# Best Management Practices

# Agricultural Phosphorus Management

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In association with: Colorado Department of Agriculture and the
Agricultural Chemicals and Groundwater Protection Advisory Committee

The authors and the Colorado Department of Agriculture gratefully acknowledge the extensive input and leadership of the Agricultural Chemicals and Groundwater Protection Advisory Committee, representing production agriculture, agricultural chemical dealers and applicators, the green industry, and the general public.

With cooperation from: Colorado Department of Public Health and Environment
USDA Natural Resources Conservation Service – Colorado State Office
Colorado State University Department of Soil and Crop Sciences


Special acknowledgments to the original BMP Technical Review Team:

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Phosphorus (P) is an essential nutrient for all forms of terrestrial life and is one of the 18 chemical elements known to be required for plant growth. In Colorado, agricultural soils generally contain from 800 to 2,000 pounds of total P per acre in the tillage layer. However, most of it is in insoluble compounds unavailable to plants. The remainder cycles within plants, animals, soil, and the soil solution in biologically available forms and organic P compounds. A simplified P cycle is depicted in Figure 1, showing the principal P inputs and sinks. In production agriculture, fertilizer and manure are the major P additions to this cycle. Without these inputs, intensive commercial agriculture would not be viable on many soils. However, proper management of soils and P fertilizers is essential to protect water quality from degradation.

Water quality problems associated with P are generally confined to surface water. Phosphorus in most Colorado soils is tightly held to soil particles and does not leach to groundwater. However, the P held in organic phases from residues such as manure can dissolve in water and be lost if improperly managed. Adsorbed P on soil particles can cause surface water contamination as P containing sediments move off the land in agricultural runoff. When large amounts of nutrients enter lakes and streams, they accelerate the natural aging process, or eutrophication, by enhancing the growth of algae and other aquatic weeds. As these plants flourish, depleted oxygen and light reduce the survival of more desirable species and the natural food chain declines. Eventually, impounded waters such as lakes, ponds, and reservoirs become overgrown with aquatic vegetation and, in a sense, die.

Insufficient phosphorus (P) in crop fields can cause deficiency symptoms and reduce yield (left image). Excess P can cause water quality degradation if runoff reaches water bodies (right image).

## The BMP Approach

Phosphorus is a nutrient that can impair surface water quality if concentrations reach certain thresholds. In Colorado, phosphorus in surface water is regulated by the Department of Public Heath & Environment (CDPHE) under Regulation 85 adopted in 2012. This regulation established mandatory discharge limitations for point sources such as wastewater treatment plants. In contrast, nonpoint sources of nutrients such as agriculture are encouraged to adopt voluntary measures or Best Management Practices (BMPs) to address off field losses for the first 10 years of this regulation. Voluntary adoption of BMPs by agriculture is critical to prevent contamination of water resources and improve public perception of the industry. In addition, there is potential for regulation of some agricultural practices if voluntary approaches are deemed insufficient. Adopting BMPs now can help agriculture maintain this voluntary approach and keep nutrient management decisions in producer's hands.

BMPs are recommended methods, structures, or practices designed to prevent or reduce water pollution. Implicit within the BMPs concept is a voluntary, site-specific approach to water quality problems. Development of BMPs in Colorado is being accomplished largely at the local level, with significant input from chemical applicators and other local experts. Many of these methods are already standard practices, known to be both environmentally and economically beneficial.

A number of human activities contribute to P movement in our environment through runoff and erosion. Agricultural soils may deliver even larger amounts of P to water when sediments move off of fertilized or manured lands. Feedlot runoff also can contain significant quantities of nutrients.

