Treatment</th>
<th>N (kg/ha)</th>
<th>P₂O₅ (kg/ha)</th>
<th>K₂O (kg/ha)</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Φ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.78</td>
</tr>
<tr>
<td>2</td>
<td>P2K</td>
<td>0</td>
<td>100</td>
<td>50</td>
<td>4.80</td>
</tr>
<tr>
<td>3</td>
<td>NK</td>
<td>150</td>
<td>0</td>
<td>50</td>
<td>6.56</td>
</tr>
<tr>
<td>4</td>
<td>NP2</td>
<td>150</td>
<td>100</td>
<td>0</td>
<td>6.17</td>
</tr>
<tr>
<td>5</td>
<td>NKP1</td>
<td>150</td>
<td>50</td>
<td>50</td>
<td>6.56</td>
</tr>
<tr>
<td>6</td>
<td>NKP2</td>
<td>150</td>
<td>100</td>
<td>50</td>
<td>7.20</td>
</tr>
<tr>
<td>7</td>
<td>NKP1BU*</td>
<td>150</td>
<td>150</td>
<td>50</td>
<td>6.85</td>
</tr>
<tr>
<td>8</td>
<td>NKP2BU</td>
<td>150</td>
<td>300</td>
<td>50</td>
<td>6.91</td>
</tr>
<tr>
<td>9</td>
<td>RISSAC-RIA-1**</td>
<td>88</td>
<td>55</td>
<td>0</td>
<td>5.50</td>
</tr>
<tr>
<td>10</td>
<td>RISSAC-RIA-2</td>
<td>99</td>
<td>61</td>
<td>19</td>
<td>6.57</td>
</tr>
<tr>
<td>11</td>
<td>RISSAC-RIA-3</td>
<td>110</td>
<td>66</td>
<td>38</td>
<td>6.91</td>
</tr>
<tr>
<td>12</td>
<td>RISSAC-RIA-4</td>
<td>121</td>
<td>72</td>
<td>56</td>
<td>6.56</td>
</tr>
<tr>
<td>13</td>
<td>Talajerő Kkt</td>
<td>140</td>
<td>100</td>
<td>0</td>
<td>7.31</td>
</tr>
<tr>
<td>14</td>
<td>MEM NAK</td>
<td>155</td>
<td>75</td>
<td>90</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td>LSD₀.₀₁</td>
<td></td>
<td></td>
<td></td>
<td>1.28</td>
</tr>
</tbody>
</table>

Mean
6.31

** BU: the three-year P doses in one initial build-up application at the start of the trial;
** RISSAC-RIA-1: minimum level; RISSAC-RIA-2: environmental friendly level; RISSAC-RIA-3: balance-based level; RISSAC-RIA-4: integrated level

Winter wheat yield gained 2.4 t/ha grain in response to N application, while P application generated a yield increase of 0.6 t/ha grain and K application resulted in a 1.0 t grain/ha growth in yield. Reponses to application of the three nutrients indicated that the soil supplies of these nutrients were good, i.e., consistent with the NPK supply categories established under the recommendation system. The only exception was probably potassium. It must be noted, however, that the Balatonszentgyörgy trial was unfortunately laid out on a heterogeneous area: Nutrient supply capacity in the western part of the trial site was lower than that in the eastern part. Relatively high heterogeneity is also evident from the high LSD₀.₀₁ values (1.28 t/ha) and the high coefficient of variation (%CV) obtained in the trial (Table 1.).
It is worth stressing that RISSAC-RIA-2 level (environment friendly system) suggested the application of only 56% of the total amount of NPK recommended by the MEM NAK intensive system for equal winter wheat yields in these treatments. Thus, the objective behind setting up new, cost-saving and environment friendly system was fulfilled: To reduce NPK application as much as possible, without causing yield losses, and while sustaining high yield levels (Table 1).

The economic analysis of the first year of IMPHOS-1 trial on winter wheat, Balatonszentgyörgy, is given in Figure 1. It shows net profits resulting from the application of different recommendation systems:

- RISSAC-RIA-1 (minimum level): 38 thousand Hungarian Forints (HUF);
- RISSAC-RIA-2 (environmental friendly level): 62 thousand HUF;
- RISSAC-RIA-3 (balance-based level): 66 thousand HUF;
- RISSAC-RIA-4 (integrated level): 53 thousand HUF;
- Talajerō (integrated level): 67 thousand HUF;
- MEM NAK (intensive level): 47 thousand HUF.

Highest net profits were obtained in Talajerō (integrated level) and with RISSAC-RIA-3 (balance-based level).

(1 USD = 180 HUF)

**IMPHOS-2 trial, Mezőkövesd**

The doses of fertilizer nutrient N-P2O5-K2O applied in each one of the treatment, and the resulting winter wheat grain yields are shown in Table 2.

Winter wheat yield response to N application resulted in grain yield gain of 0.4 t/ha, but only 0.8 t/ha increase in response to P application, and 0.0 t/ha in response to K application. These responses to applications of N, P, and K is a proof that the soil capacity of supply of the three nutrients was good, i.e., consistent with the classification of the NPK supply categories established in the recommendation system. The measurement of responses to NPK indicated even more accurately the importance of the NPK supplies than in the case of the Balatonszentgyörgy trial. Weather conditions were very much favorable for winter wheat growth in 2003/2004; this is demonstrated by the level of average grain yield of 10.6 t/ha obtained in the Mezőkövesd trial (Table 2).
Similar to the Balatonszentgyörgy trial, RISSAC-RIA-2 (environment friendly) trials suggested that the requirement is only half of the NPK rate recommended by the MEM NAK intensive system for achieving equal winter wheat grain yields at Mezőkövesd while applying the same treatments (Table 2).

The economic analysis of the first year of IMPHOS-2 trial on winter wheat in Mezőkövesd, is given in Figure 2. The net profits obtained from different recommendations were the following:
- RISSAC-RIA-1 (minimum level): 158 thousand HUF (Hungarian Forints) (180 HUF is equivalent to 1 USD);
- RISSAC-RIA-2 (environment friendly level): 170 thousand HUF;
- RISSAC-RIA-3 (balance based level): 168 thousand HUF;
- RISSAC-RIA-4 (integrated level): 177 thousand HUF;
- Talajerö (integrated level): 144 thousand HUF;
- MEM NAK (intensive level): 150 thousand HUF.

The highest net profits were realized at RISSAC-RIA-2 (environment friendly level), RISSAC-RIA-3 (balance-based level), and RISSAC-RIA-4 (integrated level).

** IMPHOS-3 trial at Nagyhőrcsök-Sarhatvan**

The three fertilizer nutrients N-P$_2$O$_5$-K$_2$O were applied under the various treatments and the resulting winter wheat grain yields are shown in Table 3.

Winter wheat responded to N application with an yield increase of 2.3 t/ha grain, but only 1.0 t/ha grain to P application and 0.4 t/ha to K application. Again, responses to application of the three nutrients indicated good soil capacity to supply the three nutrients, consistent with the NPK supply categories established in the recommendation system (Table 3.).

Similar to the IMPHOS-1, IMPHOS-2, and IMPHOS-3 trials, RISSAC-RIA-2 (environment friendly) suggested fertilizer requirement is only around 55% of the total NPK rate recommended under the MEM NAK intensive system, for achieving equal level of winter wheat grain yields from these treatments. It seems, however, that the N recommendations under RISSAC-RIA-1 (minimum level) in all three sites proved to be a little too low in this wet year. However, we suggest to farmers, to be on the safe side, to apply the environment friendly system (RISSAC-RIA-2 level) (Table 3).

