NUTRIENT MANAGEMENT – WHAT'S DOABLE

John E. Sawyer
Associate Professor
Soil Fertility Extension Specialist
Department of Agronomy
Iowa State University

Successful production of agronomic crops requires careful management of many production factors, including essential crop nutrient requirements. The interrelationship between soil resources, cropping systems, field and animal production activities, and farm enterprise management defines the overall production system. An important component within this system is the goal to manage all nutrient sources by means that optimizes crop production, minimizes potential negative impact on soil and water resources, and provides profitability.

Of environmental interest are the crop essential nutrients nitrogen (N) and phosphorus (P). Because of differing chemical properties and reactivity in soil and water systems, each requires special consideration for crop nutrient management and water quality protection. As shown in the N and P cycles (Figures 1 and 2), these nutrients have complex soil-landscape interactions and management must recognize these as well as interrelated aspects of farm and non-farm activities. For both nutrients, successful crop, soil, and water management should account for various scales of influence and balance – within field, whole field, sub-watershed, local-watershed, and regional-watershed.

Nitrogen

The earth's atmosphere contains approximately 78% nitrogen gas, N_2 (see the N cycle, Figure 1). Other than for plants that can symbiotically fix N in concert with microbial populations (soybean and alfalfa being the primary crops grown in Iowa with this capability), atmospheric N_2 gas is directly unavailable as an essential nutrient source. Important crops grown in Iowa, such as corn, forage grasses, and pasture grasses, require fixed N, inorganic N either as ammonium (NH_4) or nitrate (NO_3), be supplied in the root zone to meet plant N requirements (Figure 1). This means either reliance on net conversion of organic matter to ammonium (release of N contained in soil organic matter and crop residues, the process called mineralization) or supplemental addition of fixed N via fertilizers and manure. With the decline in soil organic matter as a result of long-term cultivation for crop production, the supply of inorganic N from soil organic matter is less now than when soils were first cultivated. Along with this, there are fewer acres of forage legume crops, which fix large amounts of N, being grown in Iowa and thus supplying less plant available inorganic N to the soil. This typically necessitates more frequent and larger additions of supplemental N for production of corn, grass pasture, or grass forage crops.

Under this scenario comes the conflict between required N applications for economical crop production and desires to limit N (nitrate principally, but ammonium also) from reaching ground and surface waters. As shown in Figure 1, the N cycle is truly a complex churning of N between various chemical forms and between plants, animals, soil, water, and air. With the exception of ammonium taken up by crops or used by soil microbes, all inorganic N either from organic

Presented at the March 7-8, 2000 Agriculture and the Environment: A Wake-Up Call for Iowans conference. p. 15-24. Iowa State University, Ames, IA.

matter, fertilizer, or manure flows through the nitrate form (microbial conversion from ammonium to nitrate is called nitrification). This places N at risk of loss from soil because nitrate can either be leached from the soil or lost by denitrification to N_2 gas (ammonium is not subject to these loss mechanisms). Both of these nitrate-N loss pathways are driven by excess water – leaching or flow through the soil to tile lines or groundwater and denitrification by microbial conversion of NO_3 to N_2 gas when soils become waterlogged (water replaces air in the soil pore space which causes oxygen depletion, resulting in an environment conducive for soil microbes that cause denitrification).

The key then, to greatest plant uptake of inorganic N (either supplied from organic matter mineralization or fertilization), is limiting the conversion of ammonium to nitrate, and limiting nitrate exposure to periods of excess moisture (highly unpredictable, but most frequently occurring in the spring). This cannot be controlled precisely or completely because of the continuous nature of the soil N cycle, and because of the limited N uptake period of the two most commonly crops grown in Iowa, corn and soybean – which are both annual crops with defined and limited periods of N uptake (see Figure 3 for corn). Hence, potential loss of nitrate increases during periods when annual crop growth is not active – with Iowa rainfall patterns this typically means the springtime. In systems with continuous/perennial cropping (for example grass and legume forages), N uptake is somewhat seasonal, but is much more continuous and synchronized to release of inorganic N from organic matter or plant materials than for annual crops. These crops have well established root systems, and compared to annual crops, are more active in nutrient uptake in the spring and fall.

Also, Iowa typically has more yearly rainfall than combined evaporation and crop transpiration. This means there is net water flow through soils, with soil moisture recharge typically occurring during non-peak crop growth periods (fall and spring). For a compound like nitrate (NO_3^-) that is completely water soluble and is not attracted to soil, there will be movement with the net water flow through soil. This means nitrate will move below crop rooting zones, and reach tile lines and groundwater.

