BETTER CROPS

with plant food

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Contents

P

Phosphorus: An Essential Plant Food Nutrient

PHOSPHORUS (P) is essential for plant growth and reproduction and is a "major" nutrient along with nitrogen (N) and potassium (K). It is also vital to animal life. In fact, P is present in every living cell, both plant and animal.

Plants take up most of their P from the soil as the primary orthophosphate ($H_2PO_4^-$), smaller amounts as the secondary orthophosphate ($HPO_4^=$). The ratio of uptake between the two forms is greatly influenced by soil pH. Other P forms may be utilized, but in much smaller quantities.

Because it is mobile in the plant, P deficiency symptoms appear on the older leaves first. The plant "borrows" from mature parts to provide P to young, growing parts. The visual symptoms of a P shortage . . . other than stunted growth and reduced yields . . . are usually not as clear as N and K hunger signs. A purple or reddish color is often seen on deficient corn plants and on some other crops. At certain stages a P deficiency may cause the crop to look darker green than normal. Delayed maturity is another sign of a P shortage.

This publication examines P from several perspectives. Its purpose is to illustrate some of the ways P promotes healthy crop growth, why it should be a part of a balanced fertilizer program and why it is vital to environmental protection.■

THERE WAS a clear positive effect of phosphorus (P) on maturity in these plots.

P

Role of Phosphorus in Plants

Phosphorus (P) is vital to plant growth and is found in every living plant cell. It is involved in several key plant functions, including energy transfer, photosynthesis, the breakdown of sugars and starches, nutrient transport within the plant and the transfer of genetic characteristics from one generation to the next.

PHOSPHORUS (P) is one of the 16 nutrients essential for plant growth. This means its functions cannot be performed by any other nutrient and that an adequate supply of P is required for optimum growth and reproduction. Except for nitrogen (N) and potassium (K), P is required in greater amounts by plants than any other essential nutrient. The total P concentration in agricultural crops can vary from 0.1 to 1.0%.

Uptake and Transport of P

Phosphorus enters the plant through root hairs, root tips and the outermost layers of root cells. It is usually taken up as the primary orthophosphate ion ($H_2PO_4^-$), but can also be absorbed as the secondary orthophosphate ($HPO_4^{=}$). Soil pH determines the ratio of uptake between the two.

Once inside the plant root, the inorganic P is stored in the root or transported to the upper portions of the plant. There, through various chemical reactions, it is incorporated into organic compounds, including enzymes, nucleic acids and proteins. It is in these organic forms that P is moved throughout the plant, where it is available for further reactions.

P and Plant Energy Reactions

Phosphorus plays a vital role in virtually every plant process that involves energy transfer. High energy phosphate, held as a part of the chemical structure of adenosine triphosphate (ATP), is the source of energy that drives the various chemical reactions within the plant. When the ATP transfers the high energy phosphate to other molecules, the stage is set for a variety of processes to occur.

Photosynthesis, the most important chemical reaction in nature, utilizes light energy, in the presence of chlorophyll, to combine carbon dioxide and water into simple sugars, with the energy being captured in the high energy phosphate of ATP. The ATP is then available as an energy source for other reactions, and the sugars are used as building blocks for other cellular components such as starches, proteins and oils.

Light trapped by pigments (such as chlorophyll) is converted to chemical energy involving the high energy phosphate bonds described above. This energy is then utilized in a series of complex reactions to convert carbon dioxide to sugars. Sugars are further metabolized to produce other cell structural and storage components.

Carbohydrate metabolism, the process by which sugars and starches are broken down in growing plants, requires P. Other chemical processes, including the synthesis and utilization of carbohydrates in more mature plant tissues, also find P playing a major role in the energy transfer in chemical reactions.

P and Plant Genetics

Phosphorus is a vital component of the substances that are the building blocks of

PHOTOSYNTHESIS:

Carbon Dioxide + Water $\xrightarrow[\text{Phosphate Energy}]{\text{Chlorophyll, Sunlight}}$ Oxygen + Carbohydrates

genes and chromosomes. So, it is an intimate part of the process of carrying the genetic code from one generation to the next, providing the ''blueprint'' for all aspects of plant growth and development.

An adequate supply of P is essential to the development of new cells and the transfer of the genetic code from one cell to another as new cells are formed.

Phosphorus is also a key component of phytin, a seed component that is essential to inducing germination. The P supply to the plant has little effect on the P content of the seed produced, but P deficiency can reduce seed size, seed numbers, and viability.

P and Nutrient Transport

Plant cells can accumulate nutrients at much higher concentrations than are present in the soil solution that surrounds them. This allows roots to extract nutrients from the soil solution where they are present in very low concentrations.

Most of the movement of nutrients within the plant depends upon transport through cell membranes, requiring energy to oppose the forces of osmosis. Here again, ATP and its high energy P provide the needed energy.

Plant Reaction to P Deficiency

Without adequate P, the rates of the processes described above are depressed and growth and development cannot continue at a normal rate.

When P is limiting, more of the available P is concentrated in the roots, and top growth may be reduced.

Generally, inadequate P slows the processes of carbohydrate utilization, but carbohydrate production through photosynthesis continues. The result is a buildup of carbohydrates, and development of a dark green leaf color. In some plants, P-deficient leaves develop a purple color from the accumulation of unused sugars.

Plant roots tend to proliferate in zones where P supply is high, such as a fertilizer band. Total root mass may be reduced, so fewer roots will be available to reach water and nutrients during dry periods. ■

INADEQUATE PHOSPHORUS may result in a dark green or purple color, as in these corn leaves. Photo: Grant Heilman Photography, Inc.

P

World Production of Phosphate Rock

Phosphorus (P) is a vital resource for sustaining world agriculture. Reserves of phosphate rock are identified in many regions of the world.

PHOSPHATE ROCK is the only economical source of phosphorus (P) for production of phosphate fertilizers and phosphate chemicals. Most of the U.S.A. and world phosphate rock resources are widely distributed marine phosphorite deposits.

Identified reserves and reserve bases of this vital resource are shown in **Table 1**. Morocco has the greatest reserves, followed by South Africa, U.S.A., and U.S.S.R. China's reserves are actually much greater than indicated, and may rank as high as fourth in the world.

World production of phosphate rock ranged from 158 to 163 million tons per year between 1985 and 1987 **(Table 1)**. Three areas of the world (U.S.A., U.S.S.R. and North Africa) provided about two-thirds of this supply.

United States production of phosphate rock represented 27 to 33% of world supplies in the 1985 to 1987 period. In 1987, nine companies in Florida and one in North Carolina provided 91% of the phosphate rock. The remaining 9% was produced by six companies operating in Idaho, Montana, Tennessee and Utah.

Total capacity of the phosphate rock industry in the U.S. is 72 million tons, with 55 million tons located in Florida. U.S. mines are currently operating at about 65 to 70% of capacity.

Phosphate rock production in the U.S. surpasses domestic needs, and the excess is exported to international markets. Domestic consumption was about 41.36, 36.65 and 38.13 million tons in 1985, 1986 and 1987, respectively. The top importers of U.S. phosphate rock in 1987 were Canada and South Korea.

Table 1. World phosphate rock reserves, reserve bases and production.

			Production		
	Reserves[1]	Reserve Base	1985	1986	1987
Countries	(million tons)		(thousand tons)		
United States (U.S.A.)	1,433	5,730	54,448	42,850	44,763
Israel	—	209	4,492	4,048	4,185
Jordan	132	562	6,686	6,886	7,495
Morocco and Western Sahara (Algeria)	7,714	24,244	24,183	24,664	24,275
Senegal	44	187	1,963	2,040	2,072
South Africa	2,755	2,755	2,737	3,296	2,891
Togo	44	77	2,702	2,550	2,914
Tunisia	22	331	4,992	6,558	7,042
Other Market Economy Countries	441	3,747	—	—	—
China	231	231	7,685	10,469	9,918
U.S.S.R.	1,433	1,433	37,771	37,948	38,350
Other Centrally Planned Economies	358	358	—	—	—
World Total (may be rounded)	14,574	39,865	163,366	157,604	160,765

[1]Cost less than $32 per ton. Cost includes capital, operating expenses, taxes, royalties, and a 15% return on investment, FOB mine.

STRIP MINING methods are used for most of the rock phosphate in the U.S.A.

Mining of phosphate rock in the U.S. and elsewhere is accomplished mainly by strip mining techniques. Shaft mining is practiced at one mine in Montana.

Apatite in several different forms is the basic P compound in commercially important deposits of phosphate rock. Phosphorus in apatite minerals is only slightly soluble and of limited availability to crops. However, reactive phosphate rock and partially acidulated phosphate rock are satisfactory sources of P for crops grown on some acid tropical soils.

Acidulation or heat treatment of phosphate rock is usually necessary to break the apatite bond to render the contained phosphate more soluble. Wet process sulphuric acid acidulation is the most commonly used technique for improving the agronomic suitability of phosphate rock. The majority of finished P containing materials used in North American agriculture is based on wet process phosphoric acid resulting from the reaction of sulphuric acid with phosphate rock.

Wet process orthophosphoric acid is often further concentrated by evaporation of water to form superphosphoric acid. In this process, two or more orthophosphate molecules combine to form polyphosphate compounds. These polyphosphate products are well suited for the manufacture of clear liquid fertilizers.

Phosphate materials widely used in modern crop production systems are listed in **Table 2**, with both P and P_2O_5 concentrations expressed as percent. Some of these products supply other essential plant nutrients including nitrogen (N), calcium (Ca), and sulphur (S).

Table 2. Concentration of P in phosphate products.

Material	Concentration (percent) P	P_2O_5
Superphosphoric Acid	30-35	68-80
Wet Process Phosphoric Acid	23-24	52-55
Concentrated Superphosphate	20	46
Diammonium Phosphate	20-21	46-48
Monoammonium Phosphate	21-24	48-55
Normal Superphosphate	7-10	16-22
Phosphate Rock	12-18	27-41

For many years, normal or ordinary superphosphate was the predominant phosphate fertilizer. Be-

(continued on next page)

World Production . . . from page 7
cause of relatively low analysis and high shipping and handling costs, it has been largely replaced by higher analysis, more economical sources such as concentrated superphosphate and ammonium phosphates.

Consumption of fertilizer phosphate in the U.S.A. reached a high of approximately 5.21 million tons annually during the five-year period 1975 to 1979 **(Table 3)**. Consumption declined to an average of 4.29 million tons yearly during the three years 1985 to 1987.

Illinois was the leading fertilizer phosphate consuming state in 1987, followed by Iowa, Indiana and Minnesota **(Table 4)**. Others in the list of the top 10 phosphate using states include Texas, Ohio, California, Missouri, North Dakota and Nebraska.

Table 3. Consumption of P_2O_5 in U.S.A., five-year averages.