Figure 3 gives the economic analysis of the first year of IMPHOS-3 winter wheat trial, Nagyhőrcsök-Sarhatvan. Net profits from different recommendations were as follows:

1. RISSAC-RIA-1 (minimum level): 40 thousand HUF;
2. RISSAC-RIA-2 (environmentally friendly level): 54 thousand HUF;
3. RISSAC-RIA-3 (balance based level): 63 thousand HUF;
4. RISSAC-RIA-4 (integrated level): 46 thousand HUF;
5. Talajerö (integrated level): 48 thousand HUF;
6. MEM NAK (intensive level): 37 thousand HUF.

The highest net profits resulted from the application of RISSAC-RIA-2 (environment friendly level), and the RISSAC-RIA-3 (balance-based level).

The net profits calculated were similar in IMPHOS-1 and IMPHOS-3 trials; but were 3-4 times higher in IMPHOS-2 trial because of very high crop yields achieved in Mezőkövesd.

Besides agronomic and economic evaluation of the results from the field trials, four (4) baking quality parameters were measured on each site and each plot. In general, baking quality was best with the treatments that gave the highest yields on the sites.

**CONCLUSIONS**

The average winter wheat grain yields from the three IMPHOS trials based on different recommendations, were the following:

1. RISSAC-RIA-1 (minimum level): 6.51 t/ha;

---

**Table 3: Winter wheat yield in response to application of the Hungarian fertilizer recommendation systems, 2003/2004.**

*Field data from IMPHOS-3 trial: meadow soil, Nagyhőrcsök-Sarhatvan.*

<table>
<thead>
<tr>
<th>Code</th>
<th>Treatment</th>
<th>N (kg/ha)</th>
<th>P$_2$O$_5$ (kg/ha)</th>
<th>K$_2$O (kg/ha)</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Φ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.58</td>
</tr>
<tr>
<td>2</td>
<td>P2K</td>
<td>0</td>
<td>100</td>
<td>50</td>
<td>3.00</td>
</tr>
<tr>
<td>3</td>
<td>NK</td>
<td>150</td>
<td>0</td>
<td>100</td>
<td>4.30</td>
</tr>
<tr>
<td>4</td>
<td>NP2</td>
<td>150</td>
<td>100</td>
<td>0</td>
<td>4.94</td>
</tr>
<tr>
<td>5</td>
<td>NKP1</td>
<td>150</td>
<td>50</td>
<td>50</td>
<td>4.90</td>
</tr>
<tr>
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<td>NKP2</td>
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<td>50</td>
<td>5.30</td>
</tr>
<tr>
<td>7</td>
<td>NKP1E*</td>
<td>150</td>
<td>150</td>
<td>50</td>
<td>5.21</td>
</tr>
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<td>NKP2E</td>
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<td>300</td>
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<td>5.47</td>
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<td>9</td>
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<td>88</td>
<td>66</td>
<td>0</td>
<td>4.22</td>
</tr>
<tr>
<td>10</td>
<td>RISSAC-RIA-2</td>
<td>101</td>
<td>78</td>
<td>20</td>
<td>4.96</td>
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<td>84</td>
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<td>90</td>
<td>59</td>
<td>4.94</td>
</tr>
<tr>
<td>13</td>
<td>Talajerö Kkt</td>
<td>150</td>
<td>120</td>
<td>0</td>
<td>5.21</td>
</tr>
<tr>
<td>14</td>
<td>MEM NAK</td>
<td>120</td>
<td>138</td>
<td>102</td>
<td>4.84</td>
</tr>
</tbody>
</table>

LSD$_{0.05}$

Mean

0.63

4.64

*E: the three-year P doses in one initial build-up application at the start of the trial;** RISSAC-RIA-1: minimum level; RISSAC-RIA-2: environmental friendly level; RISSAC-RIA-3: balance-based level, RISSAC-RIA-4: integrated level
2. RISSAC-RIA-2 (environmentally friendly level): 7.34 t/ha;
3. RISSAC-RIA-3 (balance based level): 7.51 t/ha;
4. RISSAC-RIA-4 (integrated level): 7.48 t/ha;
5. Talajerő (integrated level): 7.71 t/ha;
6. MEM NAK (intensive level): 7.34 t/ha.

On average, the highest yields from the three IMPHOS trials were obtained at Talajerő (integrated) and RISSAC-RIA-3 (balance-based level).

Net profits from the three IMPHOS trials based on different recommendations were on average:

1. RISSAC-RIA-1 (minimum level): 79 thousand HUF (Hungarian Forints; 180 HUF equivalent to 1 USD);
2. RISSAC-RIA-2 (environmentally friendly level): 95 thousand HUF;
3. RISSAC-RIA-3 (balance based level): 99 thousand HUF;
4. RISSAC-RIA-4 (integrated level): 92 thousand HUF;
5. Talajerő (integrated level): 86 thousand HUF;
6. MEM NAK (intensive level): 78 thousand HUF.

Out of the three IMPHOS trials, the highest net profits resulted on average from the RISSAC-RIA-3 (balance based level), the RISSAC-RIA-2 (environment friendly level), and RISSAC-RIA-4 (integrated level).

The data from the first year of winter wheat field trials demonstrate clearly the sound and scientifically-based principles of the new, cost-saving and environment-friendly RISSAC-RIA fertilizer recommendation system. Our new fertilizer recommendation system is based on correlations established from available data. These were stored in the database of the Hungarian long-term field fertilization trials (N,P, and K) and were published between 1960 and 2000. As a result, our new system recommends lower NPK doses compared with the intensive MEM NAK system. The application of the lower doses does imply any loss in crop yield but maintained the high yield levels; and resulted in highest net profits for farmers.

Figure 2. N-P2O5-K2O doses recommended by different advisory systems, and resulting winter wheat grain yields. IMPHOS-2 field trial, Mezokövesd, Meadow soil with good N, poor P and very good K supply.

Figure 3. N-P2O5-K2O doses recommended by different advisory systems, and resulting winter wheat grain yields. IMPHOS-3 field trial, Nagyhoračsok-Sarhatvan, Chernozem soil with moderate N, poor P and good K supply.

Figure 4. Net incomes based on application of the recommendations of the Hungarian fertilizer advisory systems. IMPHOS 1-2-3 trials, winter wheat, 2004 (Sulyok, 2004)
These ideas are excerpted from a paper written by a group called "Agriculture Council of Experts" created by Sasakawa Global 2000 project in Africa. Part of the mandate of this group is to put together policy papers on fertilizer use, issue of fertilizer profitability and barriers or constraints for increasing fertilizer use in Africa. The puzzlement about fertilizer use is that the low level of use is due to a large number of factors; and implementation of any fertilizer policy requires tradeoffs between some of these factors. This excerpt will detail these, and will follow with a set of recommendations.

Barriers to increased fertilizer use

First, the lack of profitability in using fertilizer is due to unprofitable and unstable ratios between the prices of fertilizers and product prices. If one looks at any of the current price ratios, it is clear why farmers do not use fertilizer. If one then looks at the instability in the price range, one can see why they do not spend a lot of time trying to learn how to use fertilizer unless it is highly subsidized.

Second, past dependence on heavy government intervention in the economy has led to unstable supplies, inappropriate fertilizer mixes, and lack of timeliness in delivery for profitable use. On the lack of relevance of fertilizer mixes, a lot of the fertilizer supplies have been the byproduct of aid programs. That doesn't necessarily mean that the fertilizer market really is not useful, it means often that some companies are trying to get rid of unwanted fertilizer blends and sell them to aid agencies at lower prices.