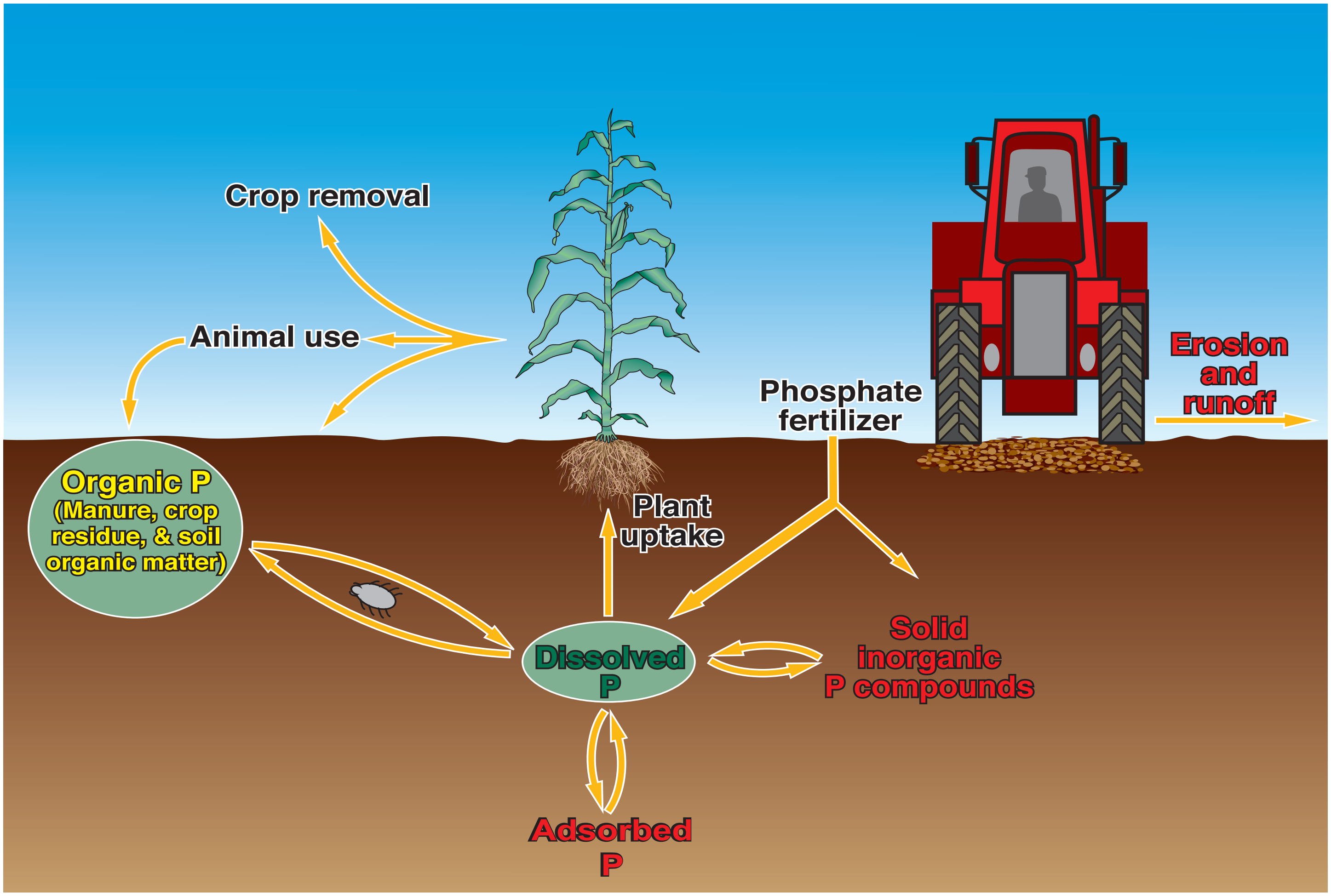


Figure 1. The phosphorus cycle in agricultural soils.

These P losses can be controlled by adopting fertilizer management and erosion control Best Management Practices (BMPs) which eliminate or minimize runoff to surface water. Since P fertilizers are a non-renewable resource and are relatively expensive, efforts to conserve P are justified.

## Phosphorus in Agricultural Soils

When added to soil, P fertilizer undergoes several different reactions, including adsorption on soil particles and precipitation. A number of factors determine the speed and fate of the reactions. They include soil pH, moisture and texture, chemical properties of the soil, and the form of fertilizer used. The net result in most Colorado soils is fixation of P by calcium in to relatively insoluble and unavailable forms. For this reason, recommendations for soils low in available P often exceed actual crop removal (Table 1).