Combine the uncontrollable and unpredictable release of inorganic N from organic matter, N application to soils from manures and fertilizers, the N uptake pattern of annual crops, incomplete inorganic N uptake by crops, the complexity of the N cycle, and unpredictable rainfall – and one easily concludes N management for crop production is neither simple nor straightforward. Neither are the solutions to reducing nitrate reaching ground or surface waters. This doesn't mean N management cannot be tailored to adequately providing crop N needs while minimizing loss from soil. It's just that realities of the N cycle and Iowa cropping systems preclude nitrate leaving farm fields.

Nitrogen Management Options

The management option with the greatest potential to limit nitrate movement below the root zone is rate of N application. Much research has documented that when fertilizer or manure N application exceeds optimal rates, nitrate accumulates in the soil and increased nitrate levels will be present at the end of the growing season. This accumulation then increases the risk for high levels of nitrate moving to ground or surface water. Studies show that the amount of nitrate that moves below the root zone is directly related to the nitrogen application rate. Over-applying fertilizer or manure as a means to offset anticipated N losses or as an attempt to produce unrealistic yields only results in more nitrate remaining in soils and therefore more nitrate subject to potential loss. For corn, nitrogen rate management should be focused on determining realistic N needs, and then managing N inputs by means that provide for the least potential for loss and greatest crop availability.

Intense research efforts continue in this area, principally to develop and refine tools that assist in determining available N in soil, and consequently N application needs. Specific ideas include: 1) soil tests, with the late spring soil nitrate test (LSNT) developed for use in corn as an example; 2) crop sensing, where the corn crop is monitored during the growing season and used as an in-season indicator of the soil N supply, with needed supplemental N application in-season as indicated from the crop sensing – there is ongoing research activity on this topic in many states, with implementation in some irrigated corn areas; 3) end of season corn sampling, where the corn stalk is sampled after maturity to determine the nitrate concentration and thus provide feedback on the entire season and N management system; and 4) placement of banded fertilizer N in soils using systems that limit water movement through the injected N.

Several corn N management options can assist in providing economical and environmental benefits.

1. Be realistic in determining N application rates. As stated above, rate of application has a direct impact on residual nitrate level in soils, and thus a large potential impact on nitrate leaching below the root zone. If one is determining rates based on expected production, for example to set manure application rates, be realistic when setting yield expectations – use proven yields, not unrealistic goals. The ranges given in Table 1 provide upper and lower suggested N rates for preplant N applications for corn. Utilizing rates within the ranges indicated for the various rotations should provide economical corn production across a wide range of growing seasons.
2. Account for previous crop and rotations. Many research studies show that when corn is grown in rotation, not only is yield higher, but required supplemental N is lower and nitrate leaching is less. Examples of these N need differences for corn in Iowa are shown in Table 1. For corn following established forage legumes, the need for additional N is very low or none. For corn following soybean, there is an average 50 lb N/acre less N need than when corn follows corn.
3. Account for the available N from manure applications. Manure is an excellent source of all crop essential nutrients, including N. If there is concern about the amount of N that will be available from manure applications, then use the LSNT soil test to check soil nitrate (Table 2) or the stalk nitrate test to monitor total season N supply. Application of manure and then applying fertilizer N without regard for or crediting N from manure results in situations of large over-application in corn production systems.
4. Avoid fall application of N fertilizers. This is especially important for sensitive areas where leaching is rapid (for example coarse textured soils and karst topography areas). Research summaries from many studies indicate that across multiple years, fall N is less effective than spring or sidedress application, corn yields are reduced, and nitrate leaving tile lines is increased. Do not apply fertilizer N or manure early in the fall. Fall fertilizer application should be limited to incidental N with phosphorus products and anhydrous

ammonia. In order to slow nitrification, application should be delayed until soil temperatures have cooled sufficiently; 50º F, with the expectation for continued cooling. Since soil temperature has the greatest impact on nitrification rate (which slows greatly below 50º F), waiting until temperatures are below 50º F will provide the best chance for fall application to behave like spring application. Use of a nitrification inhibitor, N-Serve®, will also slow the nitrification process. But again fall application should be delayed until soils are cool because inhibitors are less effective at warmer temperatures.