Third, there is uncertainty about the responses to fertilizer due to unstable weather patterns, lack of irrigation, and more importantly, unstable public policies.

Fourth, there is lack of knowledge on the part of farmers about the use of fertilizers. African farmers implement all kinds of complex systems of multiple cropping and rotations of numerous crops. Decisions about how much fertilizer to use, and where and how to apply it, become a very complicated issue.

The fifth barrier to increased fertilizer use is lack of sufficient fertilizer distribution that would facilitate delivery of input to farmers in a timely manner.

The sixth barrier is lack of appropriate fertilizer mixes that are appropriate for local conditions.

The seventh is lack of credit in the entire fertilizer distribution system, from the small farmer to the retailer and the wholesaler.

The eighth barrier is lack of foreign exchange for importers to acquire adequate and appropriate supplies.

The ninth barrier is lack of adequate research and extension systems to generate knowledge about fertilizer use and to diffuse that knowledge to the farm population.

The tenth and final barrier is an inadequate world transportation and communication infrastructure to reach distant areas and to ensure timely delivery. This issue is very neglected. Consequently, when looking at the costs of getting fertilizer to the farms and getting the product back out, there are serious problems and escalating costs. Ultimately, the question boils down to whether government wants to use fertilizer subsidies to offset some of those kinds of costs.

Policy Recommendations

The Council of Experts suggests eleven policy recommendations for reducing and eliminating these ten barriers:

First, trade and exchange rate policies are still wrong in most African countries, even though they underwent structural adjustment reforms and programs in the 1980’s. Looking at their price relative to product price at the port, fertilizers are still very unprofitable- even at the port. Exchange rates are the most important price of the economy. If government does not get them right, it is not going to be able to do much about the profitability of fertilizer.

In addition, Africa still has rather large export taxes. Africa has specialized in export taxes that limit their own farmers’ access to international markets. This drives domestic prices down to a very low level. Until governments begin to get some of these policies right, little other progress can be made. Trying to offset this with subsidies becomes a costly process and leads to questions about their sustainability. How long can governments continue to provide those kinds of subsidies?
Second, present policy trends towards the privatization of the economy should be continued. It is imperative that a private distribution sector for fertilizer should be developed and that government withdraws from this activity. So much of the fertilizer industry in the public sector is filled with people who have no knowledge of agriculture or farming or fertilizer. In addition, the public sector has often been dull and slow and unresponsive.

Third, while little can be done about unstable weather, a great deal can be done about unstable policy. Out of unstable monetary and fiscal policies one gets unstable exchange rates. This leads to price uncertainty.

Fourth, expanded research efforts are needed to better understand semi-arid soils and to solve the very specific problems caused by lack of knowledge of local responses to the application of fertilizer. Similarly, expansion of extension efforts is needed in most semi-arid African countries, to help farmers learn new production practices and more economic use of their resources. Some international agricultural research centers (IARCs) are dominated by agronomists and physical scientists, but research on soils often ends up far down on the list of priorities. The truth of the matter is, very little is known about soils in most places in the world. We tend to think that increased agricultural output comes from the introduction of improved varieties. But underdevelopment can be caused by a soil problem and the solution can be a technological innovation produced by soil scientists who know the local soils. This is very applicable to large areas of Africa.

Fifth, an efficient distribution system for fertilizer will emerge only if the government withdraws from the sector and if the use of fertilizer becomes profitable. Thus, government parastatals that occupy space in the fertilizer distribution system should be phased out quickly and macro-economic policies put in place to make agricultural production profitable. There is also a whole set of issues related to educating people in the private distribution sector, and setting up a strong extension program among fertilizer distributors so that they know something about fertilizer values. In the process they can learn about the risks and uncertainties involved in farming.

Sixth, it is difficult to generalize about fertilizer mixes. Proper mixtures vary enormously from country to country and from commodity to commodity. The only general recommendation would be that preference should be given to high concentration materials, largely because of the high transportation costs of fertilizer. Government can lower the transportation costs with high concentration materials. But fertilizer mixes still must reflect their local nutrition deficiencies and their commodities.

The seventh recommendation involves the imperfectly performing credit markets, which are a major issue in Africa and other parts of the developing world. There is hardly any place in Africa with efficient financial intermediaries. Instead, state-controlled banks take money appropriated by the government and channel it into the financial system. Distribution is not always done equitably or appropriately. Major reforms in the banking system are needed, reforms that create financial intermediaries and institutions to mobilize savings and make it available to farmers. The best institutions are cooperatives and credit unions that mobilize savings from local farmers and then provide a mechanism for reinvesting them. To do something similar for the fertilizer distribution sector is more complicated. It requires examining the barriers and constraints that the fertilizer distributors face. They often cannot get access to credit either. So again, there is another whole set of badly needed institutional innovations.

The eighth recommendation focuses on how to get more realistic exchange rates. Government first needs to get monetary and fiscal policy at least stabilized, so that they become neutral; with a flexible exchange rate that is probably as good as it can be. Government is not going to eliminate all of the instability generated from the foreign exchange markets. But if it neutralizes fiscal and monetary policy, and gets trade policy at least uniform across sectors, it can do a lot to eliminate exchange rate distortions. At the same time, it will stabilize this most important macro price.

The ninth recommendation concerns lack of infrastructure in Africa. One of the tragedies of the developing countries is that when the World Bank became heavily involved in stabilizing macro prices and policy reform, it turned away from longer term investments in physical infrastructure. Consequently, the highway, railroad, and communication sectors in Africa are really nonexistent. Africa cannot get very far until it has more physical infrastructure. It has a long way to go.

Tenth, more long-term investment in agricultural research and extension systems is also recommended. The stock of location-specific knowledge about agriculture in African countries is very, very limited.

Finally, one can hardly talk about fertilizer or fertilizer policy in Africa without talking about subsidies and the enormous pressure on African governments to provide subsidies. Norman Borlaug feels that to diffuse various improvements, Africa has to have more fertilizer use and the only way to promote fertilizer use is to subsidize it. Part of the problem, however, is that fertilizer subsidies have not been supplemented by government investments in infrastructure, institutions, and policies that permanently reduce farm level fertilizer prices (e.g., reducing transportation costs and increasing efficiency in the input and output markets). It is both more equitable and efficient to use scarce development resources to reduce or eliminate these constraints to the wider use of fertilizer. Fertilizer subsidies should be conditioned on investments that reduce the structural impediments to increased fertilizer use in the future.

At the same time, there is a certain degree of ambivalence on the whole subsidy issue. Eventually the question comes up: What are the tradeoffs? If government uses its scarce development resources to subsidize fertilizer in the short run, it has to be at the expense of longer term investments that eventually would lower fertilizer costs. It is highly recommended to look carefully at the tradeoffs and estimate just how much long-term physical infrastructure versus how much of the domestic fertilizer industry can and should government subsidize. How much agricultural research can government provide if it is also subsidizing short-term fertilizer benefits that nobody would pay for privately?
Use of Diammonium Phosphate to reduce heavy metal solubility and transport in smelter-contaminated soils

Adverse environmental impacts from exposure to Cd, Pb, and Zn from contaminated smelter sites include risk to human health, phytotoxicity, contamination of water and soil, soil erosion, and ecotoxicity. Commonly used cleanup methods involve excavation and land filling of smelter-contaminated soil. Chemical immobilization is an inexpensive in-situ remediation method where inexpensive chemicals (i.e. fertilizer, waste materials) are added to contaminated soil to reduce the solubility or immobilize the heavy metals contaminants. Many studies using chemical amendments, including organic matter, alkaline material, and phosphate fertilizer for chemical remediation of Pb, Cd, and/or Zn in contaminated soil, have been conducted in the last decade. Treatments to immobilize Pb, Cd, and Zn in contaminated soil include biosolids, composts, manures, alkaline materials and phosphate-based amendments. The success of chemical immobilization can be evaluated by its ability to reduce contaminant bioavailability and human exposure to heavy-metal contaminants in treated contaminated soil. Two important human exposure pathways are exposure to Cd and Zn through the food chain via plant uptake, and exposure to Pb through incidental ingestion of contaminated soil.