Table 1. Phosphorus removed in harvested crops

| Crop | Yield | P removed per acre (lb $P_2O_5$/A) |
|---|---|---|
| Alfalfa | 4 tons | 40 |
| Corn (grain) | 190 bu | 70 |
| Corn (silage) | 30 tons | 120 |
| Barley | 100 bu | 40 |
| Bromegrass/fescue | 4 tons | 40 |
| Potatoes | 400 cwt | 55 |
| Sugarbeets | 25 tons | 35 |
| Sunflowers | 2,000 lb | 80 |
| Wheat | 100 bu | 85 |

Source: Adapted from BMP for Manure Utilization 568A

Phosphorus is found in both organic and inorganic forms in the soil. The organic forms are found in humus, manures, and crop residues and are important for supplying P to crops. These forms also tend to be more soluble and are subject to movement in the soil solution. Microorganisms break down organic matter in a process called mineralization, converting organic forms of P to plant available inorganic forms. The inorganic ions, $H_2PO_4^-$ and $HPO_4^{-2}$, are the primary forms of P taken up by plants. In general, the inorganic forms of P contained in soil minerals are relatively insoluble and are slowly available to plants.

## Soil Testing

Soil testing is the basis of a sound P management program. Proper soil sampling procedures are essential in assuring the soil test accurately represents soil P levels of a field. Surface soil samples should normally be taken from the top six to eight inches of the soil or to the depth of the tillage layer. Under no-till managed fields, surface samples should be four to six inches deep. Divide large fields into smaller subunits based upon management, productivity, or soil type, and collect 15 to 20 cores per subunit to form one composite sample, representing approximately 40 acres.

While nitrogen analysis is needed every year, soil testing for available P is needed a minimum of once during each crop rotation cycle. Phosphorus recommendations for alfalfa are generally made for three years of production, so samples should be tested on that frequency. Maintain a record of soil test results on each field to determine long-term soil test P trends. Be aware that various soil testing labs use different extraction procedures, which can result in a range of soil test P values reported on your field (Table 2). If you change soil testing labs, ask the lab manager how soil test P values and recommendations may vary from your previous reports. .

## Managing Fertilizer to Reduce Phosphorus Losses and Maximizing Returns

Applying P fertilizer at rates higher than production requirements is unwise from both environmental and economic viewpoints. There is no agronomic justification for building P soil test levels higher than crop sufficiency levels. Phosphorus losses in surface runoff have been shown to increase with increased P application rates. Therefore, once the crop sufficiency levels have been reached in your fields, P applications should be made only as dictated by soil testing.

Placement of P fertilizer will influence the amount of P available for transport to surface water. Correct placement of fertilizers in the plant root zone will improve fertilizer use efficiency and seedling vigor, and reduce the amount of P in agricultural runoff. Phosphorus fertilizer should not be broadcast on the soil surface without incorporation, except on perennial forages. In established alfalfa pasture, P fertilizer normally should not be applied in the late fall or winter when growth is minimal and runoff potential is high. An exception to fall applied fertilizer is flood irrigated mountain meadows. In these systems, fall applied fertilizer is preferred to

Table 2. Relative soil phosphorus levels based on soil extraction method

| | ---------------Relative soil P level--------------- | | | |
|---|---|---|---|---|
| Soil Test Method | Low | Medium | High | Very High |
| | ---------------ppm P in top 12” of soil--------------- | | | |
| AB-DTPA* | 0-3 | 4-7 | 8-11 | >11 |
| $NaHCO_3$** | 0-6 | 7-14 | 15-22 | >22 |
| Bray P-1+ | 0-5 | 5-15 | 11-30 | >30 |
| Mehlich-3++ | 0-10 | 11-31 | 31-56 | >56 |
| | Probability of yield response to applied P | | | |
| | >90 | 75 | 45 | <10 |

