...crop removal of inorganic P from soil is generally low. In the United States, an average 29% of P added in fertilizer and manure is removed by harvested crops...

applications and tillage practice. Although P is relatively immobile in the soil, it is not non-mobile. It can move, especially where soils have become highly enriched with P.

Overall, soil pH is the main property controlling inorganic P forms, although Al, Fe, and Ca content determine the amounts of these forms (Figure 34-4). In acid soils, Al and Fe dominate fixation of P, while Ca compounds fix P in alkaline soils. As a result, P availability is greatest at soil pH between 6 and 7 (Figure 34-4). Immobilization of inorganic P by these processes renders a portion of the added P unavailable for plant uptake (Figure 34-5). Mehlich-3 soil P decreased with time after application of P to a clay and silt loam soil. At the same time, more inorganic P was fixed with Al and Fe (Figure 34-5). This illustrates why crop removal of inorganic P from soil is generally low. In the United States, an average 29% of P added in fertilizer and manure is removed by harvested crops, ranging from < 1% in Hawaii to 71% in Wyoming (National Research Council 1993). The low recovery reflects the predominance of high P-fixing soils in Hawaii.

The Evolution of Agriculture from P Sink to P Source

...the rapid growth of the animal industry in certain areas of the United States ... [has created] regional and local imbalances in P inputs and outputs...

In many states, animal feeding operations (AFOs) are now the major source of agricultural income. However, the rapid growth of the animal industry in certain areas of the United States has been coupled with an intensification of operations. For example, during the last 10 years, cattle, pig, and poultry numbers have increased 10% to 30%, while the number of farms on which they were reared has decreased 40% to 70% (Gardner 1998).

This intensification has been driven by a greater demand for animal products and an improved profitability associated with economies of scale. Also, it has resulted in a major one-way transfer of P from grain-producing areas to animal-producing areas, creating regional and local imbalances in P inputs and outputs (Lanyon 2000, Sharpley et al. 1998, Sims 1997). On average, only 30% of the fertilizer and feed P input to farming systems is output in crops and animal produce.

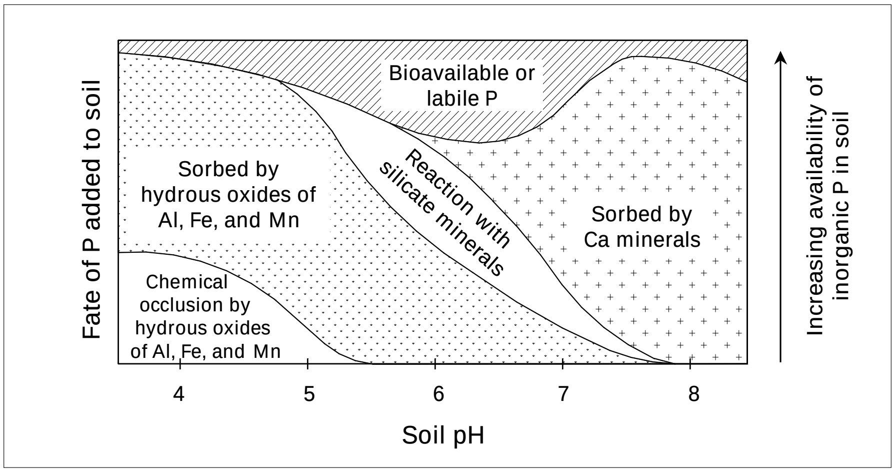

Figure 34-4. Approximate representation of the fate of P added to soil by sorption and occlusion in inorganic forms, as a function of soil pH.

Before World War II, farming communities tended to be self-sufficient; they produced enough feed locally to meet animal requirements and could recycle the manure nutrients effectively to meet crop needs. As a result, sustainable nutrient cycles tended to exist in relatively localized areas (Figure 34-6). After World War II, increased fertilizer use in crop production contributed to specialized farming systems, with crop and animal operations in different regions of the country (Figure 34-7). By 1995, over half of the corn grain produced in the Cornbelt was exported as animal feed. In fact, less than 30% of the corn grain produced on farms today is fed on the farms where it was grown.