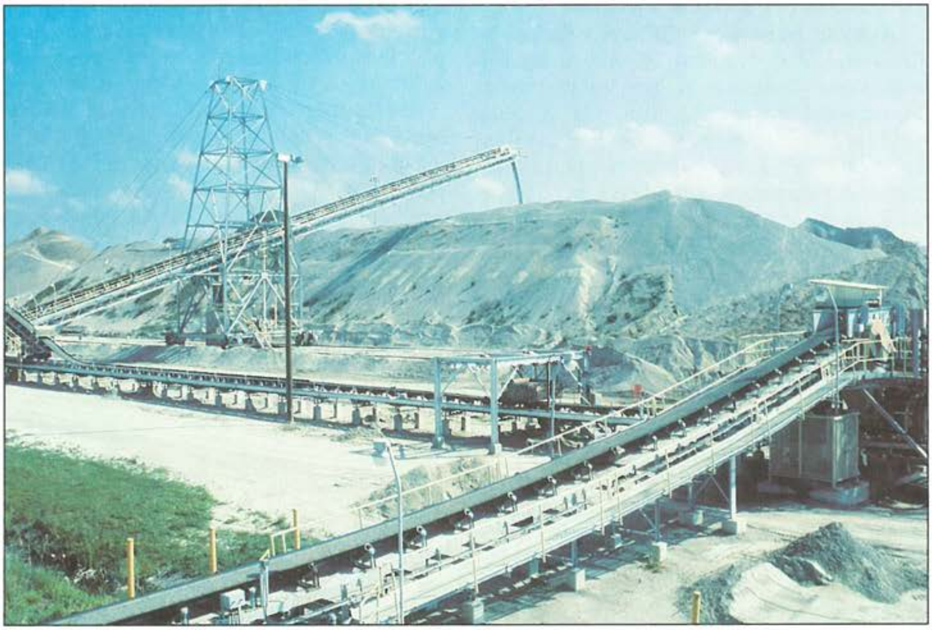
Years	Average Consumption
	million tons/year
1960-1964	2.89
1965-1969	4.16
1970-1974	4.88
1975-1979	5.21
1980-1984	4.95
1985-1987*	4.28

*Three-year average

Table 4. Top ten states in P_2O_5 consumption, 1986-1987.

State	P_2O_5 Consumption
	thousand tons
Illinois	374
Iowa	288
Indiana	265
Minnesota	228
Texas	210
Ohio	179
California	161
Missouri	150
North Dakota	147
Nebraska	140
Total in U.S.A.	4,012

Canadian consumption of fertilizer phosphate peaked at 800,400 tons of P_2O_5 in 1985. Consumption declined to 690,200 tons in 1987. The four western provinces (British Columbia, Alberta, Saskatchewan and Manitoba) use slightly more than 60% of the Canadian total.■



THE MATRIX is washed, screened and treated to upgrade the P_2O_5 content. The phosphorus in phosphate rock is relatively unavailable to plants and must be converted to compounds that are more available.

P

Important Factors Affecting Crop Response to Phosphorus

Although soil test level is a major consideration, numerous other factors also affect crop response to phosphorus (P).

PHOSPHORUS (P) responses are expected in crops growing on soils low in soil test P. However, many factors other than soil test level should be considered in decisions to apply P and in predicting P responses. Some are manageable, others are not. They include soil characteristics, crop grown, climate, tillage systems, interactions with other nutrients, crop management and fertilizer management.

Soil Physical Factors

- **Soil texture.** Responses to fertilizer P at a certain P soil test level tend to be greater on sandy soils than on those containing more silt and clay. Diffusion is an important process in P movement toward roots and is slower in coarse textured soils. Higher P soil tests or higher rates of fertilizer P are needed on such soils. Some soil components react readily with fertilizer P to lower its availability (P fixation). Fixation increases as soil clay content increases. This means that larger amounts of P must be applied to those soils in order to increase soil test values and P availability to plants. Highly weathered soils are likely to have this characteristic.
- **Soil aeration and compaction.** Phosphorus uptake by plant roots requires energy from carbohydrates. Generating that energy requires oxygen for normal root metabolism. If soils are compacted, pore space is diminished, oxygen is limited and P absorption suffers. Compaction also limits P use by decreasing the thickness of water films on soil particles through which P moves to root surfaces. Increased concentrations of soil P by adequate fertilization can help offset this effect.
- **Soil temperature.** Low soil temperatures depress P availability and plant uptake. Lower temperatures reduce the rate of mineralization of soil organic P because of lowered microbial activity. Low soil temperatures also reduce the rate of diffusion of P and decrease the amount of P reaching root surfaces. Plant metabolic processes which release energy to drive P absorption mechanisms are also slowed by low soil temperatures.

Low soil temperatures should be taken into account in the decision to apply P. Cold soils are often associated with large P responses, even at high test levels. Reduced tillage systems are associated with lower soil temperatures because of surface shading by residues. Studies have shown that reduced tillage corn and other crops respond to starter P at high soil test levels when responses in other tillage systems in the same study are nil.

- **Soil moisture.** Moisture stress also reduces P availability and uptake. Greater crop response to P at a given level of soil P may be expected under moisture stress conditions. Low soil moisture has been found to decrease P availability to wheat more than added P fertilizer increased availability. Phosphorus in the crop from fertilizer has been reported highest when moisture availability was lowest. Field studies indicate larger corn and soybean responses to P on a medium P testing soil under low rainfall conditions.

(continued on next page)

Soil Chemical Factors

- **Soil mineralogy.** Forms of mineral P in the soil are a result of the soil's parent material, weathering and, to a lesser degree, P fertilization. Types of clay, amounts of iron and aluminum oxides, and amounts of calcium carbonate affect soils' abilities to fix fertilizer P.
- **Soil organic matter.** Generally, higher soil organic matter levels are related to greater P availability. Studies have emphasized the importance of organic P in plant nutrition. Apparently a fairly constant portion of organic P is converted into inorganic forms which are taken up by plants. Gradual release of organic P provides a steady supply of P under conditions which would otherwise result in P fixation.
- **Soil pH.** Soil pH has an important role in P availability and affects the efficiency of applied P. Phosphorus fixation by iron and aluminum oxides of P is greatest in acid soils but declines as soils are limed. Availability in most soils is at a maximum in the pH range 6 to 7. As soil pH increases above 7, calcium and magnesium carbonates react with P and the availability again declines. Trying to lower the pH of calcareous soils to improve P availability is not practical. Placement is much more feasible.
- **Interactions with other nutrients.** Crop responses to P are affected by the availability of other nutrients. Deficiencies of other nutrients limit P responses. Interactions of P with micronutrients, particularly zinc (Zn), usually involve lowered micronutrient availability and uptake when P availability is high.

Phosphorus fertilizer absorption and use efficiency is improved by the presence of ammonium-N in the soil with the P. Ammonium-N absorption by roots lowers the pH in the vicinity of the root surface improving P uptake. High concentrations of ammonium-N can change the soil chemistry of P and delay normal fixation reactions.

Soil Biological Factors

Soil biological processes in addition to mineralization of organic P can influence availability and responses to applied P.

- **Effects of crop residues.** Incorporation of crop residues increases microbiological action and can result in immobilization of available P into microbial cells. The same process affects the availability of N, sulphur (S), and other nutrients. Immobilized P is gradually released for plant use as residues decompose. Soil aeration, temperature, soil moisture, pH and supplies of other nutrients such as N have a direct effect on biological action, immobilization and release of P.

- **Effects of plant roots.** Roots affect the biology of the soil by providing energy sources for microbes and influencing soil properties such as tilth, structure and nutrient availability.

- **Effects of mycorrhizae.** Mycorrhizae represent a close association of plant roots and a fungus where both partners benefit. Plants grow better when infected by the appropriate fungi which act as extended root surfaces (root hairs). Improved nutrient absorption, especially P, results from the plant-fungi association. Increasing the soil P concentration to the levels needed for high yielding crops may essentially eliminate mycorrhizal infection as a factor in overall plant growth. However, even with high P testing soils, mycorrhizal infection may be important in early season plant growth. Mycorrhizal infection may be severely reduced by fallow periods in crop production, increasing the importance of starter P fertilization for crops grown in a fallow rotation.

Crop Factors

Crop species, varieties and hybrids vary in their abilities to absorb and respond to fertilizer P. Several factors relate to those differences.

SOYBEANS, corn, grain sorghum, wheat, alfalfa and other crops respond to fertilizer P. This soybean crop was planted on a low P soil.

- **Root development and distribution.** Most available P is present in the surface soil and helps concentrate roots in that zone. However, if surface moisture is limiting, soil P becomes less useable and P use efficiency declines. High levels of applied P can help overcome this problem by allowing better root development in the subsoil and increasing plants' ability to extract water.

Outstanding corn yields are often associated with deep distribution of nutrients, including P.

Root length and density affect response to P since length is a determinant of absorbing surface area.

- **Crop varieties and hybrids.** Crop varieties and hybrids differ in their requirements for P. Corn hybrid responses to P have differed by over 100% in terms of dry matter production and by over 200% in terms of P uptake in some studies. In the future, specific recommendations for P fertilization of individual hybrids and varieties may be a part of intensive crop management.
- **Crop yield levels.** Corn and soybean studies have indicated that the amount of P taken up by plants per bushel or per ton of grain yield does not vary substantially. Yield effects on P requirements can then be estimated as essentially a straight line function.

Alfalfa, however, tends to remove more P per ton of production as yields increase due to P fertilization.

Fertilizer Factors

Chemical and physical characteristics of P fertilizers may influence crop response and management decisions on P sources.

- **Water solubility.** Water solubility of P fertilizers is considered important in some countries but there is little agreement on what percent of the total P should be water soluble. Available P is that soluble in ammonium citrate and includes the water soluble fraction. Research in North America has shown that water solubility is important but it is difficult to find data that indicate superiority of fertilizers having higher than 60% water solubility.
- **Chemical forms of P.** Studies of P fertilizer materials indicate that ammonium phosphates, superphosphates and nitric phosphates are largely equal as P sources for plants. These classes of compounds have a high percentage of P availability. Although research has shown some advantages to the presence of ammonium-N with P in terms of plant P absorption, modern crop production practices frequently involve high concentrations of N in the soil which diminish differences among these classes of compounds.

Comparisons of monoammonium phosphate (MAP), diammonium phosphate (DAP), ammonium polyphosphate (APP) and urea ammonium phosphate (UAP) show few consistent differences. At high rates, DAP can cause germination damage when placed in direct seed

(continued on page 13)

P

Effects of Phosphorus on Nitrogen Fixation

Phosphorus (P) enhances the symbiotic nitrogen (N) fixation process in legume crops. Generally, legumes require more P than grasses, which depend more on N.

PHOSPHORUS (P) plays a key role in the symbiotic nitrogen (N) fixation process. Numerous research trials throughout the world have shown positive results with P application for soils planted to legumes.

