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The key role of phosphate fertilizer for achieving balanced fertilization, food security and quality, and sustainable agriculture

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Abstract

Over the past decades, world agricultural production, in particular, cereal production shows steadily increases. Cereal production increased from 800 million tonnes in 1960, to 2 billion and 2.15 billion tonnes, in 2001/2002, and 2004/2005, respectively. Projections indicate that in 2030, cereal production will reach 2. 749 billion tonnes.

The bulk of the projected increases in crop production will have to come from higher yields, with the remaining part coming from an expansion in harvested area. Both higher yields, which normally demand higher fertilizer application rates, and land expansion will lead to an increase in fertilizer use. The historical relationship between cereal production and mineral fertilizer consumption is well known. About half of the increase in cereal production worldwide during the 1970s and 1980s has been attributed to increased fertilizer consumption.

Worldwide, plant nutrient consumption increased from 27.4 million tonnes $N+P_2O_5+K_2O$ in 1960, to 138.7 million tonnes in 2001/2002, and 149.8 million tonnes in 2004/2005. Fertilizer consumption is projected to amount to 163 million tonnes $N+P_2O_5+K_2O$ in 2008/ 2009, and 208 million tonnes in 2020. Phosphate fertilizer consumption increased from 6.2, to 32.6, 37 million tonnes P_2O_5, respectively, from 1960, 2000 and 2005. It is projected to amount to about 39.5 million tonnes P_2O_5 in 2015. These quantities, compared with world total fertilizer consumption, which is respectively, 27.4, 137.7, 151.4 and 165.1 million tonnes nutrients, in 1960, 2000, 2005 and 2015 (projection) show unbalanced use of plant nutrients at the world level. Data from major crop production regions, such as East and Southeast Asia, also show large unbalanced use of plant nutrients, and the notable production increases the region witnessed would have been larger if more phosphate fertilizers were used to achieve balanced fertilization that would also result in increased fertilizer use efficiency and reduced nutrients losses to the environment.

Food quality is increasingly an issue, primarily in developed countries, and it is having inroads in developing countries, as well. Fertilization is one of the essential tools for enhancing food and feed quality of plant products and so contributes to the nutrition of human being and animals, thus providing healthier living conditions for the world population. Phosphate fertilizer applications have show significant effect on the quality of many crops; in particular, by increasing the protein content of wheat and sugar yield of sugar beets.

By contributing to increasing crop yields, improving food quality, enhancing the environment and providing higher economic gains for farmers, phosphate fertilizers play a major role in the achievement of sustainable agriculture.

Introduction

The growing world population and the urgency of eradicating hunger and malnutrition call for determined policies and effective actions to ensure sustainable growth in agricultural productivity and production. Assured access to nutritionally adequate and safe food is essential for individual welfare and for national, social and economic development.
For biomass synthesis, which serves as the food resource for humans and animals, nutrient supply to plants is a prerequisite. Therefore, an adequate and appropriate supply of plant nutrients is a vital component of a crop production system. Agricultural intensification, one of the basic strategies for enhanced food production, is dependent on increased flows of plant nutrients to the crops for securing high yields. Unless supported by adequate nutrient augmentation, the process of agricultural intensification would lead to land degradation and threaten the sustainability of agriculture.

Over the last 40 years there has been a positive correlation between plant production and fertilizers use and this trend still continues. In general, more efficient use of fertilizers through improved timing, split applications, site-specific management, crop rotation and management, soil sampling and testing etc. could make possible higher yields with the same amount or even less fertilizers.

IMPHOS has been engaged actively in the development of balanced and more efficient fertilization in the last three decades. Through its field projects and publications, IMPHOS has focused its efforts in Africa, Asia and Europe on the need for large-scale adoption of balanced and more efficient fertilization use.

This paper dealt with the impacts of unbalanced fertilization on crop production and quality in different region of the world. It is also an attempt to provide some IMPHOS accomplishments directed at enhanced and sustainable agricultural production.