The evolution of our agricultural systems is resulting in a major transfer of nutrients from grain-producing areas to animal-producing areas, and consequently, an accumulation of P in soils of those areas. For example, the potential for P and N surplus at the farm scale can be much greater in CAFOs than in cropping systems when nutrient inputs become dominated by feed rather than fertilizer (Table 34-3). With a greater reliance on imported feeds,

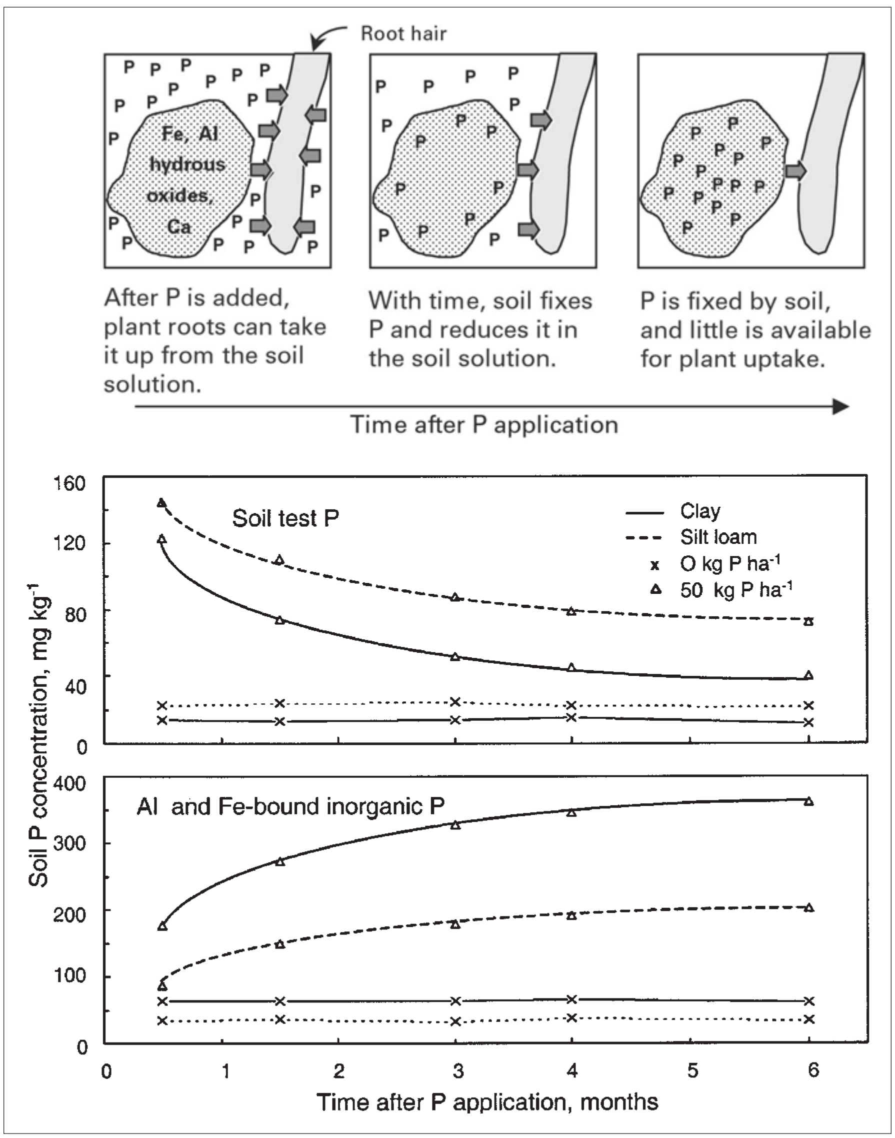

Figure 34-5. The change in soil test (Mehlich-3 P) and absorbed soil P (Al and Fe-bound) with time after P application.

Continual long-term application of fertilizer or manure at rates exceeding crop needs will increase soil P levels.