5. Spring preplant, sidedress, or preplant-sidedress split applications typically provide the least risk from loss and are preferable application timings. If weather and soil conditions are favorable, late fall application can be comparable. However, risk and probability of loss increases from fall application because of the increased time applied N is exposed to the environment, and because of variable soil moisture levels and unpredictable spring rainfall. Applying N as close to corn uptake as possible reduces the opportunity for loss to occur.
6. Sidedress or in-season application allows for small preplant or starter N applications and then adjustment to overall N rates from information gained through soil N testing or in-season corn monitoring. These methods do require more management, may require specialized application equipment, and can slow N application – which unfortunately tends to reduce desirability and slow adoption as N management systems.
7. Consider results of N diagnostic tools for making adjustments in N rates and monitoring N management systems. These include the late spring soil nitrate test (LSNT) and fall corn stalk nitrate test.
8. Account for all N applications. This includes N in phosphorus fertilizers, N in weed and feed applications, and N in starters. Suggested N rates for corn production (like those shown in Table 1) are the total N need. Therefore, primary N applications (like manure, anhydrous ammonia, urea, UAN, or ammonium sulfate) should be adjusted downward for these intended applications.
9. Rotate corn. Nitrate loss from continuous corn is typically higher than corn rotations that include crops not receiving N.

Use of these practices will not assure no nitrate leaves farm fields, but they can help reduce potential losses.

Phosphorus

Compared to the N cycle, the P cycle is somewhat less complex (Figure 2), but P is more chemically reactive with the soil. This reactivity adds to the difficulty in predicting effects of soil P on water quality. It does however, allow flexibility in management of P inputs, and within reasonable P soil test levels, increases retention of P in soils and helps limit movement to water systems.

Phosphorus is present in large quantities in most soils. Much of the P is present in mineral and organic forms that are not immediately plant available. Long-term cropping without adequate addition of supplemental P causes decline in plant-available P, and when soil supply becomes deficient, resultant reduced crop yields. Recognition of these factors lead to the development of P fertilizers, and application of P fertilizer and manure has been a common practice for improving P availability and crop yields for many years. Over time, buildup of plant-available P (measured by soil testing) has been accomplished on many soils through continued use of fertilizers and manure. For some soils, P application has resulted in very high soil test levels as a result of long-term applications in excess of P removal in harvested crops. These soils basically require the opposite management as needed on deficient soils – that is, withholding P application in order to reduce soil tests to agronomically optimal levels.

The environmental concern related to P is movement from soils to streams and lakes. The focus includes non-point (field) P sources. Enrichment of waters with P results in accelerated algae and other aquatic plant growth, and upon decomposition of this plant material, depleted oxygen levels (called eutrophication). Eutrophication limits use of surface waters for aesthetics, fisheries, recreation, industry, and drinking. Enrichment of waters with P is not a direct human health risk, but has a more in-direct effect through impacts on these various water uses. Acceleration of aquatic plant growth occurs at a very low P concentration. This varies by surface water system, but is approximately 0.01 ppm dissolved P and 0.02 ppm total P. In comparison, the soil solution P concentration for normal crop growth is approximately 0.20 to 0.30 ppm P.

In general, surface water P levels are directly related to P coming from the surrounding soil systems (for example, the level of soluble P in runoff water usually shows a linear relationship to soil P test level). Phosphorus movement from soil occurs mainly through P attached to eroded soil, and also with P dissolved in runoff water. For aquatic systems, the level of total P and water soluble P are both important for controlling aquatic plant growth. Therefore, the higher the concentration of total and plant-available P in soil systems – and especially in conjunction with greater soil erosion, surface water runoff, and transport directly to surface waters – the more P that will be delivered into surface waters. This then describes systems with greatest chance to supply enhanced P loads. Research is showing that management practices have a large impact on P losses from crop production systems.

Several factors define the potential susceptibility of a field site for supplying P to surface waters. These factors include: 1) source: total P and soil test P level, soil P test stratification (typically higher to lower with depth in the surface soil of reduced and no-till systems), and P fertilizer and manure rate, timing and placement; 2) transport: soil erosion, surface runoff, and leaching to tile lines; and 3) destination (does the P leave the field and is it delivered to a water body): distance of surface flow to a water body or leaching depth to tile lines, connectivity to a surface water body (direct channel flow versus spread flow over a large area), and intercepting buffer areas. These and other factors are frequently integrated into what is called a P index, a tool designed to evaluate the potential risk of P losses from field sites. The P index can also be used to help determine how to manage fields in order to limit P losses. The P index concept, including the various components, is currently under discussion and development in Iowa.