Here's how P works:

- Increases top and root growth (anything which restricts root development and activity of a legume reduces the ability of that plant to fix N);
- Decreases the time needed for developing nodules to become active and of benefit to the host legume;
- Increases the number and size of nodules and the amount of N assimilated per unit weight of nodules;
- Increases the percent and total amount of N in the harvested portion of the host legume;
- Adequate soil P levels increase the density of Rhizobia bacteria in the soil surrounding the root. If adequate density is not achieved, nodulation is impaired.

Effect of P on Nodule Development

Table 1 shows the research results from the application of P to alfalfa. In this study, nodules first developed on the

Table 1. Effect of P for nodule development of alfalfa 26 days after seeding.

P_2O_5 Rate	Measurements of nodule development: Dry Weight	Weight/Nodule	N Content
lb/A	mg	mg	mg
0	0.13	13	0.01
125	1.06	28	0.07
255	3.31	60	0.15

high P plots in 11 days after seeding, but not until day 14 for low P. Thereafter, nodule number, volume and dry weight were increased with high P. The nodules became pink earlier, developed quicker, and became active sooner in response to P fertilization.

P Increases Yield and N Content in Legumes

Many researchers have shown that P increases the percent N in legumes. This relationship is shown in **Table 2,** typical of the effect P has on increasing the N content.

Table 2. Effect of P fertilization on the yield and N content of legumes.

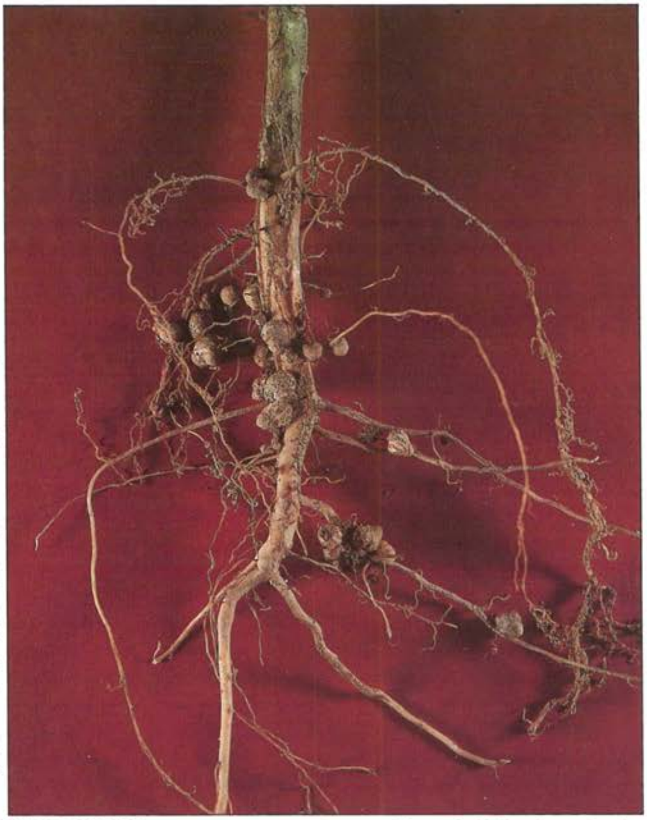
Crop	Yield, lb/A: No P	Yield, lb/A: P	Tissue N,%: No P	Tissue N,%: P
Sub. Clover	2,400	3,400	2.5	2.8
Alfalfa	4,980	10,710	3.8	4.3

Legumes make high demands on P due to the production of protein-containing compounds of which N and P are important constituents. The P content of legumes is generally much higher than that found in grasses. The vital role that high energy P storage compounds play in reactions involving energy transfer, especially those of the elemental N-fixing enzyme nitrogenase, is perhaps the reason that legumes, dependent on symbiotic N, have a higher P requirement than grasses which depend on fertilizer N.

Facts Related to P and N Fixation

- Rhizobia bacteria infection happens when a root hair (growing out from active roots) intercepts or is attracted by one of the compatible nodule organisms. Any restriction to root development and activity of the host plant restricts nodulation. Phosphorus improves legume root systems.

- Nitrogen fixation demands much readily available photosynthate in the form of sugars. Phosphorus is vital for photosynthesis, energy transfer, and the formation of sugars.
- The translocation of photosynthate from leaves to roots and the movement of N-containing compounds from nodules to other plant parts are vital to an efficient symbiotic system. Phosphorus is an integral part of the compounds needed to drive the system.
- Nitrogen fixation is a tremendous energy-consuming process. Phosphorus is essential for the formation and as a part of ATP (adenosine triphosphate), the primary energy storage compound driving plant processes.
- A healthy, active nodule often contains two to three times more P than the root on which it is formed. Legumes need high amounts of P, in readily available form, around their roots to supply P needs of the Rhizobia and the host plant.■



PHOSPHORUS encourages root growth and N-fixation in legumes. These soybean root nodules contain N-fixing bacteria.
Photo: Runk/Schoenberger from Grant Heilman Photography, Inc.

Factors affecting response . . . from page 11

contact on alkaline soils due to the release of some free ammonia. Limited rates of application control the problem. Formulations of UAP have an even greater probability of germination damage in direct seed contact due to ammonia release from urea hydrolysis. Application rates of UAP in seed contact are lower than DAP. While APP provides some superior physical characteristics in liquid fertilizers, agronomic capabilities of MAP, DAP, APP and UAP are essentially equal.

- **Physical form of P fertilizers.** Solid and fluid forms of P involve the same compounds mentioned earlier. Agronomic capabilities of solid and fluid P sources are essentially equal. Handling differences, adaptability to methods of application and abilities to incorporate micronutrients as well as pesticides are valid management considerations.
- **Phosphorus placement.** Placement can have tremendous effects on crop responses to applied P. For more information on placement, see the article beginning on page 14.■

P

Phosphorus in Fertilizer Placement

Soils are often classified by their phosphorus (P) fixing capacity. The effects of P fixation can be countered to some degree by specific placement of P, concentration of fertilizer P into smaller soil zones, often close to the growing plant. Many placement methods have been studied to determine which ones are most effective for specific crops on various soils with different tillage systems.

FERTILIZER phosphorus (P) becomes less available (fixed) when it reacts with soil components. Fertilizer placement helps overcome fixation.

Placement Methods

Various methods of P fertilizer placement are used. Here are descriptions.

Broadcast—application of P to the soil surface, usually preplant. Produces the most uniform P distribution but the lowest concentration at any given point in the soil. Adapted to heavy rates of P and high-speed operations with large equipment. May be least effective method of application on high P fixing soils.

Preplant banding—applied prior to seeding. Produces a higher P concentration zone in the soil even after tillage. Tends to be more effective when soil test P is low. Adapted to a wide range of tillage systems. Several forms of preplant banding are used.

- **Surface strip or surface banding**—involves application of solid or fluid fertilizers in strips on the soil surface or on the surface of crop residues. Typically contacts about 25% of the soil surface. May be followed by tillage for incorporation.
- **Deep banding**—also known as deep placement, dual application, dual banding, knifing, preplant banding, double shooting, root zone banding and tillage implement application. Usually refers to preplant applications of P and other nutrients, particularly nitrogen (N), injected 2 to 6 inches below the soil surface. Can be carried out at seeding with reduced tillage grain drills or row crop planters.
    - **Point injection**—a relatively new technique using a spoked wheel to inject fluid fertilizers at points about 8 inches apart, 4 to 6 inches deep. Produces high concentrations of nutrients at application points. Adapted to deep placement of P and other nutrients in heavy residues.

BROADCAST fertilizer application may be the simplest method and has advantages on fields where a "buildup" program is needed to increase soil test levels.

Starter or seed placement—a form of band application close to or in direct seed contact. Particularly effective for crops planted in cool soils

PREPLANT DEEP PLACEMENT of N and P (left) was much more effective for winter wheat than broadcast applications on this low P soil.

and/or in low P testing soils. Close proximity of P to developing plant induces seedling vigor and stimulates early growth. Placement in direct seed contact is termed "pop-up." Rates of application must be low to avoid germination damage, usually less than 15 lb P_2O_5/A.

Research has demonstrated differences in crop responses to methods of P application depending on tillage system and soil characteristics.

Crop Responses to P Placement

Small grains. Small grains, especially wheat, may respond much better to banded than broadcast P, especially on low P soil or on soils with high P fixing capacity. Small grains grown on soils with a higher P test or with higher rates of P application may respond equally as well to broadcast and P banding.

Preplant banding of N and P has shown some advantages for P use efficiency over comparable broadcast applications. Phosphorus availability is enhanced by high concentrations of ammonium-N in the same soil zone with P. Placement of nutrients into more moist soil zones may be an advantage (positional availability).

Alfalfa. Seedling alfalfa has shown improved vigor from banded P. Adverse weather conditions at seeding can enhance P banding effects on early growth and on yield. Surface strip banding and knifing of preplant P have shown some advantages with alfalfa on acid, high P fixing soils.

Perennial grasses. Established grasses have responded well to broadcast applications of P. Surface strip and knifed applications of fluids have shown advantages on high P fixing soils. Small amounts of P banded directly with the seed on high P fixing soils have greatly improved seedling growth of tropical grasses and can also benefit cool season grass establishment.

Vegetables, potatoes. High concentrations of P in the vicinity of vegetable plant roots help avoid early season stress. Banded P has been found to be important for early season, direct seeded tomatoes on cold, high pH soils. Starter P placed one to three inches below onion seed produced best seedling vigor, uniformity and plant development. Researchers concluded that placement had a larger effect on onions than did P rate. When N, P, and potassium (K) are banded together, potato yields may be better than broadcast

(continued on next page)

application due to the complimentary effect of ammonium-N on P uptake.

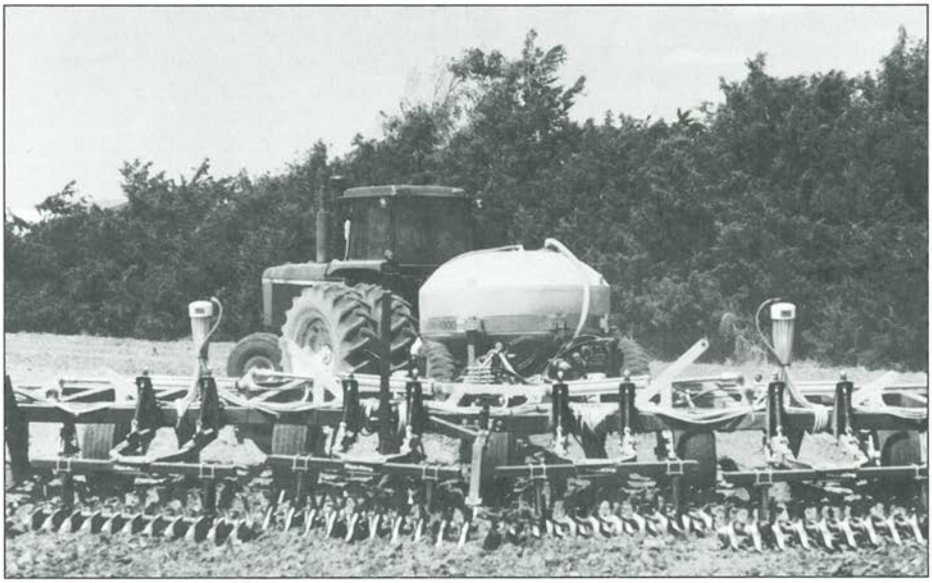
Soybeans, field beans and canola. Soybeans generally are not responsive to P placement. Best responses have been to improved P soil test levels rather than placement. Oilseed crops are particularly susceptible to seedling damage from any fertilizers placed in direct seed contact. Canadian studies have shown better response from P placement below the seed of soybeans than from P broadcast, placed below and to the side of the seed or in direct seed contact. Field beans (dry beans) are sensitive to direct seed placement of fertilizers. Phosphorus placement is recommended to be either below and to the side of the seed or broadcast. Canola has a high requirement for P and responds well to P banded below the seed. Direct seed contact of any fertilizer should be avoided for canola.