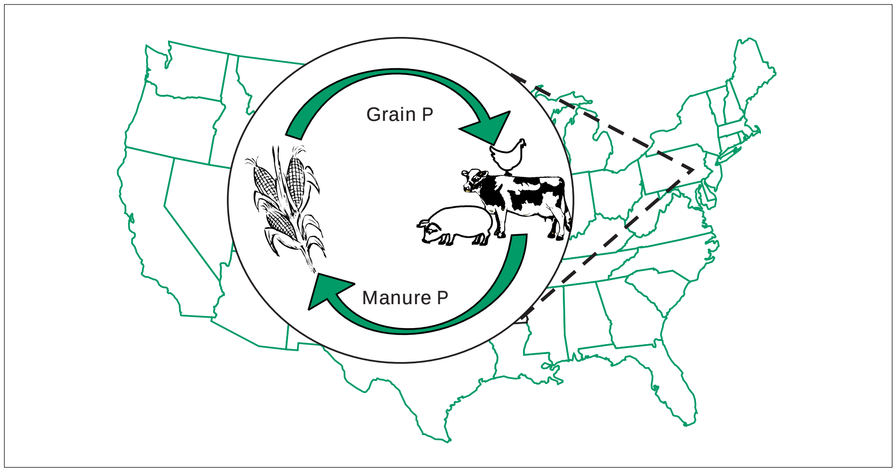

Figure 34-6. Before World War II, nutrient cycling was localized and sustainable within watersheds.

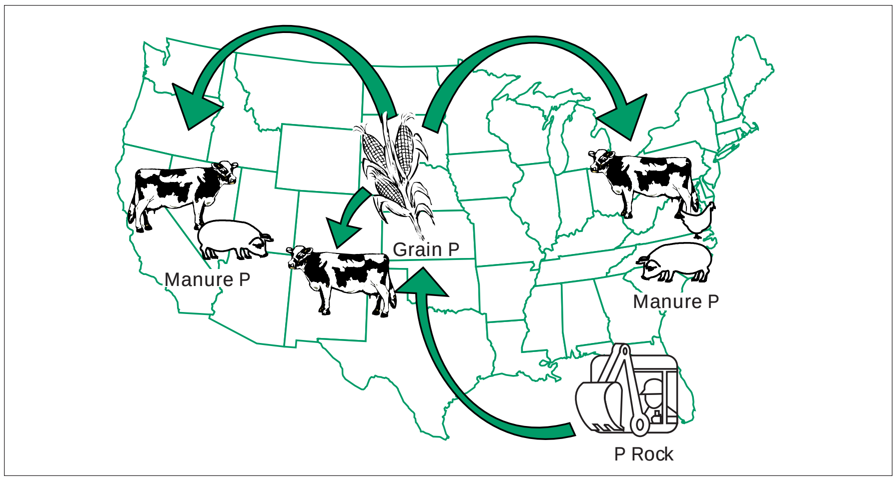

Figure 34-7. Since World War II, the nutrient cycle has been broken on a national level, with P tending to move from areas of grain production to areas of livestock production.

Table 34-3. Farming system and nutrient budget.

Farming System	Nutrient Input In: Feed	Nutrient Input In: Fertilizer	Output	Balance
	----------------- lbs/acre/yr	-----------------		
Phosphorus budget				
Cash crop [1]	—	20	18	+2
Dairy [2]	28	10	13	+25
Hog [3]	95	—	60	+35
Poultry [4]	1,390	—	470	+920
Nitrogen budget				
Cash crop [1]	—	85	82	3
Dairy [2]	138	9	68	79
Hog [3]	350	9	230	129
Poultry [4]	5,200	—	2,940	2,260

[1] 75-hectare cash crop farm growing corn and alfalfa.
[2] 100-hectare farm with 65 dairy Holsteins averaging 14,550 lbs milk/cow/yr, 5 dry cows, and 35 heifers. Crops were corn for silage and grain, and alfalfa and rye for forage.
[3] 75-hectare farm with 1,280 hogs; output includes 40 lbs P and 132 lbs N/acre/yr manure exported from the farm.
[4] 30-hectare farm with 74,000 poultry layers; output includes 7 kg P and 80 lbs N/acre/yr manure exported from the farm.
Adapted from Lanyon and Thompson 1996 and Bacon et al. 1990.

only 30% of P and 55% of N in purchased feed for a 74,000-layer operation on a 30-acre farm in Pennsylvania could be accounted for in farm outputs (Table 34-3). These nutrient budgets clearly show that the largest input of nutrients to CAFOs, and thus the primary source of any on-farm nutrient excess, is in animal feed.