To be a successful remediation method, reductions in contaminant solubility and bioavailability realized by chemical immobilization must be long-term or permanent. Chemical immobilization of Pb in contaminated soils using phosphate treatments to produce Pb pyromorphite, a geochemically stable form of Pb in soil, may meet the “permanence” or long-term stability requirement for site remediation. However, it is not possible to identify or quantify many amorphous chemical immobilization products by spectroscopic analysis or other methods. An alternate approach to evaluate the “stability” of chemical immobilization products may be to determine the ability of heavy metals to remain insoluble (not extractable) upon acidification. Soil pH is one of the most important soil chemical properties affecting solubility of Cd, Zn, and Pb. Soil weathering often involves soil acidification, and most chemical immobilization reactions are pH dependent.

The effectiveness of diammonium phosphate (DAP), as a chemical immobilization treatment to reduce heavy metal solubility and transport in smelter contaminated soil is reported. DAP treatments were evaluated using solute transport experiments with repacked soil columns. DAP was added to the soil at 460, 920, and 2300 mg P/kg. These treatments correspond to approximate P to total metal (P/Mtotal) ratios of 1/74, 1/37, 1/15 respectively. Deionized water was passed through columns repacked with DAP-treated soil. Sample effluent pH and anion concentrations (F, Cl, Br, NO3, PO4, and SO4) were immediately analysed after collection by combination of electrode and ion chromatography. Remaining effluent was acidified with trace metal grade HNO3 (pH < 2) for metal analysis (Al, As, Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Na, Ni, Pb, Zn) by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP).

Results show that DAP decreased transport of Cd, Pb, and Zn from contaminated soil (Table 1). The 2300 mg P/kg application was the most effective for immobilizing Cd, Pb, and Zn eluted from the contaminated soil when compared with the untreated check. This treatment corresponds to a P/Mtotal ratio of 1/15, where Mtotal = \sum\text{total Cd, Pb, and Zn} determined by X-ray fluorescence (XRF). Model fitted metal elution curves showed increased retardation factors (R) and distribution coefficients (Kd) with increased DAP application. Modeled elution curves showed DAP treatment increased retardation (R) of 2-fold for Cd, 6-fold for Zn, and 3.5 for Pb. Distribution coefficients (Kd) increased with P application from 4.0 to 9.0 L/kg for Cd, from 2.9 to 10.8 L/kg for Pb, and from 2.5 to 17.1 L/kg for Zn.

Conclusion: Chemical immobilization of heavy metals using DAP is an effective method of reducing metal solubility and mobility. DAP is inexpensive and commercially available in large quantities as a fertilizer. In-situ treatment with DAP at the 2300 mg P/kg treatment corresponds to estimated material costs of only US$ 2.5 m-2 to 60 cm depth (assuming bulk density of 1.4 g cm-3 ) compared with USD 730 m-2 to 60 cm depth for excavation and land filling. The optimum P/Mtotal ratio of 1/15 observed for this study may differ with varying concentrations of reactive metals in other contaminated soils and wastes.


(Website and e-mail of N. Basta: http://snr.osu.edu, basta.4@osu.edu)

<table>
<thead>
<tr>
<th>DAP Treatment mg P kg⁻¹</th>
<th>Cd mg P kg⁻¹</th>
<th>Pb μg P kg⁻¹</th>
<th>Zn mg P kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>14.9 (100)</td>
<td>460 (100)</td>
<td>108 (100)</td>
</tr>
<tr>
<td>460</td>
<td>7.1 (47.7)</td>
<td>237 (51.4)</td>
<td>5.7 (5.3)</td>
</tr>
<tr>
<td>920</td>
<td>4.1 (27.5)</td>
<td>9.5 (2.1)</td>
<td>6.0 (5.6)</td>
</tr>
<tr>
<td>2300</td>
<td>0.8 (5.4)</td>
<td>5.2 (1.1)</td>
<td>4.5 (4.2)</td>
</tr>
</tbody>
</table>

Table 1: Cumulative mass of Cd, Pb, and Zn and percent of metal eluted from the untreated column (in parentheses) through 60 pore volumes of elution.
Some properties of phosphates such as sequestration make them suitable as additives for potable water treatment. They are used to prevent "red" and "black" water; to prevent and/or retard scale formation and corrosion in the water distribution system; and to reduce soluble lead and copper in potable water delivered to the consumer's tap. These properties are discussed below:

**Iron and Manganese Control**

In ground and well waters, iron and manganese are normally present in the bivalent form \((\text{Fe}^{++} \text{ or Mn}^{++})\) which is soluble. Upon exposure to air, the forms are oxidized to the trivalent form \((\text{Fe}^{+++} \text{ or Mn}^{+++})\), which is insoluble and colored. Chlorination of water containing low levels of iron results in the formation of insoluble iron oxide or iron chloride. Insoluble iron salts are the cause of what is commonly called "red water" and can cause a reddish-brown stain on laundry, porcelain, utensils and glassware. Manganese compounds undergo similar reactions to form "black water" and can result in brownish-materials. The discoloration of water is considered aesthetically unappealing and levels of 0.5 mg/l of manganese result in objectionable flavors to the water.

The use of 2–4 ppm of a polyphosphate such as sodium hexametaphosphate (SHMP), sodium tripolyphosphate (STP) or tetracalcium pyrophosphate (TSPP) before chlorination results in the formation of colorless phosphate complexes of the heavy metal and elimination of the formation of insoluble compounds. Since calcium and magnesium salts of orthophosphates are relatively insoluble, water hardness can also be reduced by precipitation. The choice of which orthophosphate to use may be based on pH requirement.

**Lead and Copper Removal**

Lead and copper are found in drinking water largely due to leaching from piping and plumbing fixtures. Copper is restricted in municipal drinking waters to 1.3 mg/l, based on US regulatory requirement. When excess copper is present, water has a metallic flavor (at 3 mg/l) and can leave a blue to green discoloration to surfaces. In adults, water containing copper in excess of 3 mg/l can cause nausea, vomiting and abdominal pain. Lead is restricted in municipal drinking water to 15 ppb. Lead in drinking water fails to leave a residue and can generally not be tasted.

Lead exposure can cause irreversible mental and physical development in the developing foetus, the infant and the young child. In adults, prolonged exposure can lead to damage to the brain, kidneys, nervous system and red blood cells. However, lead may be present in older homes, dated municipal water systems, and brass fittings and plumbing fixtures.

The leaching of lead into plumbing systems can be greatly reduced by introducing water-soluble orthophosphates into potable water distribution systems. At low levels, the phosphates react with the lead and copper and hardness ions (calcium and/or magnesium) form an insoluble coating on the internal surfaces of the distribution system. Once this coating is formed, observed lead and copper levels in the drinking water drop rapidly. This effect can be maintained by continued metering of phosphate into the system.

**Scale Inhibition and Removal**

The formation of scale on surfaces in potable water distribution systems is due to the crystallization of carbonates or sulfates of magnesium or calcium from solution. Very low levels of polyphosphates (1-10 ppm) interfere with crystal growth. This type of scale inhibition is referred to as a threshold property because it occurs at a level much lower than would be required for a stoichiometric reaction.