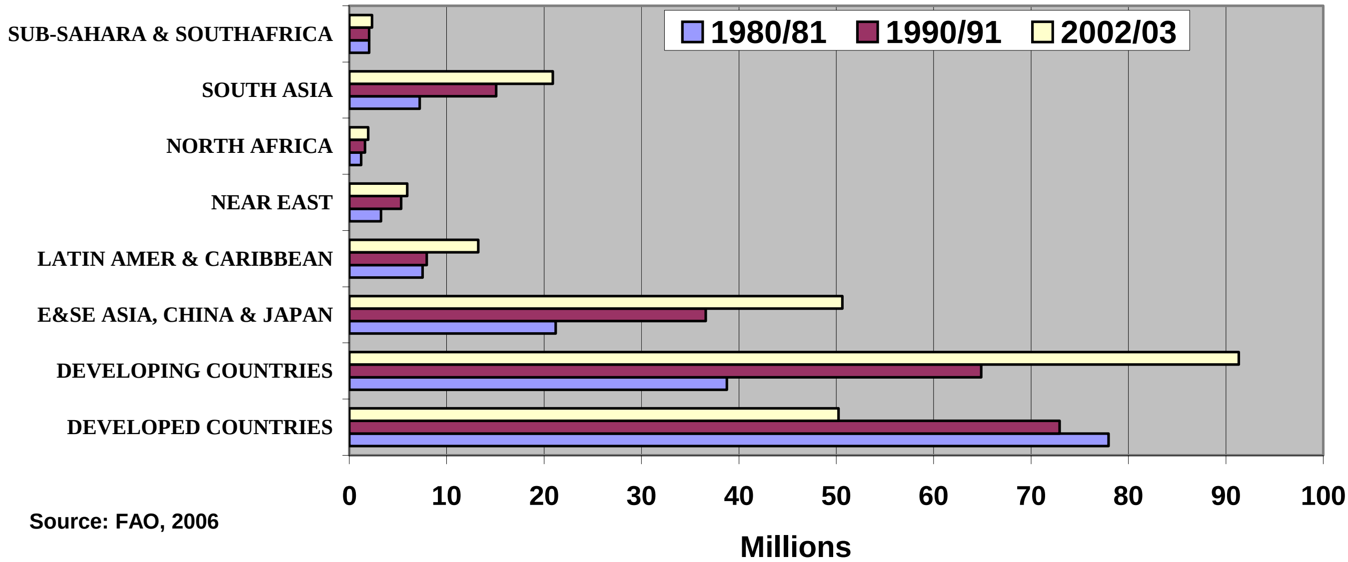
I. Evolution of world fertilizer consumption

Worldwide, plant nutrient consumption increased from 27.4 million tonnes $N+P_2O_5+K_2O$ in 1960 to 149.8 million tonnes in 2004/2005. Fertilizer consumption is projected to amount to 163 million tonnes $N+P_2O_5+K_2O$ in 2008/2009, and 208 million tonnes in 2020.

Phosphate fertilizer consumption increased from 6.2 to 37 million tonnes P_2O_5, from 1960 to 2005 and is projected to amount to about 39.5 million tonnes P_2O_5 in 2015.
Trends in fertilizer consumption show that from 1960 to the early nineteen's developed countries accounted for more than half of world fertilizer use. In 1990, their fertilization consumption was about 80 million tonnes nutrients. By 1992 developing countries fertilizer consumption surpassed the consumption of developed countries. The projection is by the year 2020, fertilizer consumption in developing countries will be at least 40% higher than the amount of fertilizer consumption in developed countries.

The steadily increases in fertilizer use in developing are much more impressive in Asia, which emerged as the region that uses about 50% of world fertilizer consumption (Figure 1). Over the past decades, countries such as China, India, Pakistan and Vietnam witnessed tremendous increases in their consumption of fertilizer.

FIGURE 1: TOTAL FERTILIZER CONSUMPTION TRENDS IN MAIN REGIONS OF THE WORLD



Source: FAO, 2006

These countries show also drastic increases in agricultural production, with some of them turning from huge food deficits and famines to the situation of exporters of grains (the case of India is well known). In the early 1990s forecasts predicted that India would be a large importer of grains in the years to follow, in fact from 2001 to 2004 India exported around 30 million tons of foodgrains and had in 2002, grain stocks, which reached 63 million tons. In the last 5 to 6 years, trends in fertilizer use and food production in India were as follows (Table 1) :

Table 1: Fertilizer use and foodgrains (Mt) productions in India, 2001-2006

	Total nutrient Consumption ($N+P_2O_5+K_2O$)	Total Foodgrains Production
2001-2002	17.4	212.9
2002-2003	16.1	174.8
2003-2004	16.8	213.2
2004-2005	18.4	198.4
2005-2006	20.3	208.3