For a more detailed discussion of the various P issues, please refer to the four articles listed in the additional references section. Not all aspects of the relationship between soil P, soil management, P management, and water quality are fully known. Research will continue to discern specific implications of P management for Iowa soils and cropping systems in regard to water quality issues.

Phosphorus Management Options

Phosphorus management practices that have the greatest potential impact on limiting P movement to surface waters are those that control soil erosion and surface runoff, and limit surface soil buildup of total and plant-available P. From this, avoiding very high soil P tests and implementing conservation practices should be the most effective management methods for controlling surface water P enrichment. Suggested interpretations of P soil test results for Iowa crops and soils is given in Table 3. Phosphorus fertilization recommendations for agronomic crops can be found in Iowa State University Extension publication Pm-1688, General Guide for Crop Nutrient Recommendations in Iowa.

Several P management options can assist in providing both environmental and economic benefits. These are generally categorized as those practices that either limit the P source or limit P transport.

1. Control soil erosion and surface water runoff through erosion control practices and surface residue (use conservation practices).
2. Maintain soil test P at recommended levels for crop production. Do not build or maintain excessively high soil P levels.
3. Apply P at suggested rates based on soil test results.
4. Apply P to sub-field areas based on soil tests and at rates required for crop production. Avoid application to field areas not needing P. These practices may require precision agriculture methods, including intense soil sampling and variable P application.
5. Limit the exposure of surface applied P (fertilizer or manure) from potential heavy rainfall/runoff periods. This is especially important for sites with high susceptibility to erosion/runoff and direct conduit to surface waters, and may require either incorporation or injection of applied P (this should be accomplished in a manner to maintain crop residue).
6. Utilize cultural practices for crop production that give greatest opportunity for high yields.
7. Investigate use of vegetative filter strips and wetlands between field areas and surface water bodies.
8. Investigate feeding strategies that lower P concentration in manure.

There is still much to be learned about the relationships between soil landscape management, P management practices, and P movement to surface waters. As water quality criteria for P are refined, specific field, soil, and P management requirements should become more clearly defined.

Additional References

Iowa State University Publications

Pm-1714. Nitrogen fertilizer recommendations for corn in Iowa.
Pm-1584. Cornstalk testing to evaluate nitrogen management.

Pm-1811. Managing manure nutrients for crop production.
Pm-1688. General guide for crop nutrient recommendations for Iowa.

Reference Articles

Managing phosphorus: agronomic and environmental concerns. R. Voss. 1999. p. 19-30. In Proceedings of the 11th Integrated Crop Management Conference. December 1 and 2. Iowa State University.

Managing manure phosphorus. B. Eghball. 1999. p. 37-42. In Proceedings of the 11th Integrated Crop Management Conference. December 1 and 2. Iowa State University.

Soil phosphorus testing for crop production and environmental purposes. A. Mallarino. 1999. p. 185-192. In Proceedings of the 11th Integrated Crop Management Conference. December 1 and 2. Iowa State University.

Phosphorus and surface water quality. J.L. Baker. 1999. p. 231-237. In Proceedings of the 11th Integrated Crop Management Conference. December 1 and 2. Iowa State University.