Threshold inhibition by polyphosphate of calcium and magnesium carbonate formation is particularly effective at a pH range 8-10 where carbonate scale in potable water is a major problem. Calcium sulphate scale is often a problem at lower pH ranges. The same mechanism of scale inhibition that can occur with calcium carbonate at a high pH range can also occur with calcium sulphate at a lower pH range at similar low (1-10 ppm) levels of phosphate addition.

Experience has shown that polyphosphates not only inhibit scale formation, but they can also help remove existing hard deposited carbonate or sulphate scale. Pipelines carrying potable water treated with polyphosphates for extended periods of time (several months) first show a gradual softening of the scale followed by disintegration and removal. The soft scale particles are deflocculated by the polyphosphate and carried away resulting in clean piping system.

**Corrosion Control**

Water quality varies significantly throughout the world. The corrosiveness of water can be attributed to low pH (acidity), high temperature, low total dissolved solids, a high flow rate, and the presence of dissimilar metals and dissolved gases (as oxygen and carbon dioxide). When these factors are combined, the corrosion is accelerated.

Polyphosphates, alone or in combination with orthophosphates, can effectively control corrosion on both ferrous and non-ferrous metals and alloys. Polyphosphates are particularly effective as corrosion control agents at lower temperature and pH of less than 7.5. They have also been shown to be effective in brackish water (greater or equal to 2,000 ppm sodium chloride-NaCl) with corrosion reduction of up to 90% being reported.

**Chlorine Stabilization**

Heavy metals such as iron are capable of catalyzing the decomposition of chlo-
Fertilization and Food Quality

Phosphate products

Phosphate products for potable water treatment can be broadly classified into three groups: phosphoric acid, orthophosphates, and condensed phosphates. They encompass a wide variety of chemical compounds having potential for potable water treatment applications. The application of each phosphate product depends upon the specific properties or treatment desired. Phosphate for potable water treatment along with their designated maximum use levels according to US National Sanitation Foundation International (NSF) are listed in the table below.

<table>
<thead>
<tr>
<th>Phosphate for potable water treatment</th>
<th>Maximum Use Level (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphoric acid</td>
<td></td>
</tr>
<tr>
<td>36% acid</td>
<td>27.0</td>
</tr>
<tr>
<td>75% acid</td>
<td>13.0</td>
</tr>
<tr>
<td>80% acid</td>
<td>12.0</td>
</tr>
<tr>
<td>85% acid</td>
<td>12.0</td>
</tr>
<tr>
<td>Orthophosphates</td>
<td></td>
</tr>
<tr>
<td>Monosodium Phosphates (MSP)</td>
<td>13.0</td>
</tr>
<tr>
<td>Disodium Phosphate (DSP)</td>
<td>15.0</td>
</tr>
<tr>
<td>Trisodium Phosphates (TSP)</td>
<td>17.0</td>
</tr>
<tr>
<td>Monopotassium Phosphate (MKP)</td>
<td>14.0</td>
</tr>
<tr>
<td>Dipotassium Phosphates (DKP)</td>
<td>36.0</td>
</tr>
<tr>
<td>Tricalcium Phosphate (TCP)</td>
<td>12.0</td>
</tr>
<tr>
<td>Condensed Phosphates</td>
<td></td>
</tr>
<tr>
<td>Sodium Acid Pyrophosphate (SAPP)</td>
<td>12.0</td>
</tr>
<tr>
<td>Sodium Trimetaphosphate (STMP)</td>
<td>11.0</td>
</tr>
<tr>
<td>Tetrasodium Pyrophosphate (STP)</td>
<td>14.0</td>
</tr>
<tr>
<td>Sodium Tripolyphosphate (STP)</td>
<td>13.0</td>
</tr>
<tr>
<td>Tetrapotassium Pyrophosphate (TDKP)</td>
<td>17.0</td>
</tr>
<tr>
<td>Tetrapotassium Pyrophosphate, 60% Solution</td>
<td>29.0</td>
</tr>
<tr>
<td>Sodium Hexametaphosphate (SHMP)</td>
<td>12.0</td>
</tr>
</tbody>
</table>

**Source:** American Chemistry Council, 2004
The Phosphate Forum of the Americas

Nitrogen Fertilization and food quality

N fertilization affects plant health, vitality, germinating power, and the quality of its young leaves and branches. Increased N supplies to plants affect the protein contents and metabolism in several ways:

1. The content of crude protein, particularly of cereal grain, increases from a range of 10-15% to a range of 16 to 20%;
2. Increase in protein and albumen contents;
3. Higher contents of carotene and chlorophyll;
4. Higher contents of vitamins B1 and C.

Some N-compounds that are significant in quality assessment of plants are presented in the table:

1. Nitrate: mineral N-form, important substance for protein synthesis
2. Nitrates: formed excess nitrate under certain conditions
3. Pure protein:
   - Low-value protein: prolamine, soluble in alcohol, and glutenine; soluble in alkalis
   - High-value protein: albumin, water-soluble, and globulin, soluble in salt solution
4. Amines: amides, asparagines and glutenine are storage forms of nitrogen
5. Amines: nitrosamines are formed from nitrite and secondary amines and betaine.
6. Cyclic N-compounds, such as chlorophyll, N-containing vitamin (thiamine, vitamin B1) and alkaloids.

Phosphate (P) Fertilization and food quality

P supplies play a central role in food quality because of their role in plant metabolism:

1. In fodder, increased total P contents is an important aspect of feed quality, as insufficient P is often detrimental to the...
fertility of cows feeding on that fodder.

2. Increased concentration of inorganic phosphates mainly in straw of green plants, and of phytin as storage form, particularly in the kernels.

3. Higher content of nuclein P

4. Higher concentration of essential amino acids in the kernels;

5. Increased content of carbohydrates (sugar, starch);

6. Increased content of some vitamins, such as B1;

7. Reduced content of nicotine in tobacco;

8. Reduced concentration of harmful oxalic acid in leaf vegetables and sugar-beet leaves fed to cows;

9. Increased concentration of coumarin in grass

Some P-compounds important for quality assessment in plants are presented in the following table:

1. Inorganic phosphate: Form of phosphate anions absorbed and partly stored.

2. Phosphoric acid ester: product of phosphorylation


4. Phosphatides: phospholipoids, important constituents of cell membranes, consisting of glycerin, fatty acids, phosphoryl groups and amines.

5. Phosphoproteids: products of the combination of protein and phosphate

6. Nucleoproteids: P-containing enzymes that are complex compounds essential for cell synthesis and metabolism.

Potassium (K) Fertilization and food quality

While N- and P-contents of harvested produce are significant quality characteristics per se, this is not the case with potassium. Food usually contains more potassium than required for adequate animal and human nutrition. It is less important than sodium in regulating swelling capacity. While excessive potassium in food crops is not detrimental in itself, it tends to reduce the Ca, Mg, and Na contents.

On the other hand, potassium has a positive effect on enzyme activity and entire metabolism and quality of vegetal products. K supplies to plants bring about the following changes:

1. Intensified photosynthesis leading to increased content of raw fibers (cellulose), vitamin C and essential carbohydrates.

2. Reduced content through dilution of crude protein but increased valuable fraction of pure protein, while less valuable N reserves are decreased.

3. Increased content of carotene as a preliminary form of vitamin A as well as vitamin C.

4. Reduced losses of starch-containing tubers (e.g., potatoes) during storage, since potassium reduces the undesirable starch decomposition with enzymes.