Continual long-term application of fertilizer or manure at rates exceeding crop needs will increase soil P levels. In many areas of intensive confined animal production, manures are normally applied at rates designed to meet crop N requirements to avoid groundwater quality problems created by leaching of excess N. This often results in a buildup of soil test P above amounts sufficient for optimal crop yields. As Figure 34-8 shows, the amounts of P added in "average" dairy manure (8-10 tons/acre and 0.5% P) and poultry litter (4 tons/acre and 1.5% P) applications are considerably greater than is removed in harvested corn for example. The result is an accumulation of soil P.

A 2000 survey of several state soil test laboratories revealed that high soil P levels are a regional phenomenon and that soils of high P content unfortunately tend to be located near sensitive bodies of water such as the Great Lakes, Lake Champlain, Chesapeake and Delaware Bays, Lake Okeechobee, the Everglades, and other freshwater bodies and estuaries (Figure 34-9). Most soils analyzed in these areas had soil test P levels in the high or very high categories, indicating that little or no supplemental P was required for the current crop and possibly for several future crops. Most soils in other regions of the country tested medium or low; most Great Plains soils, for example, still require P for optimum crop yields.

Within states and regions, distinct areas of general P deficit and surplus exist. For example, soil test summaries for Delaware indicate the magnitude and localization of high soil test P levels that can occur in areas dominated by intensive animal production (Figure 34-10). In Sussex County, Delaware, with a high concentration of poultry operations, 87% of fields tested in 1992 to 1996 had optimum (25-50 ppm) or excessive soil test P (> 50 ppm, as determined by Mehlich-1). In New Castle County, with only limited animal production, 72% of the fields tested were rated as low (< 13 ppm) or medium (13-25 ppm).

Though rapidly built up by P applications, the decline in available soil P is slow once further applications are stopped. Thus, the determination of how long soil test P will remain above crop sufficiency levels is of economic and

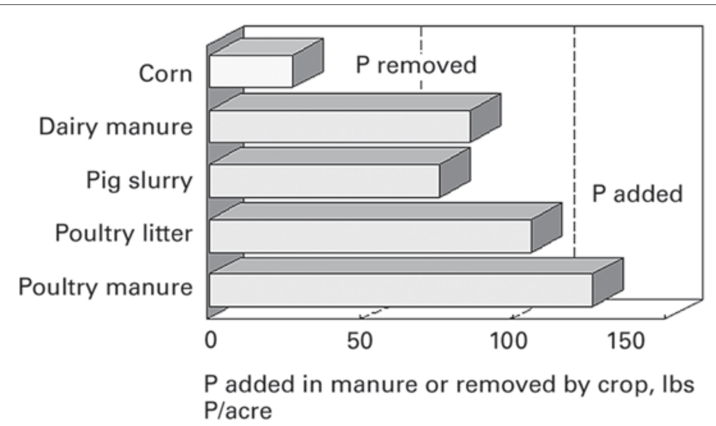

Figure 34-8. Applying manure to meet crop N needs (about 200 lbs available N/acre) will add much more P than corn uses annually.

Continual long-term application of fertilizer or manure at rates exceeding crop needs will increase soil P levels.

Though rapidly built up by P applications, the decline in available soil P is slow once further applications are stopped.

Figure 34-9. A survey of agricultural soils analyzed by state soil test labs in 2000 shows a regional buildup of soil test P near P-sensitive waters.
Adapted from Fixen and Roberts 2002..