*Ammonium bicarbonate (DTPA) extraction for basic calcareous soils P rate

**Sodium bicarbonate (Olsen’s) extraction for basic calcareous soils P rate

+Bray & Kurtz P-1 for acid and neutral soils

++Mehlich extraction for acid and neutral soils

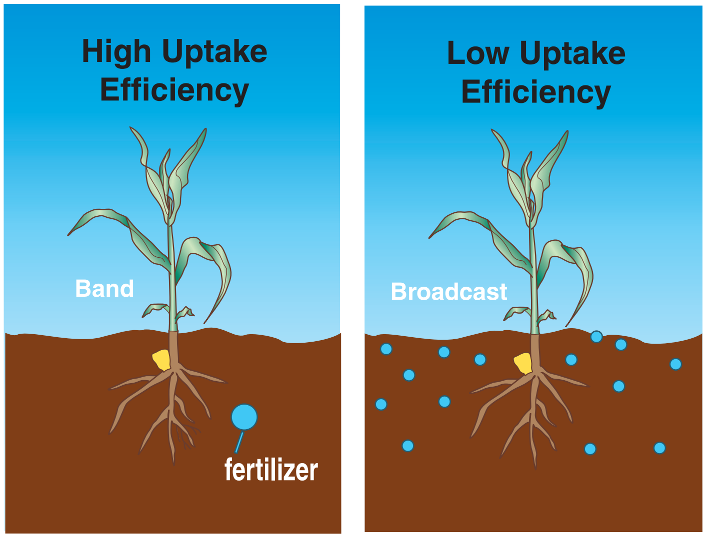


Figure 2. Banding phosphorus fertilizer (right) is more efficient than broadcast (left) applications. When banded, less P is lost to fixation in high pH soils or becomes available for runoff. Because P is immobile in soils, young corn plants with limited root systems often show deficiency, especially in cool, wet soils. Therefore, placement near the roots ensures maxium uptake. Subsurface band placement is also critical for no-till situations.

spring applied before the first irrigation. Broadcast applications generally are less efficient and leave more P at the soil surface than banding (Figure 2). Band application at planting is considered the most efficient method for many crops. Subsurface placement is especially important under reduced tillage cropping systems to achieve maximum crop yields.

Variable fertilizer rate management can improve both fertilizer use efficiency and economic returns. While this strategy can be adopted for any fertilized field, it makes the most sense in relatively large fields where the producer has knowledge of how crop yields and soil type vary across the field. To use a variable fertilizer rate strategy:

1. Divide the field into different management zones based upon a map of yields or soil types.
2. Soil sample the management units separately.
3. Fertilize each unit according to P soil test level and yield capability.

Field maps should be modified at harvest as necessary to refine the boundaries of management units. Consult with your fertilizer dealer or crop advisor prior to adopting this BMP.

### Phosphorus Management in Highly Calcareous Soils

Soluble forms of plant available P react with calcium in high pH soils to form insoluble minerals. This P is then largely unavailable for future plant uptake. These soils typically have a high calcium carbonate or lime ($CaCO_3$) content. Soil labs typically report this soil property as Estimated Lime (EL) in the qualitative terms: low (0 to 1 percent), medium (1 to 2 percent), and high (above 2 percent). Specific values are determined only when requested. When lime content exceeds two percent, P fertilizer should be placed close to the plant root zone, and banded when possible, to increase uptake efficiency. Research in Colorado has also shown that P content in runoff from storm water is considerably lower in soils with a lime analysis of greater than four percent. These soils should be considered when materials containing higher rates of P such as manure need to be applied at rates above the recommended agronomic rate or crop removal rate. Before application, a soil test that quantifies the high lime content should be used. These sites should be sampled annually to monitor changing soil test P and lime.

## Managing Manure to Reduce Phosphorus Losses

Manure is an excellent source of P for crop production. However, if manure is not incorporated into the soil, runoff may carry both soluble and sediment-associated nutrients to surface waters. The most common strategies for manure utilization are: (1) application for maximum nutrient efficiency and (2) application for maximum disposal rates of manure. While the second strategy presents a more difficult challenge from a water quality viewpoint, both management methods should consider application rates, timing, site characteristics, and water quality impacts.

Table 3. Approximate P content of various manures[1] when applied to land (wet weight basis)

| Manure | | Percent moisture | Average $P_2O_5$ content[2] |
|---|---|---|---|
| Beef | solid | 32 | 24 lb/ton |
| | lagoon | 99 | 9 lb/1,000 gal |
| Dairy | solid | 46 | 16 lb/ton |
| | liquid | 92 | 18 lb/1,000 gal |
| Swine | solid | 82 | 9 lb/ton |
| | liquid | 96 | 27 lb/1,000 gal |
| Sheep | | 31 | 26 lb/ton |
| Chickens | without litter | 55 | 48 lb/ton |
| | with litter | 25 | 45 lb/ton |

[1] Phosphorus content of manure may vary significantly. Have a sample analyzed by a qualified laboratory to determine actual P credit.

[2] Available $P_2O_5$ in the first year after application will be approximately 60 percent of the total reported on your analyses.

BMP for Manure Utilization 568A.

Manure managed for maximum nutrient efficiency is the most sound manure application program. Producers need soil and manure analyses to determine the correct application rate based upon crop uptake of N and P. Either of these nutrients may limit application rate, as both nutrients are present in large quantities in manures. In many cases, the best program is to rotate fields receiving manures to avoid salt or nutrient build up.

