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.

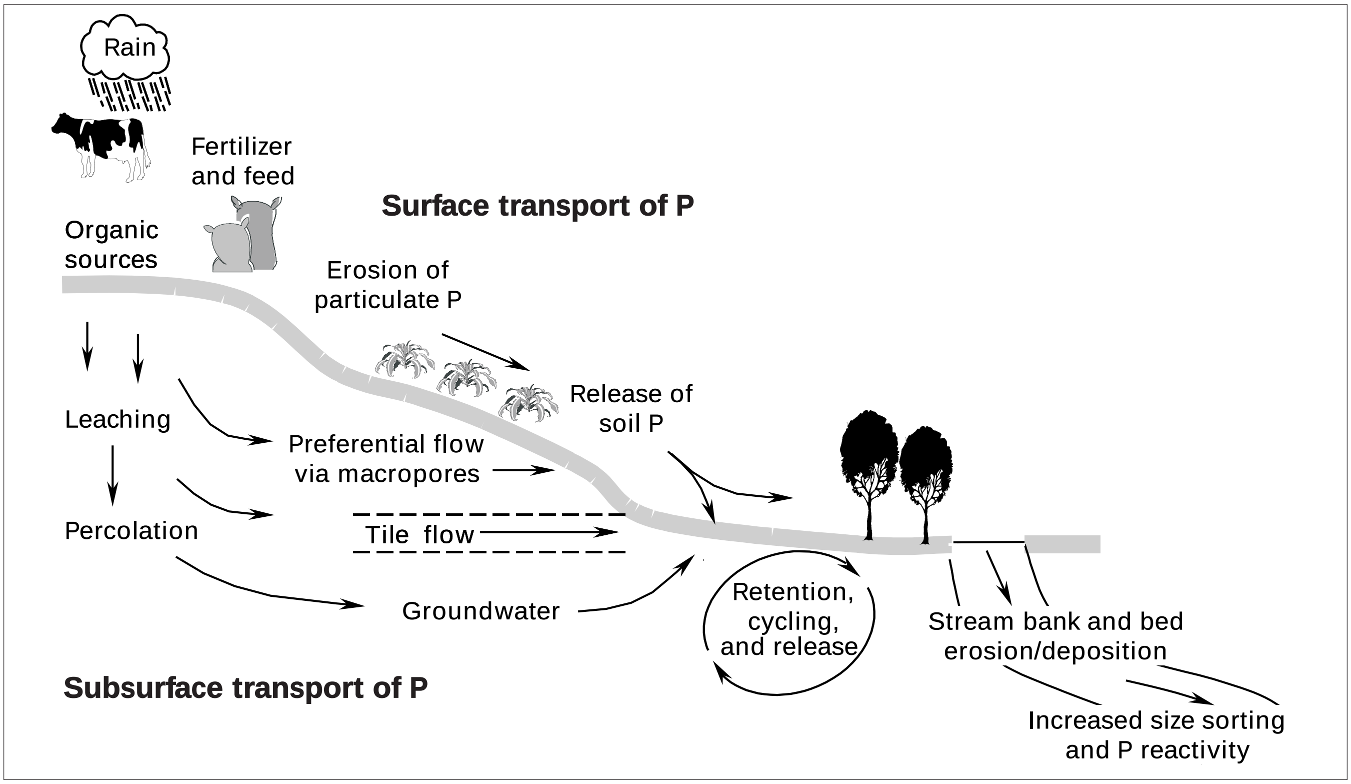

Figure 34-11. Factors affecting P transport to surface waters in agricultural ecosystems.

prime importance in minimizing P loss from agricultural land. However, it may not be sufficient in and of itself.

The dissolved form of P comes from the release of P from soil and plant material (Figure 34-11). This release occurs when rainfall or irrigation water interacts with a thin layer of surface soil (1-2 inches) and plant material before leaving the field as surface runoff. Most dissolved P is immediately available for biological uptake. Sediment P is not readily available but can be a long-term source of P for algae.