In China, from 1980 to the year 2002, total fertilizer use increased from 15.3 to 39.5 million tonnes nutrients, while total cereal production increased by 1.44 times, from 315 to 454 million tonnes. For the same period, P fertilizer use increased from 2.7 to 9.9 million tonnes P_2O_5. From 1996 onwards, China alone consumes over 30% of mineral fertilizer produced worldwide. It is expected that, as food demand increases continuously, due to the increase in population, the use of mineral fertilizer in the country would increase further during the coming 50 years. Food production in China has surged over the past three decades (Figure 2). The drastic increase in food production began during the cultural reforms. From 1978 to 1984, China's grain production increased by more than five percent annually from 238 million tons to 322 million tons. This is even more remarkable given that arable land mass saw a net decrease of 4.5 million hectares during the same period of time. In 1982, application of mineral fertilizer surpassed that of organic fertilizer in terms of contribution to the total nutrient supply to agricultural lands.

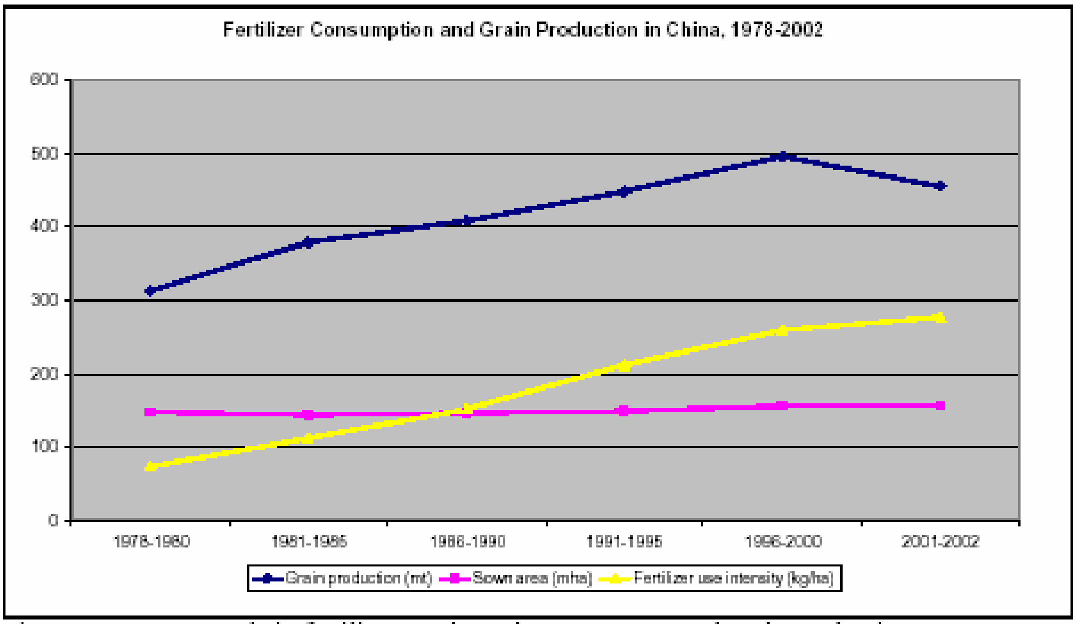


Figure 2. Recent trends in fertilizer use intensity, sown area, and grain production. Data source: Zhang *et al.* in prep.

The increase in consumption of mineral fertilizers over the past few decades spurred the Chinese government to promote fertilizer production, which jumped from 12 million tons nutrients in 1980 to 36 million tons in 2002. In the 1990's China imported about 25 percent of the mineral fertilizer it consumed.

In Pakistan, trends in fertilizer consumption show notable increases from 1986 to 2005 with consumption of fertilizer increasing from 0.13 to 3.7 million tonnes nutrients. In particular, N and P2O5 witnessed substantial increases (Table 2). Crop production, and namely wheat, rice, maize, cotton and sugar cane production.

Table 2: Fertilizer nutrient consumptions (x 000 tonnes) in Pakistan, 1996-2005

Year	N	P_2O_5	K_2O	Total
1996-1997	1985	419	8	**2412**
1997-1998	2075	551	20	**2646**
1998-1999	2097	465	21	**2583**
1999-2000	2218	597	19	**2834**
2000-2001	2264	677	23	**2964**
2001-2002	2285	625	19	**2929**
2002-2003	2349	650	20	**3019**
2003-2004	2527	673	22	**3222**
2004-2005	2796	865	33	**3694**

II. Unbalanced use of fertilizers and its impacts

Many studies all over the world have done a simple regression analysis between food grain production and fertilizer consumption during 1961 to 2006 and showed that the partial factor productivity of fertilizers has been continuously declining. The data indicate a reduction in crop response to fertilizer application, especially when balanced fertilization is not practiced.