Colorado producers faced with the need for manure disposal at maximum application rates should have manures analyzed for nutrient content and apply according to crop nitrogen needs. However, this strategy may lead to an accumulation of P over long-term, repeated applications. Therefore, it is essential that producers manage water on their field carefully, minimizing runoff and leaching. Poultry manure contains exceptionally high levels of P and should be applied at rates based upon crop P removal. Annual soil tests are strongly recommended on all fields receiving manure. Operators should rotate manure applications when soil tests show nutrient levels greater than, or sufficient for, crop needs.

Composting manure will reduce volume and water content by up to 50 percent and reduces odor. Composting converts nitrogen and P to more stable organic compounds that will become slowly available to plants after application. Composted manure is more transportable and can be spread more evenly with the right equipment. Research in Colorado has shown that P in soil amended with compost was lower than in manured plots. Compost or other manure treatment technologies like solid separation should be considered when a land base for manure application is insufficient to accommodate the nutrients produced by a livestock facility.

The Colorado Phosphorus Risk Index (COPI) is an evaluation tool to estimate P loss from manured fields. Fields that receive frequent high rates of manure should be evaluated using the COPI to determine risk of P loss and management changes

## Consider the Four 'R's when managing phosphorus in your operation:

- Right amount – P rate determined by crop requirement for appropriate yield goal, soil testing, and nutrient credits.
- Right Time – Time P application to maximize plant uptake and reduce losses.
- Right Place – Utilize P application techniques and incorporation to reduce runoff.
- Right Source – Apply P nutrients according to field characteristics and potential for movement.

Learn more at:
http://www.nutrientstewardship.org/4rs

that could lower this risk.

As with commercial P fertilizers, manure should be incorporated immediately after application. Injection of liquid manure beneath the soil surface with specialized equipment is also a recommended practice. Unlike commercial fertilizer, the P content of manure can vary significantly. Approximate values are available for various manure sources (Table 3), but manure sampling and analysis are the best way to calculate nutrient credit.

Site characteristics such as land slope, surface residue, and proximity to surface water, must be used to determine which management measures are needed to protect surface water from P enrichment from manure. In some cases, sites with excessive slope or highly erodible soils are not suitable for manure application, even with careful management. Application of manure on frozen or wet soils subject to runoff is not recommended.

Runoff from feedlots and manure stockpile sites also can contribute nutrients to nearby surface waters. These facilities should be managed to divert or minimize the total runoff as required by Colorado and federal laws. BMPs to reduce runoff impacts include use of yard shaping, settling basins, diversions, and filter strips (Table 4).

## Managing Soil to Reduce Phosphorus Losses

Although there are a number of sources of sediment entering our waters, soil erosion from agricultural fields is a significant contributor to nonpoint source pollution in Colorado. The consequences of cropland erosion include loss of fertile topsoil, eutrophication and sedimentation of surface waters, destruction of habitat, and decreased recreational and aesthetic value of lakes and streams. Runoff from agricultural land also can transport pesticides and microbial pathogens, as well as nutrients.
Owners of agricultural land should contact the Natural Resources Conservation Service (NRCS) for help in evaluating the erosion potential of their lands and in determining what control measures are needed. In some cases, the NRCS has cost-share funds available to help producers install BMPs on their land.

A number of management practices and structures for controlling runoff and erosion are currently available for use. In some cases, there is a trade-off between reducing runoff and increasing deep percolation to groundwater. BMPs for managing surface runoff and soil erosion are listed in Table 3.

## Summary

Phosphorus fertilizer use efficiency in agricultural soils can be enhanced or reduced by a producer's choice of fertilizer placement, timing, and rate. Proper management of P fertilizer, manure, and soil is essential to prevent agricultural P from degrading water quality. Nonpoint source pollution from Colorado farmland can be controlled if each land manager adopts those BMPs that contribute to efficient use of nutrients. Every farm is unique and requires a particular combination of practices that meet the needs of the land and the enterprise. Producers can obtain profitable yields and minimize adverse environmental impacts by adopting BMPs appropriate to their land and choice of cropping systems.