...P export occurs mainly in surface runoff rather than in subsurface flow.

Pathways

In most watersheds, P export occurs mainly in surface runoff rather than in subsurface flow. However, in some regions, notably the Coastal Plains, Florida, and fields with subsurface drains, P can be transported in drainage waters. Generally, the concentration of P in water percolating through the soil profile is small due to fixation of P by P-deficient subsoils. Exceptions occur in sandy, acid organic, or peaty soils with low P fixation or holding capacities and in soils where the preferential flow of water can occur rapidly through macropores and earthworm holes.

Irrigation, especially furrow irrigation, can significantly increase the potential for soil and water contact, and thus, increase P loss by both surface runoff and erosion in return flows. Furrow irrigation exposes unprotected surface soil to the erosive effect of water movement. The process of irrigation also has the potential to greatly increase the land area that can serve as a potential source for P movement. This source of P movement is especially important in the western United States.

The loss of dissolved P in surface runoff depends on the P content of surface soil...

The loss of dissolved P in surface runoff depends on the P content of surface soil (Figure 34-12). These data were obtained from several locations within a

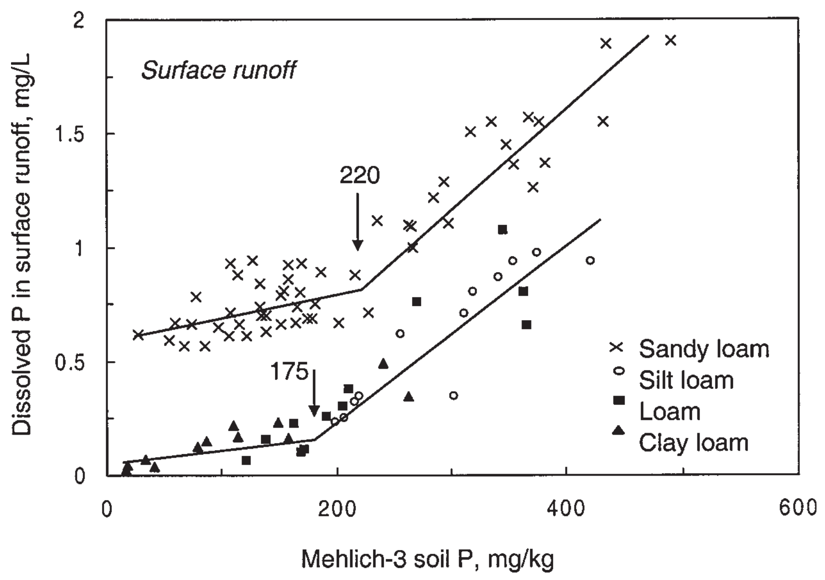

Figure 34-12. Relationship between the concentration of dissolved P in surface runoff and Mehlich-3 extractable soil P concentration of surface soil (0-2 inch depth) from a central PA watershed.

40-ha watershed (FD-36) in south-central Pennsylvania (Northumberland County). Locations were selected to give a wide range in soil test P concentration as Mehlich-3 P (15-500 mg/kg). A change point in the relationship between soil and surface runoff P was determined (220 and 175 mg/kg, Figure 34-12). The potential for soil P release above this point is greater than below it. The variation in this soil P change point or threshold among soils (Figure 34-12) shows the ability of soils to release P to runoff is a function of soil type. Clearly, several soil and site management factors influence P loss.

The P concentration in subsurface flow is also related to surface soil P (Figure 34-13). Thirty-cm deep lysimeters were taken from the same Pennsylvania watershed as the preceding and subject to simulated rainfall (6.5 cm/hr for 30 min). The concentration of dissolved P in drainage from the lysimeter increased (0.07 to 2.02 mg/L) as the Mehlich-3 P concentration of surface soil increased (15 to 775 mg/kg, Figure 34-13). This data manifest a change point that was similar to the change point identified for surface runoff. The dependence of leachate P on surface soil P is evidence of the importance of P transport in preferential flow pathways such as macropores, earthworm holes, and old root channels.