The data from the trials on the farmers' fields conducted in India during 1999-2003 showed that the average response of cereals to fertilizer was 8-9 kg grain/kg fertilizer. The efficiency of fertilizer nitrogen is only 30-40% in rice and 50-60% in other cereals, while the efficiency of fertilizer phosphorus is 15-20% in most crops. The efficiency of K is 60-80%, while that for S is 8-12%.

As regards the micronutrients, the efficiency of most of them is below 5%. There are several causes of declining/low crop response to fertilizers or efficiency of fertilizer applications, but the major factor is the continuous nutrient mining of the soils without adequate replenishment to the desired extent. For example, It is estimated that about 28 millions Mt of primary plant nutrients (NPK) are removed annually by crops in India, while only 18 millions Mt or even less are applied as fertilizer, leaving a net negative balance of about 10 millions Mt of primary plant nutrients (NPK). An analysis of the data pertaining to rice-wheat cropping system from 24 research stations in India revealed that the rice yields are declining more rapidly as compared to wheat yields, and soil P and K depletion seemed to be a general cause. Similarly, an other set of data showed that the yield decline in both rice and wheat was the highest when N alone was applied at 120 kg/ha. As the depletion of native soil P increased with time, the response of both rice and wheat to applied P showed an increase after 10 years of cropping. Also, as the native soil K decreased over time, the response to applied K started to increase after 5 years in both rice and wheat. Such reports are several in numbers.

Furthermore, the soils are also getting continuously depleted of secondary plant nutrient S and micronutrients. If this nutrient drain continues, the sustained high productivity and sustainability of agriculture will be an impossible task. Thus, inadequate and imbalanced fertilization is a major causative factor for low efficiency of fertilizer use in crop production.

Balanced fertilization does not only mean a certain definite proportion of nitrogen, phosphorus and potash or other nutrients to be added in the form of fertilizer, but it has to take into account the availability of nutrients already present in the soil, crop requirement and other factors. It should take into account the crop removal of nutrients, the economics of fertilizers and profitability, farmers ability to invest, agro-techniques, soil moisture regime, weed control, plant protection, seed rate, sowing time, soil salinity, alkalinity, physical environment, microbiological condition of the soil, available nutrient status of soil, cropping sequence, etc. It is not a state but a dynamic concept.

We can say that balanced use of fertilizers should be mainly aimed at: (a) increasing crop yield, (b) increasing crop quality,(c) increasing farm income, (d) correction of inherent soil nutrient deficiencies, (e) maintaining or improving lasting soil fertility, (f)

avoiding damage to the environment, and (g) restoring fertility and productivity of the land that has been degraded by wrong and exploitative activities in the past.
Nutrient consumption ratios of some regions and the world are presented in table 3.

Table 3: Nutrient consumption ratio (2002)

	N	P2O5	K2O
World	**1.0**	**0.4**	**0.2**
Developed Countries	1.0	0.4	0.3
Developing Countries	1.0	0.4	0.2
Latin America & Caribbean	**1.0**	**0.7**	**0.6**
Africa	1.0	0.3	0.2
East & South East Asia	1.0	0.3	0.3
South Asia	1.0	0.3	0.1
Europe	1.0	0.2	0.3

At the world level, the above table shows imbalanced use of P and K with respect to N, as the normal or generally accepted "balanced ratio" between N, P and K is 1:0.5:0.5. Its shows also a rather large variation among the selected regions, with Latin America and the Caribbean being the only region were P and K consumption, compared to N, are higher than the normal figure. But, this is not an indication of very high level of P and K uses compared with the needs of the crop grown, but rather a low level of N use that might limit the efficiency of the applied P and K fertilizers and the level of crop production. Meanwhile, it is worth to stress that there are large areas of soybean crops and pastures cropped with legume fodders that do not need high applications of N as for the case of cereals.

In the other regions, from Africa through Europe and Asia, P and K applications are much unbalanced with regard to N. Data from countries of Asia, where IMPHOS is being conducting several promotional activities towards balanced use of fertilizers, are presented below. In India, data from 1980-1981 to 2005-2006 are given in table 4.