The Nitrogen Cycle

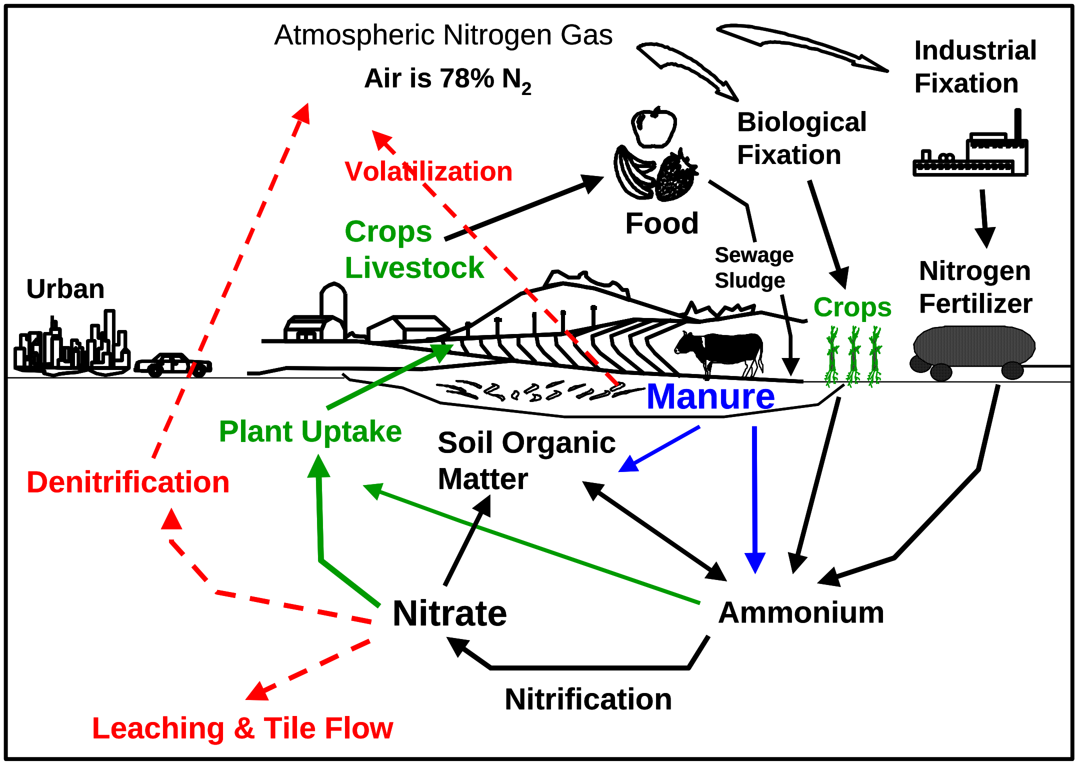

Figure 1. Abbreviated general nitrogen cycle.

The Phosphorus Cycle

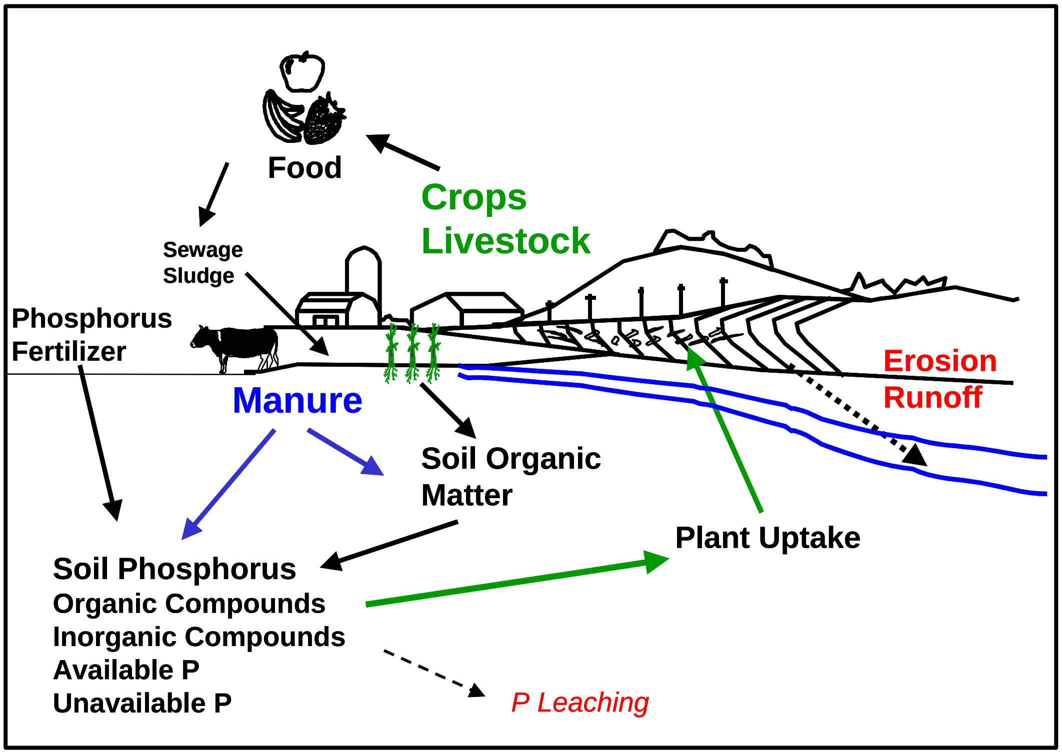

Figure 2. Abbreviated general phosphorus cycle.