Sunflowers. Like soybeans and canola, sunflowers are sensitive to soluble salts in direct seed contact. The P requirement of sunflowers is similar to wheat, but P placement below and to the side of the seed is apparently beneficial. Deep placed P may be most beneficial during flowering.

Cotton. On medium to high P soils, there seems to be little yield difference between banded and broadcast P. At lower P test levels, banding trends toward higher yields.

Corn and grain sorghum. Many agronomists have concluded that most profitable corn yields cannot be reached unless the entire root zone has been built up to a relatively high level of available P. But some leases or financial arrangements do not allow soil building rates of P application. Higher short-term efficiency is needed then. Banded or starter applications of P for corn and grain sorghum have tended to show greater efficiency when soil conditions are cool at planting. Cool soil conditions are often associated with reduced tillage, producing many recommendations for starter.

Several studies comparing starter (including P) effects across tillage systems indicate starter responses were greatest in reduced tillage systems (no-till and ridge-till), even when P soil tests were high. Fallow conditions prior to dryland corn in



DEVELOPMENTS in fertilizer application equipment and tillage systems have multiplied the number of decisions and choices available to crop growers.

STARTER P produced this spectacular growth response in grain sorghum, resulting in advanced maturity and higher yields. Soil test P was low.

the Great Plains set the stage for large starter P responses in both conventional and no-till systems.

Starter P can have significant effects on grain moisture in corn and grain sorghum. Advanced maturity and higher yields can combine to produce lower grain moisture levels at harvest and save money on lowered drying costs.

Summary

Absolute conclusions and recommendations for P application methods are difficult. Following are some general observations:

- Effects of P placement on P availability are complex and are affected by crop, other nutrients, soil properties, tillage systems and weather conditions.
- Placement of P for small grains may be more critical than for row crops and forages. Limited root systems, shorter growing seasons and cooler temperatures enhance the response to banded P over broadcast.
- Placement of large quantities of ammonium-N with P improves P uptake and slows fixation.
- Deeper placement of P into soil where moisture is less limiting to uptake may improve P use efficiency and yields in dry climates.
- On high P soils, maintenance P applications may be effective regardless of methods of application.
- Reduced tillage crops, row crops and spring seeded small grains may require P placement close to the seed regardless of P soil test.
- Limited root systems in some specialty and vegetable crops make P placement an important management practice.
- Where P fixation is an overriding factor, banding all the P is probably advisable. High P concentrations in bands help delay normal fixation reactions.
- High yielding row crops, especially corn, may require relatively high P levels throughout the rooting zone for maximum yields. On low to medium P soils, banding at least some of the P may provide a yield advantage.
- Where P use has been minimal in the past and resources are limited, banding moderate amounts of P on more acres will likely optimize returns.■

P

Phosphorus Increases Crop Yields

The most important reason for phosphorus (P) application is to increase profit potential which results from higher crop yields.

HIGHER YIELDS and greater profits are major reasons why farmers apply phosphorus (P) to crops. All crops need P for profitable yields. The amount needed depends on soil P levels and other factors. On many soils, P is the nutrient that most limits plant growth.

A sampling of documented crop responses to P follows. The range of crops and locations indicates the importance of P to profitable agricultural production.

Corn

A high-yielding corn crop puts a large demand on the soil to supply adequate P. This makes corn yield and profit responses common. An example in **Table 1** shows results from a long-term P study in Iowa.

Table 1. Corn response to P in a long-term study.

Annual P_2O_5 Rate lb/A	P Soil Test lb/A	Avg. Yield 10 Years bu/A	Yield 10th Year bu/A
0	14	142	145
23	23	157	175
46	37	161	186
69	64	164	188

Iowa

Research in Ohio showed corn yields increasing up to the highest rate of P_2O_5 applied on a low-testing soil **(Table 2)**.

Table 2. Corn yield increases from P fertilization.

P_2O_5 Rate lb/A	Corn Yield bu/A
0	150
20	166
40	175
80	183
120	191

Ohio

Going from 80 to 120 lb/A of P_2O_5 still gave a profitable yield increase of 8 bu/A.

On cold, wet soils corn often responds to row applications of P. Wisconsin research showed that even on high-P soils a starter application of P boosted yields by as much as 31 bu/A.

Wheat

Most soils used for wheat production need P fertilizer for profitable yields. **Table 3** shows the difference P can make in growing wheat in Kansas.

Table 3. Adequate P increases wheat yields.

P_2O_5 Rate lb/A	Wheat Yield bu/A
0	27
16	48
32	52
64	60

In Colorado tests on 64 wheat sites over a five-year period, one-third of the sites responded to broadcast P applications with an average yield boost of 5.2 bu/A.

Wheat growers see the best grain production when both nitrogen (N) and P are applied at optimum rates. In **Table 4,** data from Manitoba show the effectiveness of balanced N and P fertilization.

Table 4. Both N and P are needed for optimum wheat yields.

N Rate lb/A	P_2O_5 Rate, lb/A 0	18	45	Response to P, bu/A
	–Wheat Yield, bu/A–			
0	14	17	20	6
54	41	42	46	5
107	47	54	64	17
Response to N	33	37	44	

Manitoba

Soybeans

Soybeans can be quite responsive to P fertilization, as was shown on newly cleared land in Virginia **(Table 5).** The 50 lb/A of banded P_2O_5 produced a good yield response at the zero and 200 lb/A rates of broadcast P_2O_5.

Table 5. Soybean response to P on newly cleared land.

----------P_2O_5, lb/A---------- Broadcast	Banded 0	Banded 50	Response to Banded P
	----Soybean Yield, bu/A----		
0	16	35	19
200	35	43	8
400	43	44	1
600	44	45	1
Response to Broadcast P	28	10	

Virginia

In the last 10 years of a 24-year Indiana experiment, soybeans receiving both P and K fertilizer averaged almost 54 bu/A. When P was omitted in these 10 years, average yield dropped to 44 bu/A—or an 18.5% reduction without P.

Cotton

Starter fertilizer containing N and P gave consistent increases in lint yields of cotton on 18 locations over a two-year period in Mississippi. Phosphorus was found to be the nutrient producing the yield response at two locations where nutrient effects were separated, shown in **Table 6**.

Table 6. Effect of no starter, N starter and N-P starter on lint cotton yield.

Location	No Starter	N Only	N-P Starter
	-----------Lint Yield, lb/A-----------		
Webb	815	796	905
Glendora	1,033	975	1,170

Mississippi

Five advantages to using starter fertilizer on cotton were observed or measured: 1) enhances the development of a better early root system; 2) helps overcome early adverse conditions; 3) initiates earlier fruiting; 4) hastens maturity; and 5) increases yields.

Grain Sorghum

Grain sorghum gave outstanding yield responses to starter P in a three-year Kansas study on a low-P soil, as shown in **Table 7**. In the same study, there were no differences in yield responses between ortho and polyphosphate P sources.

Table 7. Starter P boosts grain sorghum yields.

P_2O_5 Rate lb/A	Grain Sorghum Yield, bu/A
0	80
18	111
36	117

Kansas

Snap Beans

Snap beans responded to P fertilization in five out of seven years of studies in Tennessee. The optimum rate was found to be about 50 lb/A of P_2O_5. Higher rates sometimes depressed yields due to a possible induced zinc (Zn) deficiency. Zinc fertilization corrects such deficiencies.

Potatoes

Growers know that P is an essential component of growing profitable potatoes. Yield responses to P are common even on high-P soils. For example, potato yields dropped from 320 cwt/A to 239 cwt/A when 100 lb/A of P_2O_5 was omitted from the optimum fertilizer treatment in a New Jersey trial on a high-P soil. Workers in Idaho found banded P not as effective as plowdown or disking in producing highest tuber yields.

Alfalfa

Alfalfa removes about 12 lb of P_2O_5 for every ton of hay harvested. This high demand for P creates conditions for large and profitable yield increases to P fertilization. A long-term study in Kansas showed alfalfa response to P at various rates **(Table 8).■**

Table 8. Effect of P fertilization on alfalfa yield.

P_2O_5, lb/A Annual	Alfalfa Yield, tons/A Year 1	2	3	4	5	6
0	8.1	7.7	7.4	7.1	9.1	8.2
40	9.3	9.3	8.9	8.5	10.6	9.7
80	9.3	9.7	9.5	8.8	11.4	10.4
120	9.6	10.6	10.0	9.5	12.1	11.4

Kansas

P

Phosphorus and Moisture

Phosphorus (P) as part of a balanced soil fertility program can increase water use efficiency and help crops withstand moisture stress conditions.

ADEQUATE SOIL FERTILITY, including phosphorus (P), helps crops increase water use efficiency (WUE). This can be expressed as units of yield per inch of water used. Adequate fertility also improves crop tolerance to drought. These benefits occur for many reasons.

- **Water evaporation from the soil surface is reduced** by earlier, fuller canopy development.
- **Runoff and soil erosion are reduced** by heavier crop residues that decrease soil crusting and increase water infiltration.
- **More organic matter** is produced from heavier crop residues, improving soil tilth and water infiltration.
- **Soil rooting volume is increased,** enlarging the area from which water can be extracted.
- **Vigorous plants** have greater resistance to diseases and nematodes and can compete with weeds.
- **Earlier maturity** can avoid heat and moisture stress during the critical pollination period for corn and other crops.

Moisture Level Affects P Uptake

Drought reduces plant uptake of P. Water films around soil particles become thin and the movement to roots by diffusion is slowed.

In a Colorado study, high P levels in the soil helped maintain P uptake as soil moisture stress increased.

An Iowa study showed that high stress reduced P uptake, but fertilizing with P increased content 50% **(Table 1).**

Temperature and P Level Affect WUE

Starter P can help overcome slow growth due to cold soil temperatures.

Table 1. Stress and rate of P affect uptake of P by corn.

N	P_2O_5	K_2O	No stress	High stress
----------lb/A--------			------------% P----------	
160	0	50	0.36	0.12
160	160	50	0.32	0.18

Iowa

Vigorous early growth leads to a larger root system, increases WUE and produces higher yields.