Table 4: Ratio of use of NPK, India

Year	N	P_2O_5	K_2O
1980-1981	1.0	0.3	0.1
1985-1986	1.0	0.4	0.1
1990-1991	1.0	0.4	0.2
1992-1993	1.0	0.3	0.1
1993-1994	1.0	0.3	0.1
2000-2001	1.0	0.4	0.1
2005-2006	1.0	0.4	0.2

In Pakistan during the last decade, from 1996 to 2005, N, P and K consumption while increasing notably, in particular, for N and P, imbalances in the use of these three nutrients are important, as illustrated below in table 5.

Table 5: Ratio of use of N, P and K, Pakistan

Year	**N**	**P_2O_5**	**K_2O**
1996-1997	1.0	0.2	0.004
1997-1998	1.0	0.3	0.01
1998-1999	1.0	0.2	0.01
1999-2000	1.0	0.3	0.01
2000-2001	1.0	0.3	0.01
2001-2002	1.0	0.3	0.01
2002-2003	1.0	0.3	0.01
2003-2004	1.0	0.3	0.01
2004-2005	1.0	0.3	0.01

In China, NPK nutrients use is also much unbalanced; in 2002, N:P:K ratio was 1.0:0.4:0.2 .

Among the many consequences that result from unbalanced use of fertilizers are the followings:

- The decrease in fertilizer use efficiency, in particular, for N. In china, results from a study covering 5.7 million hectares show that on average fertilizer use efficiency decreased by 8.2% ;
- Yield reduction that, in the above example ranged from 0.4 to 1 t/ha;
- Reduction of farmer's income;
- The mining, in some situation (India) of P and K on a very large scale;
- Lower response ratios, from 10 in 1970s to 6, at present, in India ;
- Increasing N losses to the environment by leaching and volatilization.

III. Increasing P use for balanced fertilization and increased crop production

In Asia, there is generally an over application of N compared with P, in particular. This is well documented from China to Pakistan. IMPHOS has launched several projects in this region to promote the balanced use of fertilizer nutrients. In Pakistan, the project conducted by IMPHOS lasted form 1986 to 2005 and yielded many significant results that clearly demonstrate the important role of balancing N with P to increases crop production. This case will be used to illustrate the impact on crop production that can result from more balanced fertilization practices.

Over the course of the project, 712 demonstration trials were conducted on seven crops that comprise 412 trials on wheat, 159 on rice, 57 on cotton, 54 on maize, 9 on sugarcane, 11 on oilseed and 10 on onion. Region-wise, the four agricultural provinces of Pakistan were covered, with 366 trials conducted in Punjab, 152 in Sindh, 137 in NWFP (North West Frontier Province) and 57 in Baluchistan. Trials were conducted under irrigated and rainfed conditions, using simple treatments that consist of:

- 0-0-0
- N-0-0
- N-P-0
- N-P-K

On some locations, the control treatment (0-0-0) is replaced by the farmer's practice. When comparing the balanced treatment with actual farmer practices, which are very unbalanced in favour to N, and scaling up the results to the country level, aggregate data show very important effects of the balanced use of N, P and K on the production of the selected crops.

For example, the average yield of wheat obtained in Punjab for the period of 1987 to 2005, was 1370 kg/ha on the control, 2168 kg/ha for N and 3284 kg/ha for NP (N and P2O5 doses per hectare were, respectively, 120 and 90). The increase per unit of nutrient was 6.6 kg for N and 12.4 kg for P.

The impact of a balanced use of P with respect to N is quite important on the production of all crops. Table 6 showed that the additional yield with 50% adoption of a balanced use of P vis-à-vis N, represented an average increase of 30% over the national production of the selected crops, that amounts to about 11.7 million tonnes. It would be a godsend for cash corps, which accounted for 80% of Pakistan's foreign exchange earnings through export of cotton, rice, and other products based on agricultural raw materials.

Wheat is the staple food of the vast majority of Pakistanis, so it is tone of the most important crop of the country, and there is never a production that matches the needs of the populations. There is often shortage in wheat production as it was the case in 2005, with 800 thousand tonnes deficit in wheat production; this deficit would have been covered by only 10% adoption of balanced NP fertilization in the country.

Table 6: Impact on crop production if balanced NP fertilization is adopted on 50% of cropped land.