Surface runoff generally occurs only from limited source areas within a watershed. These source areas vary rapidly in time, expanding and contracting quickly during a storm as a function of rainfall intensity and duration, antecedent moisture conditions, temperature, soils, topography, groundwater, and moisture status over a watershed. Because surface runoff is the main mechanism by which P and sediment is exported from most watersheds, it is clear that P export will be negligible if surface runoff does not occur. Thus, consideration of how water moves and where surface runoff occurs is critical to a more detailed understanding of P export from agricultural watersheds.

Also, the amount of P loss necessary to cause water quality problems usually is very small compared to the amounts required by crops or contained in typical

...the P concentration in subsurface flow is also related to surface soil P...

For P to be lost, surface or sub-surface runoff must occur...

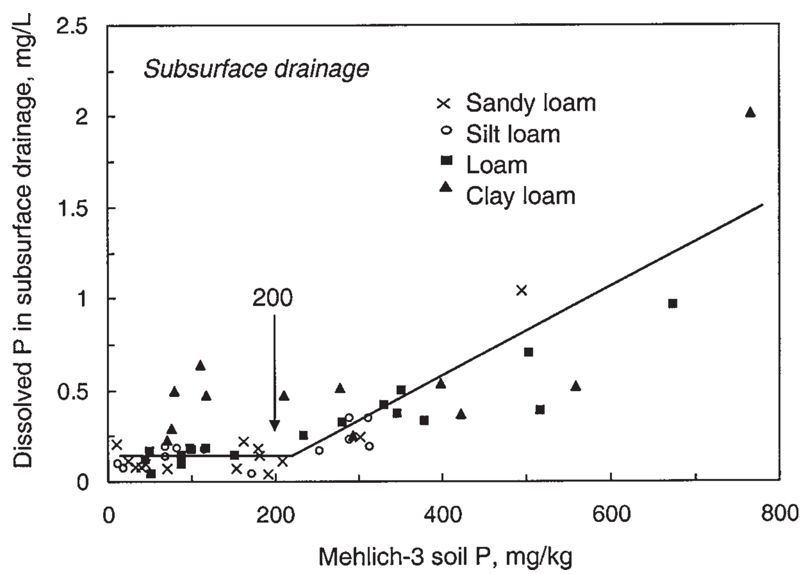

Figure 34-13. Relationship between the concentration of dissolved P in subsurface drainage from 30 cm deep lysimeters and the Mehlich-3 extractable soil P concentration of surface soil (0-2 inch depth) from a central PA watershed.

manure or fertilizer P applications. For example, lake water concentrations of P above 0.02 mg/L generally accelerate eutrophication. These values are an order of magnitude lower than P concentrations in soil solution critical for plant growth (0.2-0.3 mg/L), emphasizing the disparity between critical lake and soil P concentrations. Consequently, this complicates strategies to change farm management, because the loss is too small to show up in most standard practical or economic indicators of crop production efficiency used in farm management.

Environmental Risk Assessment and P Management

The USDA and EPA have developed a Unified Strategy for AFOs to address water quality concerns related to nutrient management (USDA and U.S. EPA 1999). An important part of this strategy is that it spells out how acceptable manure application rates will be determined in these plans. Both N and P must be considered in plans developed under this strategy. The strategy outlines three options for determining appropriate P-based nutrient management plans: agronomic soil test P, environmental soil P thresholds, and P indexing of site vulnerability.

Agronomic soil test P

In this option, manure application rates are based on the recommendations for optimum production of the crop. In other words, if the soil test called for a P addition to grow the crop, manure could be applied only to supply the recommended P. If the soil P test did not recommend any P addition, little or no manure could be applied.