Response to P Increases with Low Rainfall

Crop response to P increases under low rainfall. In a long-term experiment in Indiana (18 years) soybeans showed a greater percentage yield increase from P with a lower amount of rainfall for the 12-week period following planting.

In Virginia, although corn yielded much higher in the good years, the percentage increase in yields was much higher with P application in dry years **(Table 2).**

Table 2. P increases corn yield in dry years.

P_2O_5	Good years	Dry years
lb/A	--percentage increase in yield--	
0	—	—
25	57	66
50	71	100
100	63	128

Virginia

P Improves WUE

The amount of effective water stored in the soil is increased when P increases plant growth, including root density and rooting depth. For example, when P increases yield, as shown for alfalfa in **Table 3,** WUE also increases.

PHOSPHORUS increased yield and water use efficiency in this irrigated alfalfa study.

Table 3. P increases alfalfa yield and WUE.

P_2O_5	Yield	WUE
lb/A	tons/A	lb/inch of water
100	8.3	188
200	9.4	213
400	11.2	253
600	11.8	267

Arizona

Looking at this information another way, alfalfa receiving high P produced at a higher yield level for a given amount of moisture in an Arizona study. This is true over a wide range of soil moisture conditions. The relationship held also for cotton responding to nitrogen (N).

Nutrient interactions with P are important to WUE. On a P deficient soil in Montana, N alone had little effect on WUE of wheat **(Table 4).** However, when adequate P was added, WUE increased substantially.

Table 4. N and P increase WUE of spring wheat, fallow—12-year average.

P_2O_5	N, lb/A 0	N, lb/A 40	$NaHCO_3$-P (0-15.2 cm)
lb/A	bu/inch of water		ppm
0	2.4	2.4	5.5
20	2.6	2.6	7.2
40	2.8	3.1	8.9
80	3.0	3.6	13.4
160	3.0	3.6	20.4

Montana

Montana data also indicate that the method of P and N application can have significant effects on wheat yields and WUE **(Table 5).**

Table 5. Deep placement of N-P improves WUE of spring wheat.

N	P_2O_5	Deep placement N-P	Separate application preplant N, P with seed
--lb/A--		---bu grain/acre/inch of water---	
0	0	4.0	4.0
0	60	6.1	5.5
57	60	7.2	5.2
77	60	6.7	5.0

Montana

Deep placement of P and N preplant produced higher yields and better WUE than did preplant N and P applied with the seed. Positional availability and N effects on P availability were probably responsible for these differences.

Summary

- The highest water use efficiency is obtained with higher crop yields.
- Water use efficiency is increased when P increases crop yields.
- High P nutrition clearly helps crops through periods of moisture stress.■

P

Phosphorus Nutrition Improves Plant Disease Resistance

Phosphorus (P) as part of a total plant nutrition program can effectively reduce the incidence and severity of many crop diseases.

PHOSPHORUS (P) improves crop resistance and tolerance to diseases which destroy yield and quality. This protection is due, in part, to the functions of P in plant development. For example, P promotes a rapidly developing root system. It provides the stored energy for driving major plant functions. Plus, P plays a key role in promoting proper seed development.

Root System

A vigorous plant root system is good defense against yield destroying root diseases. Phosphorus promotes rapid root development in young plants growing under adverse moisture and temperature conditions. Disease problems such as root rot of wheat have been reduced by the application of P in several research studies.

Common root rot inflicts heavy losses on both wheat and barley yields. In Canada, application of 100 lb/A P_2O_5 to a low P soil reduced yield losses due to root rot from 15% down to 9% with four varieties of barley. In other studies, applied P reduced disease infection on barley from 42% without P to 21% with applied P.

The severity of wheat root rot can be diminished with proper P nutrition **(Table 1)**. In Canada, scientists report this influence to be greatest on young plants and prior to the heading stage of growth.

Table 1. P application reduces root rot of wheat.

Date in season	Applied P_2O_5, lb/A		
	0	35	50
	--------Diseased Plants (%)--------		
June 28	55	42	31
July 26	92	79	69
August 30	97	92	87

Canada

With cotton, the application of P reduced the severity of *Phymatotrichum* root rot. Under conditions of high nitrogen (N) application P had little effect on the control of this root rot problem.

Stem and Leaf Diseases

Stem and leaf disease problems increase with nutrient shortages and crop stress. As shown in **Table 2,** P and potassium (K) improved soybean yield and reduced pod and stem blight.

Table 2. P and K increase soybean yield and reduce disease.

P_2O_5	K_2O	Yield (2-yr. avg.)	Pod and Stem Blight	Purple Stain
---lb/A---		bu/A	-----------%-----------	
0	0	23	12	14
400	0	26	8	11
0	400	36	1	5
400	400	39	0	4

Virginia

Septoria leaf blotch on wheat was reduced nearly 20% by applied P and 33% with K. In another study, 60 lb/A of P_2O_5 reduced infection by take-all root rot fungus in wheat from 73 to 58%. Yield increased from 45 to 58 bu/A . . . . more than a two-dollar return for each dollar invested in P.

In a survey of Illinois field research, scientists concluded that on low P soils, applied P reduced cob rot of corn. This influence was noted when the causal organism was *Fusarium*. Other studies reveal that P can diminish the incidence of boil smut of corn.

Best control of leaf and stem diseases on rice results when plant needs for both P and K are provided. Research has shown how P teams with K to reduce bacterial leaf blight on rice. In **Table 3**, P plus K reduced stem rot incidence and maximized the yield of grain.

Table 3. P and K increase rice yield and reduce stem rot.

$N - P_2O_5 - K_2O$ -----lb/A-----	Disease %	Yield Index
0 - 0 - 0	47	100
120 - 60 - 0	69	66
120 - 0 - 60	7	163
120 - 60 - 60	4	187

India

Tobacco leaf disease problems have been reduced with applied P. Examples include a lowering of incidence of downy mildew, blue mold and tobacco leaf-curl virus. Phosphorus had little influence on control of *Cercospora* leaf spot.

Seed yield plus seed quality determines crop value at harvest time. Phosphorus and K helped reduce purple stain, *Cercospora*, in soybean seed **(Table 2)** . . . . one factor leading to dockage at harvest time. Other studies tie sound P nutrition to less shriveled seed and improved seed germination.

With barley, scientists report yield and test weight were improved and fewer thin kernels were noted when P plus K was applied. This effect was noted when the crop was under added stress from barley yellow dwarf virus disease.

A balanced fertilization program is essential for best crop disease resistance. Plants under nutrient stress are more susceptible to disease attack. A shortage of P can reduce crop use efficiency of K and N. Such nutrient deficiency stress can increase plant susceptibility to disease attack.

With sugarcane, P and K reduced the severity of brown stripe disease. In a similar manner, tobacco showed a greater incidence of leaf spot (*Alternaria longipes*) with excess N. Building P and K into a balanced nutrition program reduced this problem.

Correcting P deficiency in rice also helped to minimize blast disease prob-

LEAF RUST on the flag leaves of wheat in a Kansas study showed severe effects without P fertilization. Although P did not cure leaf rust, it enabled plants to better withstand the stress.

THE WHEAT PLOTS fertilized with only N and K yielded 77 bu/A.

THE NPK TREATMENT produced wheat yields of 91 bu/A.

lems. Blast was increased with high rates of P and N . . . . emphasizing the importance of balanced plant nutrition and disease control.

Crop stress brought on by drought, compaction, excess moisture, temperature extremes, physical plant injury and nutrient imbalance serves to lower plant resistance and increase disease problems. A balanced fertilization program along with other best management practices helps keep disease problems to a minimum.■

P

Phosphorus Improves Crop Quality

Improved crop quality is a benefit of phosphorus (P) which may be overlooked. Quality factors include maturity, winterhardiness, sugar content, feed value, or reduced disease loss for various crops.

HIGHER CROP QUALITY from phosphorus (P) fertilization is a bonus on top of higher yields. Phosphorus improves crop quality in many ways: less grain drying expense, higher sugar content, less disease loss, improved winter survivability, less dockage, a greater proportion of marketable yield, better feed value, and improved drought resistance.

Lower grain moisture of corn at harvest is an added plus of P fertilization often overlooked.

It is easy to see corn maturing faster. However, another important benefit of P fertilization is a lower drying expense. An example from Ohio, shown in **Table 1,** demonstrates this well.

Table 1. Phosphorus increases corn yields, reduces grain moisture and cuts drying costs.

P_2O_5 Rate lb/A	Corn Yield (15.5% moisture) bu/A	Grain Moisture %	Drying Cost Saved[1] $/A
0	145	27.0	—
20	158	26.0	3
40	169	25.5	5
80	174	24.6	8
120	179	24.2	10
Response to P	34	2.8	

Ohio

[1]Assuming 2¢ for each percent of moisture removed per bushel.

Phosphorus increased corn yield by a profitable 34 bu/A, while reducing grain moisture by nearly 3%. This translated into a savings of $10/A, assuming a drying charge of 2¢ for each percent of moisture removed per bushel.

A higher sugar content was the result of P fertilization of sugarcane in a Louisiana experiment.

Improved survival of winter barley was a quality benefit of P found by New York researchers. The initial level of soil P played a major role in determining barley yield. Direct applications of fertilizer P could not compensate completely for a low-P soil, as shown in **Table 2.**

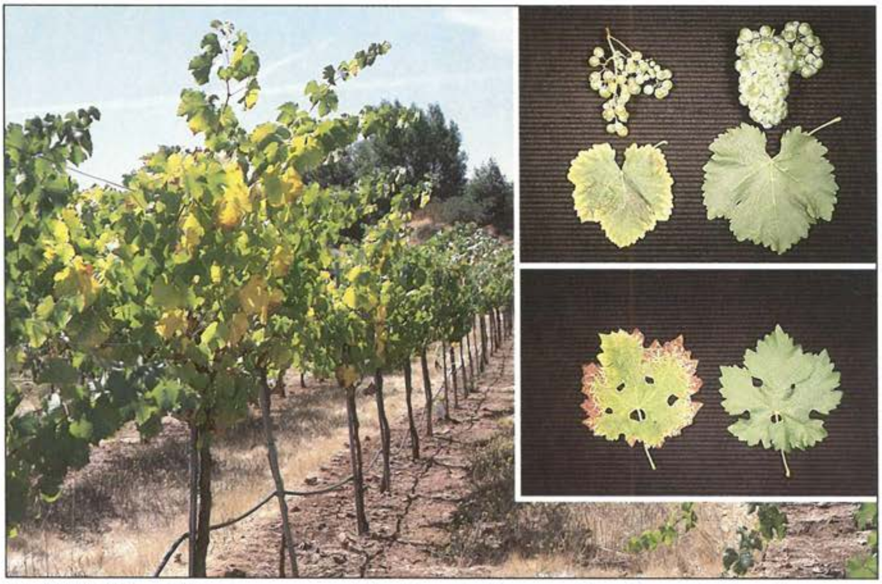
Table 2. For best survival of winter barley both a higher soil test P level and applied P are needed.