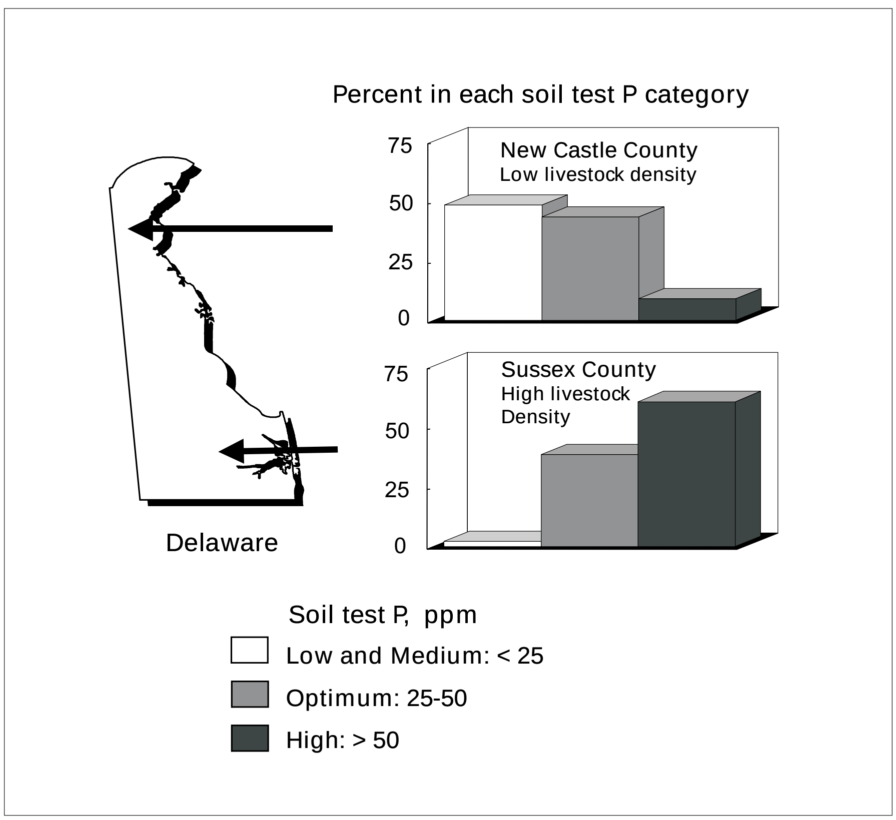

Figure 34-10. Elevated soil test P levels (as Mehlich-1 P) are usually localized in areas of confined animal operations.

environmental importance to farmers who must integrate manure P into sustainable nutrient management systems. For example, if a field has a high potential to enrich agricultural runoff with P due to excessive soil P, how long will it be before crop uptake will lower soil P levels so that manure can be applied again without increasing the potential for P loss? Studies in North Carolina found it would take almost 20 years, without further P additions, for corn and soybean production to decrease soil test P (Mehlich-1 P) from 100 ppm to the agronomic threshold of 20 ppm for a Portsmouth fine sandy loam (McCollum 1991)

Processes and Pathways of P Transport in Agricultural Runoff

The term "agricultural runoff" encompasses two processes that occur in the field: surface runoff and subsurface flow. In reality, these can be vague terms to describe very dynamic processes. For example, surface or overland flow can infiltrate into a soil during movement down a slope, move laterally as interflow, and reappear as surface flow. In this lesson, we use agricultural runoff when referring to the total loss of water from a watershed by all surface and subsurface pathways. The main factors influencing P losses are summarized in Table 34-4.

Forms and processes

The loss of P in agricultural runoff occurs in sediment-bound and dissolved forms (Figure 34-11). Sediment P includes P associated with soil particles and organic material eroded during flow events and constitutes 60% to 90% of P transported in surface runoff from most cultivated land. Surface runoff from grass, forest, or uncultivated soils carries little sediment, and therefore, is generally dominated by dissolved P. Thus, erosion control is of

The loss of P in agricultural runoff occurs in sediment-bound and dissolved forms…

Table 34-4. Factors influencing P loss.

Factors	Description
Erosion	Total P loss is strongly related to erosion.
Surface runoff	Water serves as the transport mechanism for P either off or through the soil.
Subsurface flow	In sandy, organic, and P-saturated soils or soils with preferential pathways, P can leach through the soil.
Soil texture	Influences relative volumes of surface and subsurface flow
Irrigation runoff	Improper irrigation management can increase P loss by increasing surface runoff and erosion.
Connectivity to stream	The closer the field is to the stream, the greater the chance of P reaching it.
Proximity of P-sensitive water	Some watersheds are closer to P-sensitive waters than others (that is, point of impact).
Sensitivity to P inputs	Shallow lakes with large surface areas tend to be more vulnerable to eutrophication.
Soil P	As soil P increases, P loss in sediment, surface runoff, and subsurface flow increases.
Application rate	The more P (fertilizer or manure) applied, the greater th e risk of P loss
Application method	P loss increases in the following order: subsurface injection, plowed under, and surface broadcast with no incorporation.
Application source	The P in some fertilizers and manure is more soluble than in others, and thus , more susceptible to runoff.
Application timing	The sooner it rains after P is applied, the greater the risk for P loss.