5. Reduced “darkening” of potatoes;

6. Reduced virus incidence in young potato plants.

Fertilization with other nutrients and food quality

In addition to N, P and K, the supply of other nutrients such as calcium, magnesium, sulfur and trace elements (Fe, Mn, Zn, Cu, etc..) also impacts the quality of food.

Calcium, as a constituent of pectin, is important for fluid retention regulation. The supply of fertilizer-containing calcium to fruit trees reduces the incidence of apple brown-spot disease, which lowers considerably the commercial and storage quality of apples.

Magnesium content of plants is increased by fertilization, leading to increased content of chlorophyll, carotene, and total carbohydrates.

Sulfur plays a key role in the synthesis of S-containing amino acids such as cysteine, cystine, and methionine. Deficiency in sulfur inhibits the synthesis of some oils, particularly mustard oil and leek oil, which are important for food crop quality and resistance to infection.

Micronutrients (or trace elements) known to be required for higher green plants are in the number of at least seven (7) micronutrients: iron, manganese, zinc, copper, boron, molybdenum, and chlorine. A deficiency in trace elements results in failure of vital metabolic functions in plants, reducing the quality of harvested produce. With adequate supply of trace elements, there is generally increased contents of many valuable substances, e.g. protein quality is improved. On the other hand, trace element content should not be increased close to the toxicity limit because this is not only detrimental to plant health as such, but can also affect negatively the composition of organic constituents of food.

Iron in green leaves is an important source of dietary supply of this element to humans.

Manganese fertilization increases the Mn-content of crops if soil provides favorable mobility conditions. Increased Mn supplies to optimal level raise the contents of some vitamins (carotene, Vitamin C).

Copper is especially important for fodder quality. Increased Cu supplies raise protein content and quality of crops, while Cu deficiency causes spotliness in certain fruit crops.

Zinc is an important quality characteristic of fodder. Zinc fertilization increases Zn contents of plants, but beyond certain limits, Zn concentration leads to toxicity because plants can absorb many times their normal requirements of Zn when it is available.

Boron raises the sugar content and enhances the commercial quality of fruits and vegetables, while deficiency causes spots and fissures that substantially reduce the value of these products.

Molybdenum reduces nitrate content and increases protein concentration in legumes.

Conclusion

The quality of plant products depends on many factors including optimal supplies of all nutritional substances required for growth. Minerals play a key role in obtaining high quality products.

Food quality is a rather complex concept that depends on many value-determining ingredients. Since it is very difficult to improve all value components simultaneously, quality improvement in practice always means improvement of particular desirable characteristics.

The nutrient source in itself is quite insignificant for the quality of plant products, regardless whether the nutrient is derived from organic or mineral source, farmyard manure or commercial fertilizer, because plants absorb nutrients in the form of salts, which may be derived from the soil or directly or indirectly from fertilizers. But without mineral fertilization, men and animals would face serious deficiency of valuable food ingredients; with the resulting prospect of acute and latent deficiencies and diseases that were common not a very long time ago.

Proper fertilization improves the food and feed quality of plant products and contributes to the nutrition of man and animal, thus providing healthier living conditions for both.

INTRODUCTION

In most industrial applications, sulfuric acid is used today indirectly as a reagent rather than an ingredient. The largest single sulfuric acid consumer by far is the phosphate industry.

The present document deals with the many processes of sulfuric acid production which have been developed according to the large number of sources of raw materials (SO2), and their specific characteristics.

The first part of this document treats raw material preparation including storage and handling, emission levels, consumption of water/energy and other resources and the production techniques.

The second part will be presented in the next issue of this Newsletter and will overview techniques applicable to sulfuric acid production, environmental performance, general techniques, best available techniques, energy consideration in plants with double and single absorption and the conclusions and recommendations.

In General, sulfuric acid production proceeds in two distinct fundamental steps:

RAW MATERIAL PREPARATION INCLUDING STORAGE AND HANDLING

Sulphur storage and handling

Liquid Sulfur is in general a product of the desulphurisation of natural gas and crude oil. The typical analysis of molten sulphur is cited below:

<table>
<thead>
<tr>
<th>Element</th>
<th>Content</th>
<th>Content in one specific pyrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>max. 0.015% weight</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>max. 0.02% weight</td>
<td></td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>ca. 1-2 mg.Kg⁻¹</td>
<td></td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>0 mg. Kg⁻¹</td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>max. 1 mg.Kg⁻¹</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>max. 1 mg.Kg⁻¹</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>max. 0.05% weight</td>
<td></td>
</tr>
</tbody>
</table>

Water in contact with pyrites becomes acidic in wet conditions. With too high a moisture content the pyrites will give clogging problems in the internal transport system at the plant.

Metal sulphide ores

Generally primary copper is produced from sulfur ores and therefore sulfur is a byproduct of the majority of copper processes.

Zinc and lead are for a major part produced from sulfur ores and thus sulfuric acid is also a final product of treating these ores in metallurgical processes.

Organic spent acids

Spent acids come mainly from organic chemical production. Sulfuric acid is mostly used as a catalyst. Alkylation processes in refineries and nitration and sulphonation processes in the chemical industry generate large amounts of...
spent acids which, after regeneration, become clean acid which can be recycled in any process.

**H₂S or other sulfur containing gases**

Off-gases containing H₂S and CS₂ are formed during the production of textile fibers, which are made in the viscose process. Off-gases containing H₂S or SO₂, depending on the process, are formed during the production of synthesis gas using fuel oil as feedstock.

**SO₂ gases from different sources**

Gases containing up to 90% SO₂ from the production of organic compounds such as sulphonates and sulphites or from the combustion of gases containing H₂S, can be used as a source of SO₂ after the separation of organic compounds.

### Material Processing

#### Conversion of SO₂ into SO₃

The design and operation of sulfuric acid plants are focused on the following gas phase chemical equilibrium reaction and using a catalyst:

\[ \text{SO}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{SO}_3 \quad \Delta H = -99 \text{ KJ} / \text{mol} \]

The conversion rate is defined as follows:

\[ \text{SO}_2 \text{ in} - \text{SO}_2 \text{ out} \]

Concentration rate = \(\text{x100}\) (%) \text{SO}_2 in

Both stoichiometric and thermodynamic considerations are taken into account in maximizing the formation of SO₃. Variation of temperature, pressure, or the concentration of a reactant are the main factors shifting the chemical equilibrium.

The following methods are available to maximize the formation of SO₃:

- Removal of heat
- Increased oxygen concentration
- Removal of SO₃
- Raised system pressure
- Selection of the catalyst to reduce the working temperature
- Increased reaction time

The optimum also depends on the SO₂ concentration in the raw gas and on its variability with time. Consequently, each process is more or less specific for a particular SO₂ source.

#### Absorption of SO₃

Sulfuric acid is obtained from the absorption of SO₃ and water into H₂SO₄.

The efficiency of absorption step is related to:

- The H₂SO₄ concentration of the absorption liquid (98.5 - 99.5%)
- The range of temperature of the absorption liquid.
- The technique of the distillation of acid
- The raw gas humidity
- The mist filter
- The temperature of incoming gas
- The co-current or counter-current character of the gas stream in the absorbing liquid.

SO₃ emissions depends on:

- The temperature of gas leaving absorption
- The construction and operation of the final absorber
- The device for separating H₂SO₄ aerosols
- The acid mist formed upstream of the absorber through the presence of water vapor.