	Wheat	Rice	Maize	Sugarcane	Total
Area (thousand ha)	7 ,333	2, 156	335	206	10, 030
Additional production (Thousand tonnes)	4, 422	2 ,895	350	4, 014	11,681

IV. P fertilizers and food quality

The quality of vegetal products depends on many factors, among others, optimal supplies of all substances required for growth. Minerals occupy a central position for obtaining high quality products.

Properly applied fertilization improves food quality through a higher quality of vegetal products (thus indirectly of animal products, as well) so it contributes not only to nourish men and animals but also to provide them with healthier living conditions.

The many important tasks of phosphate in metabolism are the reason that P supplies play a central role in food quality. Phosphate supplies cause the following changes:

1. Increased total P contents of plants; in the case of fodder this is an important quality criterion as insufficient P content is detrimental to the fertility of cows, milk production and quality;
2. Increased content of inorganic phosphates in green plants, as does the content of phytin as storage form. Phytin increases particularly in the kernels, whereas inorganic phosphate increases mainly in the straw;
3. Higher content of nuclein P
4. Higher content of essential amino acids in the kernels;
5. Increased content of carbohydrates (sugar, starch);
6. Increased content of some vitamins, such as B_1;
7. Reduced content of nicotine in tobacco:
8. Reduced content of oxalic acid, in leaf vegetables this product is harmful to humans and in sugar-beet leaves, harmful to cows;
9. Increased content of coumarin in grass

Some P-compounds important for quality assessment in plants are presented below:

1. **Inorganic phosphate**: phosphate anions are the absorbed and partly stored P- form.
2. **Phosphoric acid ester**: product of phosphorylization
3. **Phytin**: storage of phosphate in organic bonding as Ca-, Mg-salt of phytinic acid.
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, complex compounds important for cell synthesis and metabolism.

So, balanced fertilization practices not only increase crop yields and farmer' incomes, but also much improve the quality of food products. Data from experiments conducted by IMPHOS in Poland these past years provide some illustrations on the effects of P applications, along with sufficient level of applications of N and K, on the quality of wheat and sugar beet.

On Wheat, figure 3, increasing P applications much increase the total content of proteins, from 9. 4 to 16.3%, that is 70% increase. As this quality is much important for commercial wheat produced for bread production, farmers will add to gains from the increase of their wheat yields, better prices that will further increase their incomes. On sugar beet, figure 4, sugar content increases to increased P applications, from 0 to 15, and 60 Kg/ha P2O5.

Figure 3: Effect of P applications on the total wheat content of protein, Poland 2005