Applied P_2O_5 lb/A	Initial Soil P Level: Low	Medium	Medium-High	Response to Soil P
	----% plant survival----			%
0	17	43	79	62
20	33	59	81	48
40	35	59	84	49
80	45	63	92	47
Response to Applied P	28	20	13	

New York

In Manitoba, P increased winter survival of zero-tilled wheat. Without P, 60% of the plants survived compared to 74% survival with 45 lb/A of applied P_2O_5. In Alberta, 40 lb/A of P_2O_5 improved the cold hardiness of winter wheat crowns; the temperature causing 50% mortality was 11.3° F without the P_2O_5, compared to 7.2° F with the P_2O_5.

Virginia workers found that in addition to raising soybean yields, germination and the percent of sound seed were improved by 120 lb/A of P_2O_5 **(Table 3).** A 400 lb/A rate in a separate study reduced purple seed stain of soybeans by 6%.



PHOSPHORUS deficiency may result in stunted vine growth and poor fruitset in grapes.

Table 3. Phosphorus increases soybean yield and improves seed quality.

	P_2O_5, lb/A 0	120	Yield/Quality Response to P
Soybean Yield, bu/A	32	41	9 bu/A
Sound Seed, %	70	80	10%
Germination, %	85	95	10%

Orange quality and total marketable yield were improved by P in Arizona research. Several important characteristics of orange production were affected.

- Percent juice by weight was increased by 7%.
- Solid-acid ratio was reduced by 7%, indicating a sweeter fruit.
- Marketable fruit yield was increased by 16%.
- Peel thickness was reduced by 8%.
- Fruit culled by weight was reduced by 12%.

The P content of wheat is an important quality factor because it affects the grain's worth as an animal feed. Wheat grown in Saskatchewan, for example, often tests below the minimum P requirement for animal feeding. Researchers looking for ways to elevate wheat grain's P content to acceptable levels found that residual soil P was more effective than P applied with the seed at planting **(Table 4).** The benefit from the residual P persisted for eight years.

Table 4. Effect of residual P applications and applied P on raising the P content of wheat grain.

P applied with seed lb/A P_2O_5	Residual P lb/A P_2O_5 0	820	Response to residual P
	------Percent P in grain------		
0	0.31	0.40	0.09
102	0.35	0.41	0.06
Response to applied P	0.04	0.01	

Improved drought resistance is another quality benefit of P fertilization. In Ohio research, a good year was followed by a year of greater heat and moisture stress. The P in the stress year boosted soybean yields by 6 bu/A, compared to no yield increase in the good year.■

P

Phosphorus Interactions with Other Nutrients

Phosphorus (P) fertilization practices develop soil reservoirs of the nutrient to supply crops with their P needs even during peak demands of the crop. This can set the stage for other inputs such as early planting, improved varieties, higher populations or other essential nutrients to be or become yield limiting factors. Phosphorus is affected by or affects the availability or utilization of many other nutrients. The effect of P on other nutrients or practices or the effect of other nutrients or practices on P are interactions.

AN INTERACTION OCCURS when the response of one or a series of factors is modified by the effect of one or more other factors. As stated by one soil scientist, an interaction occurs when two factors are limiting or nearly limiting growth and the addition of one of these has little effect on growth. But when both are added together, there is a considerable effect on growth and yield of the crop. These interactions can be positive or negative.

Positive interactions of P with other essential nutrients have been evaluated in many research studies on many crops. Certain crop production practices along with environmental conditions can serve as indicators when nutrient interactions might occur:

- Higher crop yields place greater stress on soil nutrient reserves to supply nutrients in greater amounts and in some instances at a higher rate.
- Liming of acid soils alters nutrient availability to growing plants. Liming can improve P availability, but alter availability of other nutrients, especially most micronutrients.
- Buildup soil fertility programs provide major nutrient needs and set the stage for micronutrients to become the next yield limiting factor.
- Changes in the nutrient status of the root zone can result from land leveling, deeper tillage, minimum tillage, and/or loss of topsoil through erosion.

Nutrient Interactions with Phosphorus

Nitrogen (N). Several N/P interactions exist. The primary effect of banded placement of N and P fertilizers is greater P uptake because of increased P solubility. Ammoniacal-N fertilizers increase P availability, thereby increasing growth and yields.

Examples of positive N/P interactions are shown in **Tables 1 and 2.**

Table 1. N/P interaction affects corn yield.

N lb/A	P_2O_5 lb/A	Yield bu/A	Increase bu/A
0	0	41	—
200	0	50	9
0	160	58	17
200	160	123	82

Illinois

Table 2. N/P interactions affect dryland wheat yields and profits.

N lb/A	P_2O_5 lb/A	Yield bu/A	Prod. costs $/A	Prod. costs $/bu	Net return $/A
0	0	32	98	3.06	14
30	0	42	106	2.52	41
30	30	45	114	2.53	44
60	0	38	112	2.95	21
60	60	58	123	2.12	80

Colorado

Low soil test P. N, 20¢/lb; P_2O_5, 22¢/lb; wheat $3.50/bu.

Potassium (K). There are few reported cases of a P/K interaction, but research illustrates the positive effects of balancing P and K to eliminate them as limiting factors and to produce a positive interaction.

Table 3. Positive P/K interactions can make a difference with soybeans.

P_2O_5 lb/A	K_2O lb/A	Yield bu/A
0	0	24
30	0	26
0	120	37
30	120	45

Virginia

Table 4. P and K work together for higher wheat yields (average of two varieties).

P_2O_5 Rate, lb/A	K_2O, lb/A: 0	40	80
	Yield, bu/A		
0	52	64	64
30	78	84	87
60	77	88	91

Kansas

With Tilt fungicide. Low P and K soil test. N, 75 lb/A.

Table 5. Positive P/K interaction increases Coastal bermudagrass yields.

P_2O_5 lb/A	K_2O lb/A	Yield lb/A
0	0	5,375
0	300	5,294
100	0	6,510
100	300	9,146

Texas

Sulphur (S). Research in California illustrates the effects of a positive P/S interaction on increased forage production and the resulting improved animal performance due to improved yields and nutritive value of the forage. Phosphorus alone did not increase lamb gain significantly, but the P/S interaction greatly increased production.

Micronutrients. Phosphorus interactions with micronutrients have been reported on a wide variety of crops. Interactions with P have been reported for

INTERACTION of P/S increased forage production and boosted lamb gains in California research.

Table 6. P/S interaction improves lamb gain.

Fertilizer treatment	Lamb gain: 7 yr, lb/A	From fert, lb/A
Check	1,170	0
S_1	1,816	646
P	1,571	401
P_1S_1	1,946	776
P_3	1,595	425
P_3S	2,035	865

California

boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Soils with high soil P levels (naturally or through buildup) should be monitored for a possible micronutrient interaction.

• **Boron.** Phosphorus/B interactions caused a reduced B absorption by corn seedlings grown in an acid soil high in P. However, strawberries gave no significant interaction between P and B.

• **Copper.** Phosphorus/Cu interaction was found when high levels of P accentuated an acute Cu deficiency in citrus seedlings. However, Cu and Zn solubilities can be increased by high levels of P fertilization. This interaction is believed to occur at the site of absorption . . . possibly with Cu precipitation at the root surface. In other studies,

(continued on next page)

Interactions...from page 27
applied P reduced the effect of toxic levels of Cu. Excess Cu can decrease P and Fe absorption.

• **Iron.** Phosphorus/Fe interaction showed up in bush beans grown in either an excess or deficient level of soil P. In either case Fe absorption was reduced. On high Cu soils, P can enhance Cu depression of Fe uptake. The effects of P and Cu were additive. Both corn and rice, grown on soils containing excess Cu, exhibit severe Fe chlorosis. Heavy P fertilization is often recommended under such circumstances.

• **Manganese.** Phosphorus/Mn interactions can develop when soil Mn availability increases with higher soil P levels. On some soils this is believed partially due to increased soil acidity from high rates of P.

• **Molybdenum.** The P/Mo interaction depends upon whether the soil is alkaline or acidic in nature. For acidic soils, P increases Mo uptake while reducing Mo uptake on alkaline soils. The increase with acidic soils is believed to be the result of enhanced absorption and translocation due to the $H_2PO_4^-$ ion.

ADDED fertilizer P without supplemental Zn (on a low Zn soil) can make Zn deficiencies more severe. Plants on the left received P, no Zn. Those on the right received both P and Zn. Soil analyses can readily predict this problem.

• **Zinc.** Phosphorus/Zn interactions can reduce Zn absorption when P availability is increased.

Research indicates the tendency of P to depress Zn nutrition is physiological in nature and not due to inactivation in the soil.

Nutrient accumulation studies in corn have found P and Zn uptake, translocation, and deposition patterns to be quite similar.

In high yield environments, negative interactions among micronutrients can become severe. Results on corn in Kansas given in **Table 7** illustrate how negative responses can be turned to positive interactions with proper fertilization.

Table 7. Turn negative responses on corn into positive interactions.

P_2O_5 lb/A	Zn lb/A	Yield bu/A
0	0	131
80	0	119
0	20	109
80	20	175

Kansas

Phosphorus/Zn interactions can be dramatic, but can easily be avoided by soil testing. Zinc deficiencies are readily detected by soil analyses and corrective Zn fertilization is simple and effective.

Agronomic Significance

Crop response to applied P varies with time, rate and method of application. It varies with soil physical and chemical properties—with high yield management practices—and is affected by factors which restrict plant growth, such as nutrient deficiencies. Nutrient interactions have been noted for cereals, vegetables, tree, specialty and row crops.

Early diagnosis of deficiencies of P and/or other nutrients can help minimize losses in crop yield—in crop quality—and in farm profits. In-field inspection along with soil and plant analyses will help provide needed facts for immediate correction and next-season planning.■

P

Phosphorus and the Environment

Phosphorus (P) is essential for all life and without it profitable agriculture would be impossible and food production inadequate. While the essential nature of P is unquestioned, there is some concern that P can be lost to the environment through improper use.

THE LOSS of phosphorus (P) to the environment is almost totally associated with erosion or soil movement. Research has shown that P is extremely immobile in the soil. It is adsorbed very strongly by surfaces of iron, aluminum and manganese oxides and hydroxides.

Since P is adsorbed by clay particles, it essentially stays close to where applied—unless the soil particles move. Dr. Jerry Mannering, Purdue University says, "If sediment loss is stopped, there is essentially no problem with P and potassium (K) losses on most soils. Erosion is a culprit, not applied P and K."

When good tillage and soil conservation practices are combined with adequate fertility and other input management practices, the loss of P is minimized. **Table 1** shows the comparison of a conventional crop management system with a conservation system plus higher P fertility.

Table 1. Comparison of soil loss and P loss by tillage system and crop.