### Table 2: Methods of dinitrification

<table>
<thead>
<tr>
<th>Method of dinitrification</th>
<th>Special conditions</th>
<th>Effect</th>
<th>In tail gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>Absorber/tanks</td>
<td>++/only&lt;80% acid</td>
<td>N₂</td>
</tr>
<tr>
<td>Dihydrazinedisulphate 40%</td>
<td>Absorber/tanks</td>
<td>+++/acid and oleum</td>
<td>N₂, N₂O</td>
</tr>
<tr>
<td>Amidosulphonic acid 15%</td>
<td>Absorber/tanks</td>
<td>+++/only 50-99.5% acid</td>
<td>N₂</td>
</tr>
<tr>
<td>SO₂ saturated acid</td>
<td>78% H₂SO₄ separated tower</td>
<td>+++/only acid/water balance</td>
<td>NOₓ</td>
</tr>
</tbody>
</table>

### Product finishing

#### Dilution of absorber acids

The acid produced (95.5% - 96.5% or 98.5% - 99.5%), is diluted with water down to the commercial concentrations: 25%, 37%, 48%, 96% and 98% H₂SO₄. The dilution can be made in a bath process or continuously through in-line mixing.

#### SO₂ stripping

A small amount of air is blown through the warm acid in a column or tower to reduce the remaining SO₂ in the acid to less than 20 mg SO₂/Kg acid. The air containing SO₂ is returned to the process.

### Purification

Sulfuric acid from the startup of acid plants after long shutdown may be contaminated and clouded by insoluble iron sulphate, or silicate from bricks or packing. The acid can be filtered using conventional methods.

#### Denitrification

Several methods are used for the denitrification of sulfuric acid and oleum. Various chemicals are used to reduce NOHSO₄ or nitrate to N₂ or NₓOᵧ.

The methods of denitrification are illustrated in table 2.

#### Decolorization

Sulfuric acid produced from smelter plants or from acid regeneration plants can contain hydrocarbons, which is absorbed in sulfuric acid. This causes a black color. The decolourisation is known as acid bleaching (Table 3).

### Use of Auxiliary Chemicals/Materials

#### Catalysts

Producing sulfuric acid by the contact process needs to produce SO₃ by passing SO₂ and oxygen over a catalyst according the equation:

\[ \text{SO}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{SO}_3 \quad \Delta H \]

Today vanadium pentoxide (V₂O₅) is used almost exclusively. Ring shaped catalysts, which are mostly used today,

### Table 3: Acid bleaching

<table>
<thead>
<tr>
<th>Method of decolorization</th>
<th>Special conditions</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen peroxide solution &lt; 60%</td>
<td>Absorber/tanks</td>
<td>+++/acid and oleum</td>
</tr>
</tbody>
</table>
give a lower pressure drop and are less sensitive to dust blockage.

410 - 430°C is the lower temperature for conventional catalysts and 380 - 390°C for cesium doped catalysts. The upper temperature limit is 600 - 650°C above which, catalytic activity can be lost permanently due to reduction of the internal surface.

About 10 years is the average service life for the catalyst. Service life is determined by catalyst losses during the screening of the catalyst which is necessary to remove dust.

Intermediate and Final Product Storage

It is necessary to take into account the following considerations:

The receipt, handling and storage of powdered raw materials should be carried out so as to minimize the emission of dust. Liquid and gaseous feeds should be carefully contained to prevent the emission of odorous gases.

Oleum storage and handling operations should be installed with a means of controlling fume emissions.

During storage and handling of sulfuric acid, leaks may have an impact on the soil or on waters. Precautions have to be taken in order to reduce the possibility and the gravity of these leaks.

Energy Generation/Consumption, Other Specific Utilities

The process steps: burning sulfur, SO2 conversion and SO3 absorption are exothermic processes.

A sulphur burning process in conjunction with double absorption is the most energy efficient.

The different energy-winning techniques are:

- All techniques of steam generation such as super heater, economizer or steam boiler for sulphur burning.
- Steam generation by the inter-pass absorption with temperatures from 110°C to 180°C and steam pressures from 1.5 bar to 11 bars.
- Steam turbines with power generation up to 15 MWh.
- Water preheating in the end absorption from 40°C to 80°C.

Special programs are used for the optimization of the process such as cost saving and winning energy.

### Gas Cleaning of Metallurgical Off-gases

Gases containing SO2 from all metallurgical processes are cleaned before the contact process to remove the following components:

- Fumes or aerosols formed by condensation of volatile metal components such as Zn, Pb, Sb, Bi, Cd and their chlorides, sulphates and oxides.
- Volatile gaseous metals such as As, Se, Hg and their compounds.
- Gaseous non-metal compounds such as HF, HCl, SO3, CO.

Table 4 illustrates the different metallurgical off-gases, the main disposals and the method of cleanup.

### Handling of Waste Gas/Stack Height

The height of the exhaust stack determines the maximum SO2/SO3 concentration value in the ambient air surrounding a sulfuric acid plant. This concentration is widely fluctuating in space and time due to the thermo-aerodynamic conditions of the low-level atmosphere (0 to 500m). These conditions can vary due to the following factors:

- Vertical temperature and humidity structure.
- Wind speed and direction
- Turbulence of the atmosphere
- Sunshine intensity etc.

### EMISSION LEVELS

Figure 2 illustrates different calculated SO2 emission.

### Environmental Aspects

SO3 Emissions

The origins are:

- Bad absorption efficiency
- Vapor pressure of sulfuric acid/oleum

Minimization techniques:

- Absorption improvement
- Absorbing tower design (velocity)
- Acid distribution (flow and repartition)
- Packing efficiency
- Acid temperature (vapor pressure)

### Calculated SO2 emission

![Figure 2: Calculated SO2 emissions](image)

### Table 4: Gas cleaning of metallurgical off-gases

<table>
<thead>
<tr>
<th>Off-gas from</th>
<th>Main disposal</th>
<th>Cleanup system</th>
</tr>
</thead>
<tbody>
<tr>
<td>“CuS” smelters</td>
<td>Hg, HF</td>
<td>ESP, Gas scrubber with HgCl2 or Na2S2O3/HgS</td>
</tr>
<tr>
<td>“PbS” smelters</td>
<td>Hg</td>
<td>ESP, Gas scrubber with HgCl2</td>
</tr>
<tr>
<td>“ZnS” smelters</td>
<td>Hg</td>
<td>ESP, Gas scrubber with HgCl2</td>
</tr>
<tr>
<td>“Ni” smelters</td>
<td>Se</td>
<td>Gas scrubber</td>
</tr>
</tbody>
</table>
H2SO4 Emissions
The origins are:
- Tower design
- Mist formation
- Vapor pressure
Minimization techniques:
- Droplet carry-over
- Absorbing tower design (gas velocity, acid distribution) / Demisters (mesh pads or candles)
- Mist filter
- Process control:
  - ESP efficiency
  - Drying tower efficiency
  - Gas temperature upstream absorption
  - NOx content in the gases
  - Acid temperature at the bottom of absorption tower
  - Acid vapor pressure (temperature)
  - High efficiency demisters \( \leq 50 \text{mg.Nm}^{-3} \) (particles > 0.5 \( \mu \))