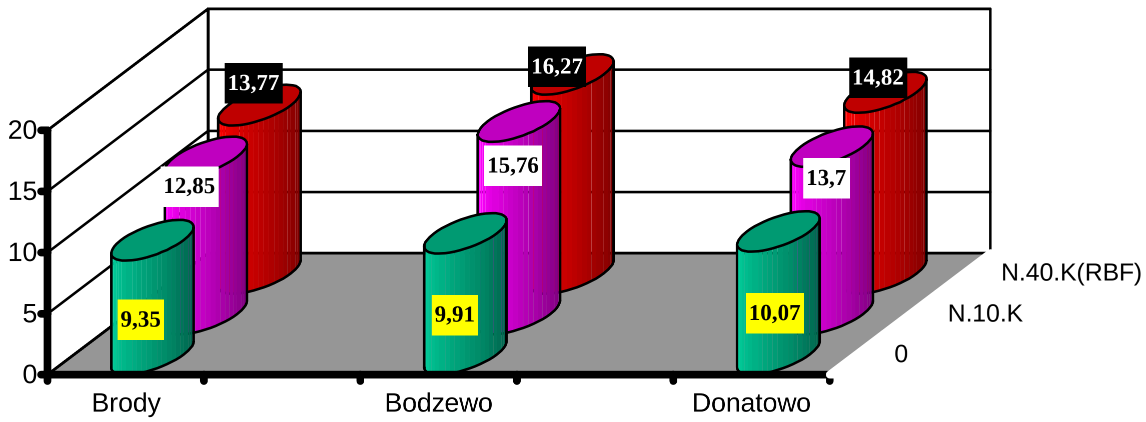
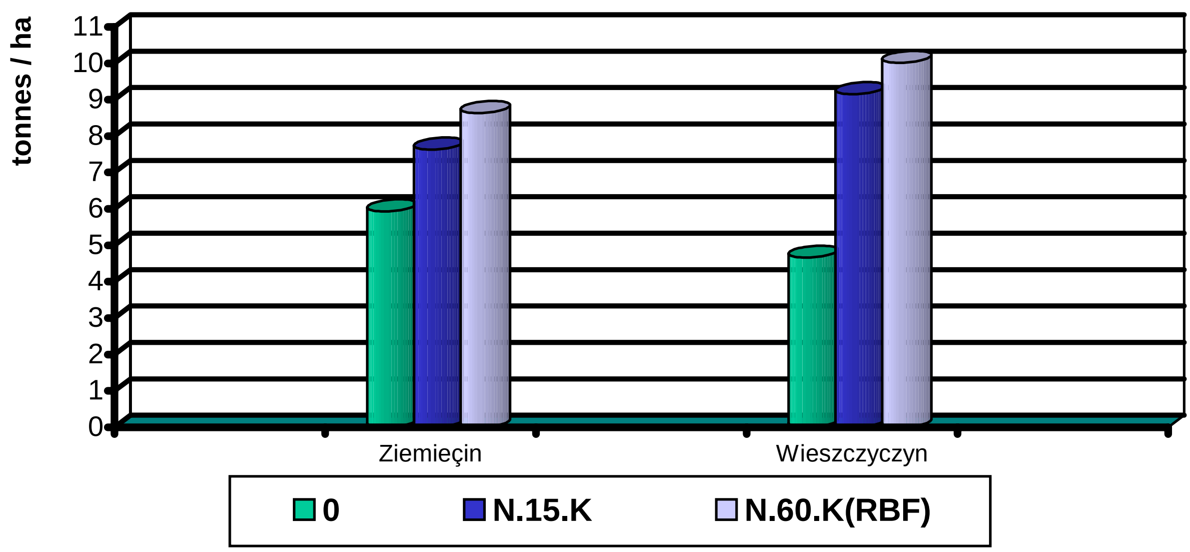


Figure 4: Sugar yield (t/ha), Poland 2005



In Wieszczyczyn, from 0, to 15,and 60 Kg/ha P2O5, sugar yield per hectare increases from 4.5, to 9 to 10 t/ha. This clearly shows dramatic sugar yield limitation if P application is not appropriate. So, in addition to facing reduced sugar beet yield, farmers will also face losses in crop product quality and finally, in incomes.

V. Maintaining soil productivity for sustainable agriculture

In the short-term it is unlikely that farmers will see the effects of not applying P fertilizers either in declining yields or as a decrease in the readily available soil P status. The only way to demonstrate the adverse effects of allowing soils to decline much below the critical values for P must be to compare yields on soils where Olsen P is in equilibrium with the P in the less readily available pool of P. Such conditions are often found only in long-term experiments. In a number of the examples, which follow there are appreciable differences in yield for small changes in Olsen P in long-term experiments.
There are a number of reasons for this:

- After a long period of uniform treatment, soil nutrient levels tend to be more uniform throughout the plot than in plots on short-term experiments or within fields.

- The yield response curve is initially very steep as Olsen P increases (Figure 5)

A sufficient available plant nutrients in soil is an important factor in maintaining soil fertility and crop production. On farms in Western Europe where there has been a long history of applying fertilizers and manures, plant nutrient reserves (P and K) have often been built up to satisfactory levels, so that only maintenance fertiliser dressings are needed to replace the removed nutrients by crops.

Survey data show, however, that farmers in Europe have decreased P fertiliser inputs in the last two decades by applying this nutrient to a smaller proportion of the arable cropped area, as a strategy for reducing production costs under difficult economic circumstances. Omission of P fertilizers for a few years, should not adversely affect yields and/or quality of cereal and oilseed rape crops grown in the rotation, unless the soil P status is already low. However, long-term experiments in England show that the continuation of such a policy will lead to yield losses once available soil P reserves have declined below the critical level appropriate for the soil and cropping system. This will also result in less efficient use of fertiliser N and other crop husbandry inputs, which is both economically and environmentally undesirable (Table 7).