Crop	System	Runoff in./yr	Soil loss lb/A/yr	P loss lb/A/yr
Corn	P[1]	5.11	6,300	2.56
	C[2]	2.25	1,490	0.75
Soybeans	P	5.57	8,430	3.41
	C	3.74	3,340	1.72

[1]P = prevailing system: plowing, row planting and cultivation

[2]C = conservation system: contour planting and cultivation, higher fertility, liming to pH 6.5.

An estimated 50% of the soil loss due to erosion in recent years occurred on 10% of the nation's cropland. This suggests big gains could be made in controlling erosion by stopping crop production on these few very erosive acres or by putting intensive erosion control measures in place on them.

Fertilizer P Use

Based on USDA statistics, crops produced in the U.S. took up more P than was applied to the soil each year since 1980. **Table 2** compares soil test P levels in 1979-80 to 1986-87 for selected states.

Table 2. Soil test P ratings for selected states.

State	Percent Medium or Less for P 1979-80	1986-87
Nebraska	69	69
Minnesota	34	33
South Dakota	59	76
Georgia	56	54
Oregon	32	49
Ohio	45	38
Colorado	70	66
North Carolina	37	37
Michigan	31	28

While some soils have been built to high P levels, there is a significant number of soils testing in the medium or less range. Many of these soils need good production management and the use of buildup applications of P, in addition to the annual maintenance rates, to help assure a profitable yield level and the most efficient use of nitrogen (N) and other inputs.

Adequate P Increases N Efficiency

Nitrogen is a potential environmental problem if excessive amounts of nitrate-N enters water supplies. As with P, good management can help avoid such problems.

(continued on next page)

CROP PRODUCTION methods which minimize soil erosion and improve water use efficiency are key to avoiding negative environmental impact from P.

For example, when recommended fertilizer P is applied N use efficiency is increased. **Table 3** is an example of this favorable environmental impact on wheat.

On a medium testing P soil, each rate of P used increased N efficiency. At the low P level, the unused N would be subject to leaching or denitrification and presents an environmental risk to groundwater. Similar observations can be cited for corn, cotton, rice—or any crop requiring N fertilizer and where a yield response to P is expected.

P and Water Use Efficiency

One issue often raised is the impact agriculture has on water availability and use. When adequate P is used in conjunction with the best management of other controllable inputs, the benefits of a lower unit production cost are combined with the benefits of a crop which uses water more efficiently.

Here's how P works for water use efficiency:

- Reducing evaporation from soil surfaces and erosive energy of raindrops due to an earlier, fuller crop canopy.
- Producing more crop residue that reduces water loss and soil erosion and increases water infiltration.
- Improving soil tilth and water infiltration by building soil organic matter.
- Enlarging root volume and improving exploration of the soil for nutrients and water.
- Shading out weeds and improving resistance to diseases and nematodes through more vigorous growth.
- Speeding maturity.

Table 3. Adequate P increased wheat yields and improved N use efficiency in Kansas.

N	P_2O_5	Yield	N Efficiency	N: Soil Supplied (–); Unused (+)[1]
-------lb/A-------		bu/A	bu/lb N	lb/A
75	0	35	.46	+ 9
75	20	51	.68	– 21
75	30	56	.75	– 30
75	40	61	.81	– 40
75	50	64	.85	– 45

[1] N lb/A applied was less than (–), or more than (+), uptake in aboveground portion of crop.

Phosphorus Efficiency and Interacting Growth Factors

Any growth factor given optimum management to increase yield also enhances efficiency of P.

Management strategies must be in place for each controllable growth factor to assure they are at an optimum level and in balance with one another, to achieve the most efficient and profitable yield for a given field. The result is most efficient yield (MEY) or the optimum possibilities for returning a profit while reducing the possibility of an unfavorable environmental impact.

Research results for corn in several locations are compiled in **Table 4**. The results indicate the impact that various growth factors can have on increasing yields and the efficiency of P.■

Table 4. The effects of several production inputs on corn yield and fertilizer efficiency (from various locations).

Production Factor	Yield	Efficiency P_2O_5	Efficiency N	N Balance Sheet[1] Soil (−); Unused (+)	State
	bu/A	--bu/lb--		lb/A	
Rotation:					
continuous	105	2.10	0.88	+ 14	North
rotation	120	2.40	0.96	− 6	Carolina
Irrigation:					
without	127	1.02	0.51	+ 85	New
with	214	1.71	0.86	− 28	Jersey
Planting Date:					
late May	132	1.32	0.66	+ 28	
early May	163	1.63	0.86	− 12	Indiana
Hybrid:					
bottom 5	149	0.99	0.60	+106	
top 5	250	1.67	0.83	− 25	Florida
Population:					
low (12,000)	155	1.44	0.52	+ 39	
high (36,000)	231	2.14	0.96	− 60	Florida
Compaction:					
compacted	123	2.46	0.62	+ 33	
not compacted	167	3.34	0.84	− 17	Indiana
pH x P:					
low pH, low P	90	—	0.60	+ 33	
best pH, high P	138	1.97	0.92	− 29	Wisconsin
P Placement (row):					
No P_2O_5	143	—	0.64	+ 39	
35 lb P_2O_5	159	4.54	0.71	+ 18	
70 lb P_2O_5	165	2.36	0.73	+ 11	Wisconsin

[1]lb of N applied per acre was less than (−), or more than (+), uptake in aboveground portion of crop.

P

Effects of Phosphorus on Crop Maturity

The influence of phosphorus (P) on crop maturity is often an added bonus to its effect on increasing yields. For example, early maturing fruits and vegetables almost always demand a premium in the marketplace. In multiple cropping, a few extra days can mean a significant difference in the relative success of the system.

THE INFLUENCE of phosphorus (P) on crop maturity has been observed by many researchers on a variety of crops.

Placement of P can influence early growth, its effects often carrying through to earlier maturity. In Indiana, 80 lb/A P_2O_5 banded resulted in a 15 bu/A corn yield increase over broadcast and 1.5% less moisture in the grain at harvest. In Alabama, on grain sorghum, there was a maturity advantage for in-row starter containing P compared to beside-row application. Both advanced maturity over the zero starter treatment.

In one study, P fertilizer reduced grain moisture in corn at harvest by as much as 7%. In another, maturity was hastened, even on those soils where initial soil P levels were high and no yield increase was observed.

Researchers in Illinois found that earlier corn silking and lower moisture contents were associated with P fertilization. **Table 1** shows the effects on silking, as measured by degree-days.

Seed-placed phosphate, applied at the rate of 40 lb/A P_2O_5, hastened grain sorghum maturity an average of four days at nine locations in the Texas Blacklands. Seedlings had more vigor, and the rapid early growth made it possible to cultivate earlier, resulting in better mechanical weed control. Results are shown in **Figure 1.**

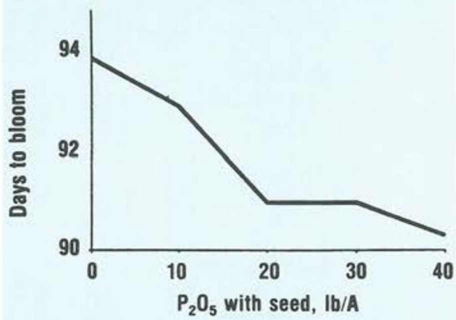


Figure 1. Effects of P applied with seed on maturity of grain sorghum.

Research in Oklahoma suggests that P speeds maturity of wheat by as much as four to seven days. Similar results have been observed in Kansas and Texas. In New York, late-planted wheat and barley ran 6% higher in moisture without P fertilization at the time the P fertilized plots were ready to harvest.

Table 1. Effect of P_2O_5 on degree-days (F) between corn emergence and silking.

N and P_2O_5 Applied, lb/A	P soil Test Levels, lb/A	Degree-days (F) Between Emergence and Silking: Early Planted	Late Planted
300-0	50	1,482	1,446
300-20	80	1,398	1,419
300-100	263	1,398	1,356

PHOSPHATE STARTER fertilizer hastened growth and maturity of the corn plot on the left above. The effect resulted in a significant yield increase compared to the plot at right where no starter P was applied.

In a Louisiana study, P fertilization hastened grain maturity and yield of wheat following rice and one year following rice, **Table 2.**

Table 2. Influence of P fertilization on wheat grain maturity and grain yield.

	Wheat Immediately Following Rice		Wheat One Year After Rice	
P_2O_5 lb/A	Days to Maturity	Relative Yield, %	Days to Maturity	Relative Yield, %
0	151	68	150	79
25	150	86	149	86
50	149	97	148	93
100	148	100	147	100

Phosphorus fertilization hastened cotton maturity by increasing yield of first pick at several locations in Arkansas. In addition, P increased total seedcotton yields. In Alabama starter fertilizer containing P increased early season plant height by 14% over the no starter treatment and boosted first pick yields by 4 to 5%.

Canadian researchers found that P fertilization advanced the maturity of green peas. Maturity of cauliflower was slightly delayed by a lack of P. In Texas, fertilizer P hastened first bloom in tomatoes by as much as 10 days or more. Broadcast treatments were less effective in promoting early bloom, **Figure 2.**■

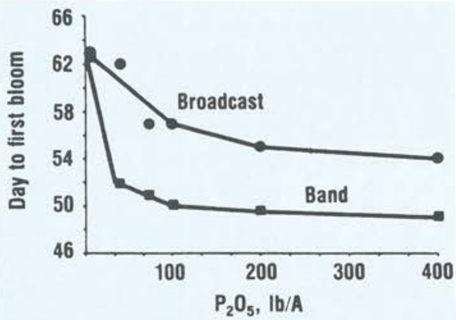


Figure 2. Influence of P rate and placement on time to first bloom of tomato plants.

P

Phosphorus for International Agriculture

As world production of food, feed and fiber increases, adequate phosphorus (P) fertility will be essential.

ALMOST 500 MILLION PEOPLE are undernourished in the world, according to FAO estimates. That number is expected to reach 600 million by the year 2000. Maintaining present nutritional standards for the world's population will require a 50% increase in food production as the population increases from 4.3 billion to an estimated 6.2 billion.

FAO estimates that approximately 25% of increased food needs can be obtained by increasing the area under cultivation, and 15% from increased multiple cropping. About 60%, however, must come from increased yields on existing lands. Low phosphorus (P) availability in many areas of the world will be a restriction in achieving needed higher yields for future.

Soil Resources

Drought, nutrient stress and shallow soils dominate the world's soils as major limitations to crop production. Many of these restrictions to crop production will be difficult to solve. Although nutrient stress is a serious constraint for improved crop production throughout the world, it is one of the few soil limitations that agriculturalists can moderate.

Fixation of P in medium to fine-textured acid soils by oxides and hydroxides of iron (Fe) and aluminum (Al) is a serious problem. Some tropical soil groups are noted for their high P fixation capacity. Research has shown that some acid soils can fix twice as much P as neutral or calcareous soils with about five times more bonding energy.