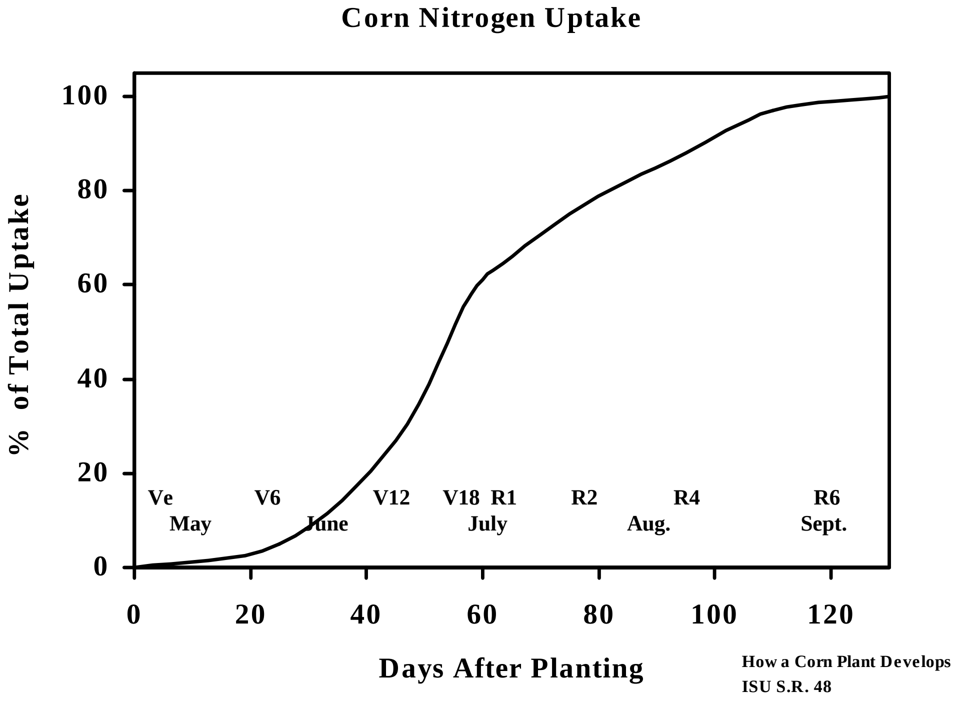

Figure 3. Corn nitrogen uptake throughout the growing season. Adapted from Iowa State University Special Report No. 48, How a Corn Plant Develops.

Preplant N Applications

Crop Category	N Rate
	lb N/acre
Recently manured soils	0 to 90
After established alfalfa	0 to 30
2nd- year after alfalfa	0 to 60
Corn after corn	150 to 200
Corn after soybean (no manure)	100 to 150

Pm-1714 Nitrogen Fertilizer Recommendations for Corn in Iowa, 1997

Table 1. Rates of N usually needed if all N is applied preplant or before crop emergence. From ISU publication Pm-1714, Nitrogen Fertilizer Recommendations for Corn in Iowa.

Grain and Fertilizer Prices	Soil Test Nitrate	Recommended N Rate	
		Excess[b] Rainfall	Normal Rainfall
	ppm N	- - - - lb N/acre - - - -	
Unfavorable	0 - 10	90	90
(1 bu buys	11 - 15	0	60
7 lb N)	16 - 20	0	0[c]
	> 20	0	0
Favorable	0 - 10	90	90
(1 bu buys	11 - 15	60	60
15 lb N)	16 - 20	0	30
	> 20	0	0

[a] Uniform, or 2 of 4 years. [b] May rainfall > 5 in. [c] Optional 30 lb N/acre.

Table 2. Nitrogen fertilizer recommendations for manured soils[a] and corn after alfalfa. A field should be considered manured if animal manures were applied with a reasonable degree of uniformity since harvest of the previous crop or in 2 of the past 4 years. From Pm-1714, Nitrogen Fertilizer Recommendations for Corn in Iowa, 1997.

	Bray P_1 or Mehlich-3 P			Olsen P		
	Wheat, alfalfa	All crops except wheat, alfalfa		Wheat, alfalfa	All crops except wheat, alfalfa	
		Subsoil P			Subsoil P	
Relative level		Low	High		Low	High
	- - - - - - - - - - - - - - - - - - ppm - - - - - - - - - - - - - - - - - -					
Very low (VL)	0-15	0-8	0-5	0-10	0-5	0-3
Low (L)	16-20	9-15	6-10	11-14	6-10	4-7
Optimum (Opt)	21-25	16-20	11-15	15-17	11-14	8-11
High (H)	26-30	21-30	16-20	18-20	15-20	12-15
Very High (VH)	31+	31+	21+	21+	21+	16+

Table 3. Interpretation of phosphorus soil test values for surface soil samples (6 to 7-inch depth). From Pm-1688, General Guide for Crop Nutrient Recommendations in Iowa, 1999.