Figure 5: The relationship between Olsen P and the yields of spring barley grown on silty clay loam

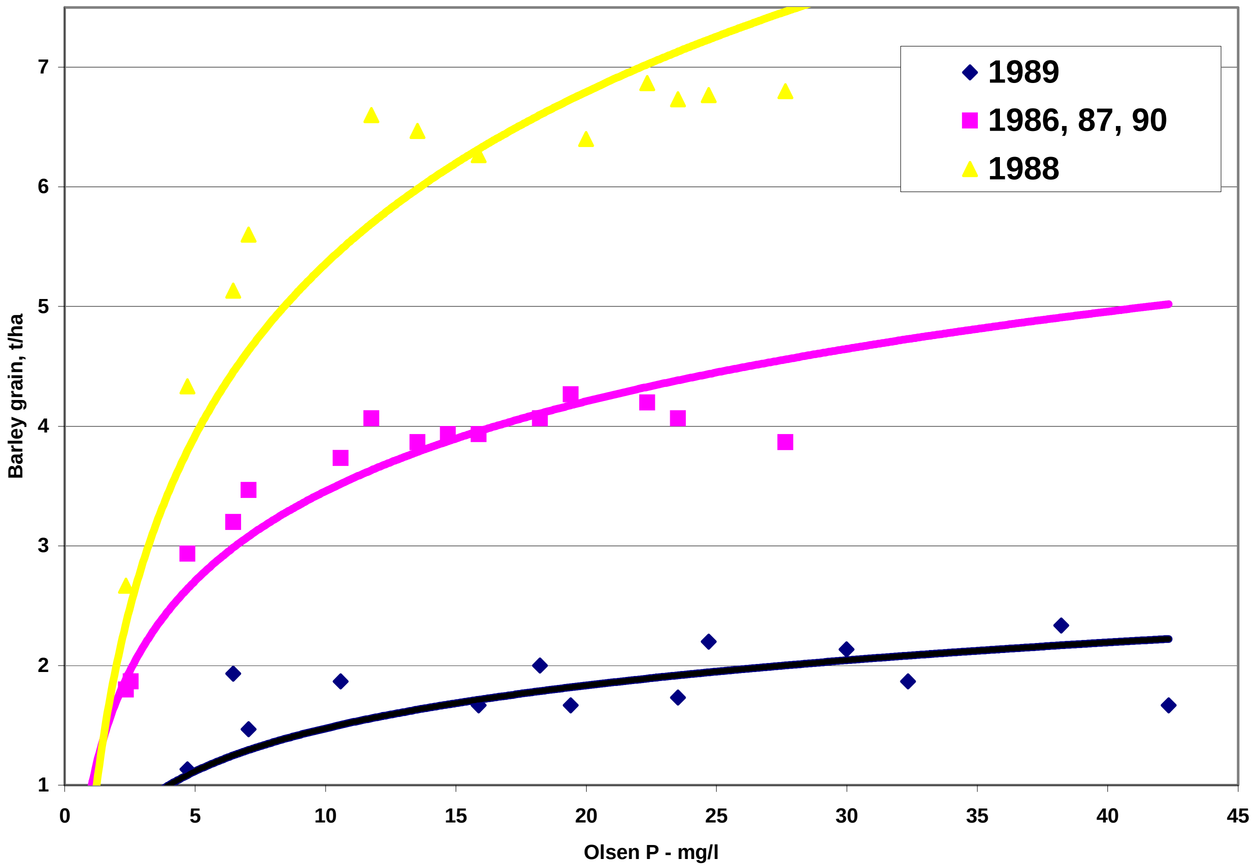


Table 7: Effect of stopping the application of phosphorus and continuing to supply fertiliser nitrogen on the yields of spring barley

	N applied, Kg/ha		
	48	96	144
Period		Grain Yield, T/ha	
1970-73	3.21	5.27	4.94
1984-87	3.76	4.81	5.05
1996-99	3.18	4.21	3.88

GENERAL CONCLUSION

Fertilizer has been and will continue to be the key input for achieving the world foodgrains production goals. Since increase in foodgrains production is possible only through increased productivity per unit land, effort should be directed towards constantly increasing crop response to fertilizers.

Some of the suggested measures are balanced and adequate N, P, K, S, Zn, B and Fe (and any other deficient nutrient) fertilization, development of quality soil-test facilities, timely availability of desired fertilizer materials, availability of good quality seed of the recommended crop varieties, implementation of recommended agronomic practices and availability of low interest credit to the farmers.

By contributing to increasing crop yields, improving food quality, enhancing the environment and providing higher economic gains for farmers, phosphate fertilizers play a major role in the achievement of balanced fertilization, food security and quality, and sustainable agriculture.