Fertilizers can be considered as one key to raising the nutritional levels of people living in tropical regions. Many elements are necessary for increased agricultural production of food crops, including nitrogen (N), potassium (K), sulphur (S), magnesium (Mg), calcium (Ca) and various trace elements. But it is commonly accepted that P is one of the main limiting factors in tropical regions.

Researchers from many countries have noted the severity of low P availability.

India. About 98% of the soils in India contain insufficient P for achieving maximum crop yield potentials.

Previous soil fertility surveys have shown that 42% of the soils tested are low, 56% are medium and only 2% are high.

Bangladesh. Based on soil analyses and greenhouse studies, an estimated 75 to 80% of the soils of Bangladesh are deficient in P.

Latin America. In Brazil P deficiency is widespread in most soils, and P fixation is a serious problem.

From 50 to 80% of soils tested in Bolivia are rated as low in available P. The Latin American tropics are highly dependent on P fertilization and P fixation in acid soils is one of the most important problems. It is responsible for the lack of development of large zones of arable lands which are not being utilized.

The development of an economically viable agriculture has been inhibited in tropical South America by acid soils which produce conditions of high phosphate fixation and extreme P deficiency.

West Asia and Africa. Phosphorus is one of the major nutrients limiting crop production in Nigeria's savanna zones.

The soils of West Asia and North Africa are highly eroded in places and generally poor in organic carbon and low in available P.

Southeast Asia. Phosphorus deficiency is widespread in the soils of Southeast Asia and P fertilizer requirements are high for the highly weathered soils of this region.

China. Low P availability in the acid soils south of the Yangtze River is generally more severe than in the neutral and calcareous soils in northern China.

Most soils in China require P fertilization for optimum yields. A few lacustrine and alluvial soils and paddy soils where relatively large amounts of P have been applied over long periods of time have adequate P status for current yields. Due to a high fixation capacity, especially on the acid soils of South China, continued applications of P will be necessary.

Crop Responses to P

"Missing element" studies (CIAT) showed that when P is missing from a complete nutrient ratio, relative yields of plumieri were only 16% of optimum yields. Low availability of other nutrients such as S, boron (B), Ca, N, K and copper (Cu) also significantly reduce yields.

In Colombia, researchers found large yield responses of field beans over three growing seasons following initial applications of P_2O_5 ranging from zero to 1,960 lb/A. The researchers indicate that 350 to 450 lb P_2O_5/A should be applied if one application is made, but also suggest considerations for applying a less soluble P source as annual application.

FAO data show varied crop response to P in diverse regions of the world. Large responses were noted for some crops: cassava and yam in West Africa; maize and sorghum in South and East Africa; rice in Latin America; cassava, groundnuts and rice in the Far East.

P Sources

Much debate still surrounds the use and evaluation of various P sources. Solubility and residual effects of P sources should be considered for the climates, crops, and soils on which these sources will be used. The final criteria for selecting the nutrient source must be based on sound economic analysis considering yield, quality, and other factors.■

LOW AVAILABILITY of phosphorus (P) is a limitation of soils in many regions of the world. The increased growth shown here for soybeans in Brazil is due to P.

P

Phosphorus in Animal Nutrition

Phosphorus (P) is an essential nutrient for all animals. In the animal body, about 80% of the P is found in the skeleton; P constitutes 22% of the mineral ash. Phosphorus deficiency is the most prevalent deficiency of cattle and sheep in the United States. Phosphorus must be balanced in the animal and human diet with adequate calcium and vitamin D for growth, reproduction, gestation and lactation.

IN THE ANIMAL BODY about 80% of the phosphorus (P) content is found in the skeleton.

The remainder is widely distributed throughout the body in combination with certain proteins and fats and as inorganic salts.

Phosphorus constitutes 22% of the mineral ash in the adult body, or 1% of body weight. Its major role is a constituent of bones and teeth.

Phosphorus is essential in proper transfer and utilization of energy. Phosphorus is present in every living cell in the nucleic acid fraction.

Calcium (Ca) and P are closely associated with each other in animal metabolism. They occur combined with each other for the most part, and an inadequate supply of either limits the nutritive value of both.

Adequate Ca and P nutrition depends on three factors: (1) A sufficient supply of each element; (2) A suitable ratio between them; (3) The presence of vitamin D.

These factors are interrelated. The desirable Ca:P ratio is between 2:1 and 1:1.

Adequate nutrition is possible outside of these limits. With adequate vitamin D, the Ca:P ratio becomes less important, and more efficient utilization is made of the Ca and P.

A liberal supply of Ca and P is essential for lactation. Calcium and P make up about 50% of the ash of milk.

In the absence of vitamin D, assimilation of Ca and P is poor even though the other factors are optimum.

Earliest symptoms of P deficiency are decreased appetite, lowered blood P, and reduced rate of gain. If severe deficiency occurs, the symptoms may include "pica," when animals have a craving for unusual foods such as wood or other materials.

Milk production decreases with P deficiency, and efficiency of feed utilization is depressed.

Long-continued P deficiency results in bone changes, lameness, and stiff joints.

Cattle and Sheep

Young and growing animals require more P than do mature ones.

Gestating and lactating animals need more P than other classes of mature animals.

Supplemental dietary P is needed under many practical feeding situations.

Phosphorus is critical for reproduction. In Arizona tests, P increased rebreeding efficiency. See **Table 1.**

Table 1. Phosphorus increases rebreeding efficiency in cattle.

P level in ration, lb	Conceived Cows, % 1st service	2nd service	Open
.080 (150% NRC rec.)	89	11	0
.054 (NRC rec.)	59	35	6

Arizona

Phosphorus apparently enhances reproductive performance at several stages in the reproductive cycle. Irregular estrous periods are associated with moderate P deficiency, infertility with marginal P levels, and anestrus with low P levels. See **Table 2.**

Table 2. Phosphorus enhances reproductive cycle in cattle.

Group	Days between calving and 1st estrus	% cows in estrus, post-calving
Control	74.9	50
P supplemented	62.4	70

Australia

In Texas tests, 64% of the control cows produced a calf on range alone compared to 85% of the cows on range plus P supplement. Pica appetite was observed in the control cows. Results in **Table 3** show P effects on calf weaning weights in a different study.

Table 3. P increases calf weaning weights.

Group	lb weaned calf/A
Control, no supplemental P	93
Bonemeal supplement	116
Disodium phosphate in drinking water	143
P fertilized range	176

Texas

Poultry

Hens use most of their P in bodily functions other than egg production. But adequate P is important to achieve a high rate of egg production.

Phosphorus deficiency causes lower body weight and reduced feed efficiency.

Low diet P can depress egg hatchability, but P content of the egg is not altered.

Caged layer hens require high P, more than hens on litter.

"Cage layer fatigue syndrome" is caused by low P levels in diet. There is a high death rate.

Much work on recommended P levels has found National Research Council (NRC) recommendations to be sound and adequate.

Swine

Phosphorus requirements of swine are similar to those of other animals.

There are wide variations in the estimates of dietary P needs. Explanations for differences are varied. The major factor relates to criteria of response.

Recommended levels of dietary P set by a survey of swine nutritionists are higher than levels developed by NRC because of recognized variability in biological activity of P sources and greater variability in estimates of requirements. This is particularly true for gestating and lactating sows.

Furthermore, it seems wise to formulate for the above-average gaining animal and the higher milk producer rather than for the average one.

Horses

The Ca and P requirements of horses have received considerable attention; Ca and P are essential for strong bone development, proper mineralization of osteoid tissue and adequate energy utilization.

The Ca:P ratio should be monitored when P intake is greater than Ca and low Ca utilization from feedstuffs occurs. Calcium: P ratios of 6:1 do not appear detrimental to mature horses if P intake is adequate. Foals and yearlings have been fed Ca:P ratios of 3:1 with no problems.

Dogs and Cats

Low P diets seldom occur in properly fed pets. However, animals require adequate Ca and P in their diets to ensure strong bones and teeth and good muscle development. A P deficiency in puppies causes rickets and poor growth. In cats a high meat diet can cause an imbalance of Ca to P, because meat is high in P.

Goats

Phosphorus is required for tissue and bone development. A deficiency will result in pica symptoms. The Ca:P ratio should not drop below 1.2 to 1.0. ■

PLANT FOOD UPTAKE

(At various yield levels, per acre)

lb/A	CORN			SOYBEANS*			WHEAT		
	120	160	200 bu	40	60	80 bu	40	80	100 bu
N	160	213	266	224	315	416	75	166	188
P_2O_5	68	91	114	38	58	78	27	54	68
K_2O	160	213	266	144	205	250	81	184	203
Mg	39	52	65	16	24	32	12	24	30
S	20	26	33	14	20	26	10	20	25

	COTTON (LINT)			GRAIN SORGHUM			POTATOES		
	750	1,125	1,500 lb	6,000	8,000	10,000 lb	300	600	900 cwt
N	105	143	180	178	238	297	150	300	450
P_2O_5	45	54	63	63	84	105	48	96	144
K_2O	65	96	126	180	240	300	270	540	810
Mg	17	26	35	30	40	50	24	40	72
S	15	23	30	28	38	47	14	27	41

	ALFALFA*			CLOVER*-GRASS			HYB. BERMUDAGRASS		
	4	6	8 tons	3	6	7 tons	6	8	10 tons
N	225	338	450	150	300	350	258	368	460
P_2O_5	60	90	120	45	90	105	60	96	120
K_2O	240	360	480	180	360	420	288	400	500
Mg	20	30	40	15	30	35	18	26	34
S	20	30	40	15	30	35	30	44	58

RESEARCH PPI EDUCATION

*Legumes get most of their nitrogen from the air.

Figures given are total amounts taken up by the crop in both the harvested and the above-ground unharvested portions. These numbers are estimates for indicated yield levels, taken from research studies, and should be used only as general guidelines.

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Phosphate Deficiency Symptoms in Corn

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PHOSPHATE shortages interfere with pollination and kernel fill. Ears are small, often are twisted and with undeveloped kernels.

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WE TAKE FOR GRANTED many of the great natural riches of North America—fresh air, water, good soil, fine climate—and remarkable people.

We do recognize our wealth in resources such as oil, coal, timber, and metals.

But how many of our people realize how fortunate we are to have supplies of phosphorus that are adequate for many years to come?

So what is so great about phosphorus? It is absolutely essential for all plant and animal life! We can live without diamonds or computers, but not without food—and that means phosphorus as a crop nutrient.

Research shows that many of the soils of the world are entirely too low in phosphorus for production of good yields of quality fruits, vegetables, fiber and forage. How lucky we are to have not only the phosphorus deposits, but an old and dedicated industry that supplies the needs for this important nutrient.

This phosphorus industry has long recognized its responsibility—its obligation to the people of the world. Through the Potash & Phosphate Institute (PPI), industry supports research and educational programs that are designed to promote the use of phosphorus where needed and in amounts that improve the environment and are profitable for the farmer.

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—J. Fielding Reed

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