Table 4. Erosion control BMPs for reducing surface losses of phosphorus from crop fields

| **Best Management Practice** | **Description** |
|---|---|
| Conservation tillage | Cropping system that maintains at least 30 percent of the soil surface covered with residues after planting |
| Conservation cover | Perennial vegetative cover established and maintained on highly erodible lands where other BMPs are insufficient to reduce adverse water quality impacts |
| Conservation cropping sequence | Crop rotation sequence designed to increase crop residues on the soil surface to reduce erosion |
| Cover crops | Annual or perennial crops planted in between rotations to provide soil cover, uptake nutrients, and store soil carbon |
| Delayed seed bed preparation | Cropping system in which all crop residues are maintained on the soil surface until three to four weeks prior to planting the succeeding crop |
| Polyacrylamide (PAM) | Irrigation water or soil amendment that flocculates sediment and reduces irrigation-induced erosion |
| Grass filter strip | Permanent sod strip planted at the base of sloping fields or between the field and surface water bodies |
| Grassed waterway | Sodded channel that provides a non-erosive outlet for runoff |
| Contour farming | Crops planted on the natural contour of the land to reduce erosion |
| Strip cropping | Alternating strips of row crops and solid seeded crops planted on the contour |
| Terrace | Earthen embankment constructed across the slope to reduce slope length and runoff velocity |
| Diversion | Grassed channel constructed across the slope, uphill of a tilled field, to divert excess water to areas where it can be managed properly |
| Sediment control basin | Basins constructed to collect runoff and trap sediments |
| Constructed wetland | Artificial wetland created downhill from irrigated crop fields where sediment and runoff are collected and assimilated by growing vegetation |

For more information, contact your local NRCS office.

## Phosphorus BMPs

Guidance Principle: Manage phosphorus requirements for crop production to maximize crop growth and economic return while minimizing degradation of water resources.

To select the phosphorus BMPs that protect the quality of the water resources near your operations, evaluate:

- potential water quality hazard of the site
- overall costs and benefits of BMPs
- most suitable practices to your site and your farm management plan

For more information about fertilizer management or specific inquiries about BMPs, see http://waterquality.colostate.edu/ for more information.

Related source material from Colorado State University Extension:

- Best Management Practices for Manure Utilization, 568A
- Best Management Practices for Colorado Corn, XCM-574A
- Fact Sheets:
  - 0.520 Selecting an analytical laboratory
  - 0.538 Fertilizing corn
  - 0.539 Fertilizing dry beans
  - 0.544 Fertilizing winter wheat
  - 0.569 Phosphorus fertilizers for organic farming systems
- NRCS Colorado Phosphorus Risk Assessment Agronomy Technical Note No. 95 (V4)
- USDA-NRCS, Agricultural Waste Management Field Handbook, 2008

P.1 Sample the tillage layer of soil in each field on a regular basis and have soil analyzed to determine available soil P levels prior to applying P fertilizer.

P.2 Credit all available P from manures and other organic residues to the P requirement for the crop.

P.3 Fertilize soils with 'low' to 'medium' P soil test values using environmentally and economically sound agronomic guidelines. In general, soils testing 'high' will not respond to additional P and should not receive fertilizer unless a banded starter is needed to compensate for low soil temperatures. Phosphorus fertilizer should not be applied to soils testing 'very high' for soil P.

P.4 Divide large, non-uniform fields, into smaller fertility management zones based upon yield potential or soil type and fertilize according to P levels determined through soil analysis.

P.5 Apply P fertilizers where they can be most efficiently taken up by the crop. Band application of P in the root zone reduces surface loss potential and enhances nutrient availability, especially in cold or P deficient soils.

P.6 Incorporate surface applied P into the soil where any potential for surface runoff or erosion exists.

P.7 Minimize soil erosion and corresponding P losses by establishing permanent vegetative cover, conservation tillage and residue management, contour farming, strip cropping, and other management practices as feasible. When erosion potential is severe, install structures such as diversions, terraces, grass waterways, filter fences, and sediment basins. Contact your local NRCS office if you need assistance in evaluating erosion potential and control options.

P.8 Maintain a buffer strip (where fertilizer and manure is not applied) a safe distance from surface water and drainage channels.

P.9 Maintain grass filter strips on the downhill perimeter of erosive crop fields to catch and filter P in surface runoff.

P.10 Manage irrigation water to minimize runoff and erosion by meeting the Irrigation BMPs or the NRCS approved Irrigation Water Management practice standard and specification.

P.11 Evaluate fields with historical manure applications using the Colorado Phosphorus Index Risk Assessment.

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