SO2 Emissions
The origins are:
- Bad conversion efficiency
- Gas bypassing (acid cross bleed or convoker)
Minimization techniques without additional process:
Gases:
- Composition (\( \text{O}_2, \text{SO}_2, \text{inert} \ldots \))
- Velocities through catalyst and repartition
- Cooling quality (heat exchangers or air cooling)
- Operating pressure
- Acid cross bleeds (\( \text{SO}_2 \) stripping, \( \text{SO}_2 \) gases drying processes)
- Temperature
Catalyst:
- Converter design
- Number of beds
- Catalyst quality and quantity
- Converter loading
Minimization techniques with additional process:
- Without by-product: Single absorption \( \rightarrow \) double absorption (if gases are higher than 6% \( \text{SO}_2 \))
- \( \text{SO}_2 \) weak \( \text{H}_2\text{SO}_4 \) possible to recycle: Activated carbon oxidation/\( \text{H}_2\text{O}_2 \) process
- With co- or by-product:
  - \( \text{NH}_3 \) scrubbing, co-product \( \rightarrow \) Ammonium sulphate
  - \( \text{NaOH} \) scrubbing, co-product \( \rightarrow \) Sodium sulphate
- \( \text{Ca}(\text{OH})_2 \) scrubbing, co-product \( \rightarrow \) Calcium sulphate
- \( \text{Mg}(\text{OH})_2 \) scrubbing, co-product \( \rightarrow \) Magnesium sulphate
- Other processes - neutralization absorption, bioconversion - exist but are less developed and depend on the specific site

Emissions into water:
- Energy release from cooling
- Accidental leakage
- Waste water treatment plants must be able to deal with heavy metals
- Emissions of noise by air cooling
- Water treatment for steam production

Solid wastes:
Spent catalyst:
Methods for disposing of spent catalyst are:
- Metal recovery
The vanadium content of the catalysts can be reclaimed for further use. The metal can be recycled as vanadium salts or as ferrovanadium for steel production.
- Landfill disposal
Two possibilities:
- Fixation:
The catalyst is fixed in an inert matrix, usually concrete or glass.
- Direct land filling
The catalyst is deposited directly into a suitably licensed landfill site.

CONSUMPTION OF WATER/ENERGY AND OTHER RESOURCES
Usually, sulfuric acid plants are used as the energy source for the production processes for other chemicals that require energy.
The use of water in the process is:
- For cooling.
- To ensure the right concentration in the absorption tower to prevent acid mist in the stack.
- To feed boiler for steam production
The kind of energy produced is steam at different pressures.

PRODUCTION TECHNIQUES
In general the technique of sulfuric acid production is divided in 2 parts: the conversion of \( \text{SO}_2 \) to \( \text{SO}_3 \) and the absorption of \( \text{SO}_3 \). Both parts depend on the concentration of \( \text{SO}_2 \) in the feed gas entering the installation.

The sources of \( \text{SO}_2 \) are:
- Sulfur burning
- Pyrites roasting
- Metal sulfide roasting and smelting
- Sulfuric acid regeneration
- Metal sulfate roasting
- Combustion of \( \text{H}_2\text{S} \) or other sulfur containing gases
- Other processes
The sulfuric acid production includes different groups depending on the level of \( \text{SO}_2 \) in the process gas.
The gas processes with Vol. \( \text{SO}_2 \) more than 3%:
- Single contact process
- Double contact process
- Wet contact process
The gas processes with Vol. \( \text{SO}_2 \) less than 3%:
- Modified lead chamber process
- \( \text{H}_2\text{O}_2 \) process
- Activated carbon
- Other processes
The combustion of sulfur is obtained either from natural deposits or from desulphurization of natural gas or crude oil. It is carried out in one-stage or two-stage sulfur combustion units at between 900 and 1800°C. The combustion chamber is followed by a process gas cooler. The content of exit \( \text{SO}_2 \) is generally up to 18% by volume.
After combustion the gases are generally diluted to 10-11% \( \text{SO}_2 \) before entering the conversion process. In the inlet, gas to converter ratio \( \text{SO}_2/\text{O}_2 \) should not be higher than 0.8 to achieve a high conversion efficiency.
For example: the highest ratio of \( \text{SO}_2 \) should not exceed 11% in a 4-bed double contact (no cesium) plant to achieve an average conversion rate of 99.6%.

Plant Nutrients and their Sources

Plant nutrients are substances that plants require for their growth. They absorb them as molecules (H₂O, CO₂, etc.), ions or electrically charged particles through their roots (mineral and organic substances, oxygen, etc) and through their leaves (carbon dioxide, water and its solutes via stomata, oxygen, etc). Nearly all cultivated plants require the following 16 nutrients:

- Carbon (C), Oxygen (O₂) and hydrogen (H), as the fundamental constituents of organic matter;
- 13 other mineral nutrients are divided into:
  1. Major nutrients: N, P, S are absorbed as anions and K, Ca, Mg are absorbed as cations.
  2. Micronutrients: Fe, Mn, Zn, Cu are absorbed as cations and Cl, B, Mo are absorbed as anions.

There are other beneficial elements such as Silicon (Si) and Sodium (Na) that also enhance plant growth but their significance depends on plant species.

Plants obtain the above nutrients from seven sources:

Good plant nutrient management should take into consideration the input from each one of these sources as they can all affect plant responses to applied mineral fertilizers. In the particular case of phosphorus, the main source of supply is soil reserves.

Nutrients occur in the soil in three different forms (figure):

1. Water-soluble nutrients: They are dissolved in the soil solution, are not bound and can move freely with water. They are therefore easily available to plants;
2. Exchangeable nutrients: cations or anions that are loosely bound in electrically charged exchange complexes of clay and humus particles. They are readily available to plants in general.
3. Reserve nutrients: They represent the overwhelming majority of soil nutrients. They are parts of moderately to slightly soluble compounds. Only a small fraction can readily be mobilized. While certain reserve nutrients are reasonably available, in practice most of them are made available over a long period of time.
The fertilizer industry offers products that contribute to the development of modern agriculture. Fertilizer has been a key agricultural input in agricultural productivity improvements that had enabled food production to increase alongside population and economic growth. These improvements have come almost entirely from increasing crop yields. The area of land under cultivation has expanded very little in recent years.

This historical trend is likely to continue in the future, albeit at a slower pace. As in the past, the increasing food demand is going to be driven by:

- **Population growth:** projected growth of approximately 1% a year over the next 20 years will take the world population from its current level of 6 billion to 7.5 billion by 2020.
- **Economic growth:** as people become wealthier, they consume more and higher-quality food; the International Food Policy Research Institute (IFPRI) forecasts a 40% increase in demand for grain by 2020.
- **Land availability:** arable land is scarce in many parts of the world and under pressure from urbanization and industrial uses; accordingly, there is continual pressure to increase the productivity of available land resources.
- **Sustainability:** without increases in productivity, more land will have to be brought under cultivation, with potentially severe adverse impact on the environment.
- **Technology:** innovations provide new benefits and new opportunities in crop production, e.g. precision agriculture, use of environment friendly glassy fertilizers... etc.

Phosphate nutrient is part of the fertilizer package that remains the driving force for the growth of crop yields and crop production that is necessary to meet the global food demand.

Globally, arable land per capita is diminishing as population increases: while arable land remains constant, improved yield is required to meet the growing world food demand.
IMPHOS is a non-profit making Institute founded in 1973 by the world’s principal producers of phosphate rock. Its primary mandate is to collect and disseminate scientific data to support the rational use of phosphates: to increase and sustain agricultural production, and to meet the food requirements of humankind worldwide.

Among its objectives, it seeks to promote, in both developed and developing countries, the efficient use of phosphates, according to the principles of integrated plant nutrient management. It also seeks to improve farming techniques for productive and sustainable crop production, whilst minimizing environmental risks. Technical research includes the synthesis of phosphorus compounds and processing technologies.

In phosphorus-deficient soils in Africa and Asia, IMPHOS is conducting several projects to demonstrate the need to supply phosphate to increase and sustain food production. In phosphorus enriched soils, in Europe, the focus is made on using phosphorus efficiently to both maintain productivity and minimize environmental risk.

To optimize the use of published research on phosphates, IMPHOS makes its expertise available, not only to member companies but also to research organizations, consumers and appropriate agencies. It also periodically organizes international conferences and regional seminars.